The following is a conversation with Betul Kachar, an astrobiologist at University of Wisconsin, studying the essential biological attributes of life.
And now, a quick few second mention of his sponsor. Check them out in the description. It's the best way to support this podcast.
We got House of Macadamias for satiating and delicious snack, Miz and Amain for style, Aidsleep for naps, ExpressVPN for privacy and security, give directly for philanthropy, and Blinkist for nonfiction. Choose wisely, my friends.
And now, onto the full ad rates. 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.
This show is brought to you by House of Macadamias, a company that ships delicious, high quality and healthy macadamia nuts directly to your door, which they did just today. Another shipment.
I got in my hand an unopened box dipped macadamia's chocolate flavor. This is the one I went through first last time. And it was delicious. It is an incredible source of happiness for me.
I knew for a long time that macadamia nuts were really healthy because I remember when I was first exploring, okay, so on keto, what is the way to get fats into the diet?
Because that's to be a high fat diet. And I was looking at nuts and I was thinking of, okay, which nuts are the healthiest? And I remember macadamia is always coming up to the top of the list.
I'm going to try not to eat all of them so that I have some for guests when they come over because it's like a perfect guest snack. It's healthy. It's delicious. It's just pure perfection.
They also sent me some macadamia bars, which were also delicious last time. I probably prefer the whole nuts. I'm nuts for nuts.
Anyway, go to house on macadamias.com slash Lex to get 20% off your first order.
This show is also brought to you by Miz and Amain, the maker of comfortable stylish dress shirts and other menswear. I wear their black dress shirt and I love it. I have a ton of them.
Sometimes when I do these ad reads, I struggle to try to convey exactly why I like this particular piece of clothing, which is where I wish there was like a brain computer interface way to directly communicate the actual experience of wearing the clothing.
And if you get a large number of people with that data, you get a sense of, okay, well, 96% of people feel good in this. That's a good chance that I will also feel good.
And that's fascinating. Of course, you could get that through self-report surveys, but it will be nice to get direct data because you can't lie, but the feelings don't lie.
But then again, there could be other kinds of variables like what else is going on in your life. You might be just in a bad mood to buy something else or watch a really sad movie while wearing the shirt. So I don't know.
It's an imperfect system that we're going to have to work out. Right now, you'll get $35 off any regular price order when you go to MizandAmain.com and use promo code Lex.
This episode is also brought to you by Eatsleep and it's Neopod 3 Mattress. They've been a sponsor forever and they've been my bed mattress cooling system when I sleep forever.
And it's a source of a lot of happiness. I recently tweeted about the number of hours there are in a regular lifetime. You know, if you live 70 to 80 years old, there's about 600 to 700,000 hours in a life.
And I think a large percent of those hours is spent sleeping. Of course, you could think of sleeping as an important process for health to regenerate your energy and all that kind of stuff.
But it is also in itself a source of happiness. And I think you want to use the best bed for the job. It's

just not a better feeling of a cool service with a warm blanket.
And a day full of battles won and you return to rest and reminisce about the battles.
So you can again the next day return to the battles that are in store for you. Check it out and get special savings when you go to ASleep.com slash Lex.
This show is also brought to you by ExpressVPN. I've used it for many years. I've had the big sexy button that just works when you press it.
And I use it, you know, it's the first layer of protection of your data, of your privacy on the Internet.
And basically a lot of different services and tools collect your data. And a good VPN should be your first layer of protection in those situations, in most situations.
You know, you can also change your location in the world. Now this is useful for different services like Netflix and so on.
But mostly I just like it from a software engineering design perspective. I love tools that just work.
They do one thing and they do it really well. And they do it across different platforms. They never break down. Everything just works.
Everything's intuitive from the UI perspective. And from the backup perspective, everything's just the work smooth.
Android, Linux, everything. I love it. Go to ExpressVPN.com slash Lex pod for an extra three months free.
This show is also brought to you by GiveDirectly, a nonprofit that lets you send cash directly to people in need.
It's perhaps a common intuitive notion, but the giving of money to alleviate some of the suffering in the world or to improve the quality of life for a bunch of people in the world is not an easy problem.
There's so many challenges and there's just a lot of studies behind the principles that GiveDirectly operates under, which is if you actually give money to the people most in need,
they're going to themselves spend that money to maximally improve their life. This too is a common intuitive notion, but it works time and time again.
Like many things, I have so much to learn in this world about challenging problems like this.
So philanthropy is definitely one of them. So I should also mention that a bunch of guests, previous guests of this podcast have used GiveDirectly to donate money.
Jack Dorsey, Elon Musk, Vitalik Buterin and several others.
Visit GiveDirectly.org slash Lex to learn more and send cash directly to someone living in extreme poverty. That's GiveDirectly.org slash Lex.
This show is also brought to you by Blinkist, my favorite app for learning new things.
Blinkist takes key ideas from thousands of nonfiction books and condenses them down into 15 minutes that you can read or listen to.
I set the goal of reading one book a week.
I said a classic book, but really what I mean is a book that really challenges you and really makes you think.
So I look forward to seeing sort of using Blinkist to help me review the books, actually also choose the books,
and maybe help others that are interested in following along with my reading to get deeper and deeper insights into these different books.
I think my perspective is on many books I read are nonstandard.

I get lost on a single quote here and there and it just kind of takes me down this whole tangent of thought.
These ideas that get inspired and get sparked and then I just construct this whole world from a single quote sometimes.
But that's what makes it interesting. It's a very subjective experience, like appreciating art, appreciating books and so on.
Anyway, you can claim a special offer for savings at Blinkist.com slash Lex.
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And now, dear friends, here's Betul Kachar.
What is the phylogenetic tree or the evolutionary tree of life?
And what can we learn by running it back and studying ancient gene sequences as you have?
I think phylogenetic trees could be one of the most romantic and beautiful notions that can come out of biology.
It shows us a way to depict the connectedness of life and all living beings with one another.
It itself is an ever-evolving notion.
Biologists like visualizations, they like these graphics, these diagrams and tree of life is one of them.
So the tree starts as a common ancestor?
It's actually the other way around. It starts from the branches, it starts from the tip of the branch, actually.
And then depending on what you collected to build the tree.
So depending on the branches, depending on what's on the tip of the branch, and I will explain what I mean,
the root will be determined by what is really sitting on the tip of the branch of the tree.
So we could study the leaves of the tree by looking at what we have today and then start to reverse engineer,
start to move back in time to try to understand what the rest of the tree, what the roots of the tree look like.
Exactly. So the tree itself, by just taking a few steps back and looking at the entire tree itself,
can give you an idea about the connectedness, the relatedness of the organisms or whatever again you use to create your tree.
There are different ways.
But in this case, I'm imagining entire diversity of life today is sitting on the tips of the branches of this tree.
And we look at biologists, look at the tree itself.
We like to think of it as the topology of the tree to understand when certain organisms or their ancestry may have merged over time.
Depending on the tools you use, you might use this tree to then reconstruct the ancestors as well.
And so what are the different ways to do the reconstruction?
So you can do that at the gene level, or you could do it at the higher complex biology level, right?
So in which way have you approached this fascinating problem?
We approached it in every way we can.
So the gene could be protein, the product of the gene, or species, or could be even groups of species.

It totally depends on what you want to do with your tree.
If you want to understand certain past events, whether an organism exchanged a certain DNA with another one along the course of evolution,
you can build your tree accordingly.
If you rather use the tree to reconstruct or resurrect ancient DNA, which is what we do, then in our case, for instance,
we do both gene, protein, and species because we want to compare the tree that we create using these different information.
Okay, well, let me ask you the ridiculous question then.
So how realistic is Jurassic Park?
Can we study the genes of ancient organisms and can we bring those ancient organisms back?
So the reason I asked that kind of ridiculous sounding question is maybe it gives us context of what we can and can't do by looking back in time.
Yeah, so dinosaurs or all these mammals, at least for us, is the exciting thing already happened by the time we hit larger organisms or to eukaryotes.
Or to you, the fun stuff is before we got to the mammal?
The fun stuff is what people think is boring, I think, the phase that's two different times in the geologic history.
One is the first life, past origin of life, how did first life look like?
And the second is why do we think that over certain periods of geologic time, no significant innovation happened to the degree of leaving no record behind?
So what do we not have a record of?
The fun stuff to you is after the origin of life, which we'll talk about, after the origin of life, there's single cell organisms.
The whole thing with the photosynthesis, the whole thing with the eukaryotes and multi-cell organisms and what else is the fun stuff?
The whole oxygen thing, which mixes in with the origin of life.
There's a bunch of different inventions, all they have to do with this primitive kind of looking organisms that we don't have a good record of.
So I will tell you the more interesting things for us.
One is the origin of life or what happened following the emergence of life, how did the first cells look like?
And then pretty much anything that we think shaped the environment and was shaped by the environment in a way that impacted the entire planet that enabled you and I to have this conversation.
We have very little understanding of the biological innovations that took place in the past of this planet.
We work with a very limited set of, I don't want to even say data because they are fossil records.
So let's say imprints either that comes from the rock and the rock record itself or what I just described, these trees that we create and whatever we can infer about the past.
So we have two distinct ways that comes from geology and biology and they each have their limitations.
Okay, so there's an interplay.

The geology gives you that little bit of data and then the biology gives you that little bit of constraints in the materials you get to work with to infer how does this result in the kind of data that we're seeing.
And now we can have this through the fog.
We can see, we can look back hundreds of millions of years, a couple of billion years and try to infer.
Even further and I like that you said fog.
It is pretty foggy and it gets foggier and foggier the further you try to see into the past.
Biology is, you basically study the survivors broadly speaking and you're trying to put together their history based on whatever you can recover today.
What makes biology fascinating also erases its own history in a way, right?
So you work with this four billion year product that's genome, that's the DNA.
It's great.
It's a very dynamic, ever-evolving chemical thing.
And so you will get some information but you're not going to get much unless you know where to look because it is responding to the environment.
Yeah, so what we have, that's fascinating.
What we have is the survivors, the successful organisms, even the primitive ones, even the bacteria we have today.
So bacteria is not primitive and we...
Sorry, sorry to offend the bacteria.
We should be very grateful to bacteria.
First of all, they are our great-great ancestors.
I like this quote by Douglas Adams, humans don't like their ancestors.
They rarely invite them over for dinner, right?
But bacteria is in your dinner.
Bacteria is in your gut.
Bacteria is helping you along the way.
So we do invite them for dinner.
Well, they get themselves invited in a way.
And they're definitely older and definitely very sophisticated, very resilient than anything else.
As someone working as a bacteriologist, I feel like I need to defend them in this case because they don't get much shout out when we think about life.
So you do study bacteria.
So which organisms gives you hints that are alive today that give you hints about what ancient organisms were like?
Is it bacteria? Is it viruses?
What do you study in the lab?
We study a variety of different bacteria depending on the questions that we ask.
We engineer bacteria.
So ideally, we want to work with bacteria that we can engineer.
Seldom, we developed the tools to engineer them.
And it depends on the question that we are interested in.
If we are interested in connecting the biology and geology to understand the early life and

fundamental innovations across billions of years, there are really good candidates like cyanobacteria.
So we use cyanobacteria very frequently in the lab.
We can engineer its genome.
We can perturb its function by poking its own DNA with the foreign DNA that we engineer in the lab.
We work with E. coli.
It's the most simple in terms of model systems goes.
Organisms that one can study well-established, sort of a lab pet, that we use it a lot for cloning and for understanding basic functions of the cell, given that it's really well studied.
So, Anna, what you do with that E. coli, you said that you inject it with foreign DNA?
We inject pretty much all the bacteria that we work with, with foreign DNA.
We also work with diazotrophs.
These are azotobacteria.
They're one of the prime nitrogen fixers, nitrogen fixing bacteria.
Can you explain what that is, nitrogen fixing?
Is that the source of its energy?
So nitrogen is a triple bond gas that's pretty abundant in the atmosphere, but nitrogen itself cannot be directly utilized by cells, given it is triple bond.
It needs to be converted to ammonia that is then used for the downstream cellular functions.
And that's what counts as nitrogen fixing?
Yes, so nitrogen needs to be fixed before our cells can make use of it.
No offense to nitrogen either.
Well, it's actually a very important element.
It's one of the most abundant elements on our planet that is used by biology.
It's in ATP.
It's in chlorophyll that relies on nitrogen.
So it's a very important enzyme for a lot of cell functions.
And there's just one mechanism that evolution invented to convert it to fix it?
So far we know there's only one nitrogen fixation pathway, as opposed to, say, carbon.
You can find up to seven or eight different carbon ways microbes invented to fix carbon.
That's not the case for nitrogen.
It's a singularity across geologic time.
We think it evolved around 2.7 maybe, roughly three, probably less than three billion years ago.
And that's the only way that nature invented to fix the nitrogen in the atmosphere for the subsequent use.
Would we still have life as we know today if we didn't invent that nitrogen fixing step?
I cannot think of it, no.
It's essential to life as we know.
You and I are having this conversation because life found a way to fix nitrogen.
Is that one of the tougher ones?
If you put it oxygen, nitrogen, carbon, what are, in terms of being able to work with these elements, what is the hardest thing?
What is the most essential for life?

Just to give context.
I think of this as the cocktail you may hear.
What's in the cocktail?
It's the schnapps, right?
Carbon, hydrogen, oxygen, nitrogen, sulfur.
So there are five elements that life relies on.
We don't quite know whether that's the only out of many options that life necessarily needs to operate on,
but that's just how it happened on our own planet.
And there are many abiotic ways to fix nitrogen, like lightning.
Lightning can accumulate ammonia.
Humans found a way about 100 years ago, I think around World War I,
the Haber-Basch process that we can abiotically convert nitrogen into ammonia.
But actually 50% of the nitrogen in our bodies comes from the human conversion of nitrogen to ammonia.
The fertilizer that we use, urea, comes from that process.
It's in our food.
So we found a way to fix our own nitrogen for ourselves.
Yeah, but that's way after the original invention of hydrogen.
Absolutely.
Absolutely.
We thought that we wouldn't have all the steps of evolution along the way.
Oh, absolutely.
We tried to replicate in the most simplest way what nature has come up with.
We do this by taking nitrogen using a lot of pressure and then generating ammonia.
Life does this in a more sophisticated way, relying on one single enzyme called nitrogenase.
The nitrogen that is used together with 8 electron donor and ATP, together with a lot of hydrogen.
Life pushes this metabolism down to create fixed nitrogen.
It's quite remarkable.
So the lab pet, E. coli, inject them with DNA, does E. coli does nitrogen fixing in part?
Or is that a different one?
So some biological engineers, engineered E. coli to fix nitrogen, I believe, not us.
We use the nature's nitrogen fixing bug and engineer it with the nitrogen fixing metabolism
that we resurrected using our computational and phylogenetic tools.
How complicated are these little organisms?
What are we talking about?
It depends on how we define complication.
Okay, so I could tell that you appreciate and respect the full complexity of even the most seemingly primitive organisms,
because none of them are primitive.
Okay, that said, what are we talking about?
What kind of machineries do they have that you're working with when you're injecting them with DNA?

So I will start with one of the most fascinating machineries that we target, which is the translation machinery.
It is a very unique subsystem of cellular life in comparison to, I would say, metabolism.
And when we are thinking about cellular life, we think of cell as the basic unit or the building block.
But from a key perspective, that's not the case.
One may argue that everything that happens inside the cell serves the translation and the translation machinery.
There is a nice paper that called this that the entire cell is hopelessly addicted to this main informatic computing,
biological, chemical system that is operating at the heart of the cell.
Which is the translation?
It is the translation.
What's the translation from what to what?
So RNA, enzymes?
It converts a linear sequence of mRNA into a later folded protein.
That's the core processing center for information, for life.
It has multiple steps.
It initiates, it elongates, it terminates, and it recycles.
It operates discrete bits of information.
It itself is like a chemical decoding device.
And that is incredibly unique for translation that I don't think you will find anywhere else in the cell that does this.
So even though it's called translation, it's really like a factory that reads the schematic and builds a three-dimensional object.
It's like a printer.
I would divide it into actually even four more additional steps or disciplines than what would it take to study it by the way you described it.
It's a chemical system.
It's the compounds that make it up are chemicals.
It's physical.
It tracks the energy to make its job, to do its job.
It's informatic.
What is processed are the bits.
It's computational.
The discrete states that the system is placed when the information is being processed.
That itself is computational.
And it's biological.
There's variability and inheritance that come from imperfect replication even and imperfect computation.
Man, that's so good.
So from the biology comes the, like when you mess up the bugs of the features, that's the biology.
Informatics is obvious in the RNA.
That's a set of information there.

The different steps along the way is actually kind of what the computer does with bits.
It's done computation physical.
There's a, I guess, like almost like a mechanical process to the whole thing that requires energy.
And actually, you know, it's manipulating actual physical objects and chemicals because you have to ultimately it's all chemistry.
Yeah.
And it tracks this information.
So it is almost a mini computer device inside ourselves.
Yeah.
And that's the oldest computational device of life.
It's likely the key operation system that had to evolve for life to emerge.
It's more interesting or it's more complicated in interesting ways than the computers we have today.
I mean, everything you said, which is really, really nice.
I mean, I guess our computers have the informatic and they have the computational, but they don't have the chemical, the physical or the biology.
Exactly.
And the computers don't have, don't link information to function, right?
They are not tightly coupled, nowhere close to what translation or the way translation does it.
So that's the number one, I think difference between the two.
And yes, it's informatic and we can discuss this further too.
100%.
Let's please discuss this further.
Which part are we discussing further?
Each one of those are fascinating worlds.
Each of the five.
Yeah.
So well, we can start with the more, I guess, the ones that are more established, which is the chemical aspect of the translation machinery.
It's the specific compounds make up the assembly of RNA chemists showed this in many different ways.
We can rip apart the entire machinery.
We know that at the core of it, there's an RNA that operates not only as an information system itself or information itself, but also as an enzyme.
And original life chemists make these molecules easily now.
We know we can manipulate RNA, we can make even with single pot chemistries, we can create compounds.
What's a single pot chemistry?
That's, I would say when you add all the recipes that you know that will lead you to the final product.
This is what original life chemists do is they come up with this pot, they throw a bunch of chemicals in and they try to, they're basically chefs of a certain kind.
I'm not sure if that's what they call it, but that's how I think of it, because it is all combined in a test tube and you know the outcome.
And it's very mathematical.

Once you know the right environment and the right chemistry that needs to get into this container or this pot, you know what the outcome is.
There is no luck there anymore.
It's a pretty rigid, established input-output system and it's all chemistry.
So you actually wear a lot of hats as one of them, original life chemists?
My PhD is in chemistry, but I don't do original life chemistry.
But you're interested in the origin of life?
Yes, absolutely.
So some of your best friends are original life chemists?
Just make sure that you have good chemist friends if you're interested in the origin of life.
That's 100% requirement, it should be mandatory.
Okay, so chemistry, so what else about this machinery that we need to know chemically?
Well, chemically I think that's it, you have enzymes, you have proteins, enzymes are doing their thing.
They know how to chew energy using ATP or GTP.
They know what to do in their own way.
They do their enzymatic thing.
So it's not just the ribosome that is at the heart of the transition, but there are a lot of different proteins.
You're looking about 100 different components that compose this machinery.
Well, let me ask kind of, maybe it's a ridiculous question, but did the chemistry make this machine?
Or did the machine use chemistry to achieve a purpose?
So like, I guess there's a lot of different chemical possibilities on earth.
Is this translation machinery just like picking and choosing different chemical reactions that it can use to achieve a purpose?
Or did the chemistry basically, like there's like a momentum, like a constraint to the thing that can only build a certain kind of machinery?
Basically, is chemistry fundamental or is it just emergent?
Like, how important is chemistry to this whole process?
You cannot have life without chemistry.
You cannot have any cellular process without chemistry.
What makes life interesting is that even if the chemistry is imperfect, even if there are accidents along the way,
if something binds to another chemical in a way it shouldn't,
there is resilience within the system that it can maybe not necessarily repair itself, but it moves on however imperfect mistakes can be handled.
That's where the biology comes in.
That's where the biology comes in.
But in terms of chemistry, you absolutely cannot have a translation machinery without chemistry.
And so you're, as I said, there are four main steps.
These are the core steps that are conserved in all translation machinery.
And I should say all life has this machine, right?
Every cell, everything.

On Earth.
On Earth.
Yeah.
Yes.
When you think of this machine, do you think very specifically about the kind of machinery that we're talking about?
Or do you think more philosophically, a machine that converts information into function?
I cannot separate the two.
I think what makes this machinery fascinating is that those five components that I listed are, they coexist.
So, for instance, if we, let's just talk about the chemistry part.
We know the certain rate constant, all these proteins that operate in this machinery needs to harbor in order to get the mechanism going.
Right? If you are bringing the information to the translation machinery and you are the initiator of this computation system,
you need to have, you can only afford a certain range of mistakes.
If you're too fast, then the next message cannot be delivered fast.
If you're too slow, then you may stall the process.
So there is definitely a chemistry constant going on within the machinery.
Again, it's not perfect, far from it.
But they all have their own margin of error that they can tolerate versus they cannot.
Otherwise, the system collapses.
So it's like a jazz ensemble, the notes of the chemistry, but you can be a little offbeat.
I love that you said jazz.
It's definitely true.
It's a party and it's like everybody's invited and they need to offer it together.
What's really cool about it, I think, there are many things that are very interesting about this thing.
But if you remove it from the cell and put it in a cell-free environment, it works just fine.
So you can get cell-free translation systems, put this translation in a test tube and it is doing its thing.
It doesn't need the rest of the cell to translate information.
Of course, you need to feed the information at least so far because we are far from evolving a translation,
maybe not so far, evolving a translation in the lab or a machinery that can process information as it generates it.
We have not done that yet.
That's a pretty complicated machinery.
It's hard for those original life chemists to find a pot that generates.
Because it's far more than chemistry.
You need biology, obviously.
You need biochemistry.
You need to think as I think network systems folk.
You need to think about computation.

You need to think about information.
And that is not happening yet except we are trying to bring this perspective.
But the more you understand how information systems work, once you see it, you cannot unsee it.
It's one of those things.
But you can still rip it out and the chemistry happens.
Yes.
And chemistry can happen even if you strip some of the parts out.
You can get very minimal level of information processing that does not look anything like the translation that cells relies on,
but chemists showed from linear, you can generate information that arrives to a processing center in the form of a linear polymer.
The informatic part of this system that I think sets it apart from computation and from metabolism comes in if you think about the information itself.
So we have four nucleotide letters that compose DNA.
And they are processed in the translation in triplets.
So you have in triplets codon fragments.
So you have four times four times four.
So you have 64 possible states that can be encoded by four letters in three positions.
So amazing.
There is only one code that says start.
There is only one.
And then there is two, if not three, that says stop.
So that's what you work with.
But you can have 64 possible states, but life only uses 20 amino acids.
So we use, life uses 64 possible states minus four, one of the starts and stops,
to code for 20 amino acids in different combinations.
That is really amazing.
If you think about, there are 500 different amino acids life can choose, right?
Narrowed it down to 20. We don't know why a lot of people think about this genetic code is quite fascinating.
So far, right?
I mean, it didn't do it for four billion years.
I don't know, we may wait for another four billion years.
But you didn't have those amino acids in the very beginning, right?
We don't know.
So we would be fooling ourselves if we said we know exactly how many amino acids existed early on.
But there's no reason to think that it wasn't the same.
Or similar.
Yeah, we don't have a good reason.
But because roughly 20 out of 60 states are used,
you're using one third of your possible states in your information system.
So this may seem like a waste.
But informatically, it's important because it is abundant and it is redundant, right?

So the code degeneracy, you see this in that is implemented by this translation missionary inside the cell.
So it means you can make errors, right?
You can make errors, but the message will still get through.
You can speak, missing some letters to the information can miss some parts,
but the message will still get through.
So that's two thirds of the not used states gives you that robustness and resilience within the system.
So at the informatic level, there's room for error.
There's probably room for error probably in all five categories that we're talking about.
There's probably room for error in the computation.
There's probably room for error in the physical.
Yes, exactly.
Everywhere there's room for error.
Because this informatic capacity is made possible together with the other components.
And not only that, but also the product yields a functional, in this case, enzyme or protein, right?
So that's really amazing for me.
It is.
I mean, in my head, just so you know, because I'm a computer science AI person,
the parallels between even like language models that encode language
or now they're able to encode basically any kind of thing, including images and actions all in this kind of way.
The parallel in terms of informatic and computation is just incredible.
Actually, I have an image.
Maybe I can send you.
Can we pull it up now?
If you just do genetic codon charts, we can pull that off.
Yeah, it's a very standard table.
So I can explain why this is so amazing.
So you're looking at this is life's alphabet, right?
And so I also want to make a very quick link now to your first question, the tree of life.
When we link, when we try to understand ancient languages, right?
Or the cultures of the, or the cultures that use these extinct languages.
We start with the modern languages, right?
So we look at Indo-European languages and try to understand certain words and make trees to understand,
you know, this is what Slavic word is for snow, something like snig.
Now we jump to languages that humans spoke, human history.
Exactly.
So we make trees to understand what is the original ancestor.
What did they use to say snow?
And if you have a lot of cultures who use the word snow, you can imagine that it was snowy.
That's why they needed that word.
It's the same thing for biology, right?

If they have some, if we understand some function about that enzyme,
we can understand the environment that they lived in.
It's the similar, it's similar in that sense.
So now you're looking at the alphabet of life.
In this case, it's not 20 or 25 letters.
It's, you have four letters.
So what is really interesting that stands out to me when I look at this,
on the outer shell, you're looking at the 20 amino acids that compose life, right?
The one, the methionine that you see, that's the start.
So the start is always the same.
To me, that is fascinating that all life starts with the same start.
There is no other start code.
So you sent the AG, you know, AUG to the cell that when that information arrives,
the transition knows, all right, I got a start.
Function is coming.
The following, this is a chain of information until the stop code arrives,
which are highlighted in black squares.
So for people just listening, we're looking at a standard RNA colored table,
organized in a wheel.
There's an outer shell and there's an inner shell all using the four letters
that we're talking about.
And with that, we can compose all of the amino acids and there's a start
and there's a stop and presumably you put together the,
with these letters, you walk around the wheel to put together the words,
the sentences that make...
Yeah, the words, the sentences and you, again, you get one start,
you get three, there are three different ways to stop this, one way to start it.
And for each letter, you have multiple options.
So you say you have a code A, the second code can be another A.
And even if you mess that up, you still can't rescue yourself.
So you can get, for instance, I'm looking at the lysine K, you get an A
and you get an A and then you get an A that gives you the lysine, right?
But if you get an A and you get an A and then get a G, you still get the lysine.
So there are different combinations.
So even if there's an error, we don't know if these are selected because they were
erroneous and somehow they got locked down.
We don't know if there's a mechanism behind this or we certainly don't know this
definitively, but this is the informatic part of this.
And notice that the colors in some tables too, the colors will be coded in a way
that the type of the nucleotides can be similar chemically.
But the point is that you will still end up with the same amino acids
or something similar to it, even if you mess up the code.
So we understand the mechanism how natural selection interplays with this

resilience to error, which errors result in the same output, like the same function
and which don't, which actually results in a dysfunction or which error.
We understand to some degree how translation and the rest of the cell
work together, how an error at the translation level,
this is the really core level, can impact the entire cell.
But we understand very little about the evolutionary mechanisms behind
the selection of the system.
It's thought to be one of the hardest problems in biology
and it is still the dark side of biology, even though it is so essential.
So this is, yeah, you're looking at the language of life, so to speak,
how it can found ways rather to tolerate its own mistakes.
So the entire phylogenetic tree can be deconstructed with this wheel of language?
Because all the final letters, that's the 20 amino acids, that's our alphabet.
They are all brought together with these bits of information, right?
So when you look at the genes, you're looking at those four letters.
When you look at the proteins, you're looking at the 20 amino acids,
which may be a little easier way to track the information when we create the tree.
So using this language, we can describe all life that's lived on Earth.
That's one perspective.
We are not that good at it yet, right?
So in theory, this is one way to look at life on Earth.
If you're a biologist and you want to understand how life evolved from a molecular perspective,
this would be the way to do it.
And this is what nature narrowed its code down to.
So when we think of nitrogen, when we think of carbon, when we think of sulfur,
it's all in this, that all these nucleotides are built based on those elements.
And this is fundamentally the informatic perspective on this whole topic.
Exactly. That's the informatic perspective.
And it's important to emphasize that this is not engineered by humans.
This evolved by itself.
Right. Humans didn't invent this just because we're just describing,
we're trying to find, trying to describe the language of life.
It appears to be a highly optimized chemical and information code.
It may indicate that a great deal of chemical evolution and this may indicate
that a lot of selection pressure and Darwinian evolution happened
prior to the rise of last universal common ancestor,
because this is almost a bridge that connects the earliest cells to the last universal common ancestor.
Can you describe what the heck you just said?
This mechanism evolved before the what common ancestor?
The last universal common ancestor.
Yes. So when we talk about the tree, when we think about the root,
if you ideally included all the living information,

all the available information that comes from living organisms on your tree,
then on the root of your tree lies the last universal common ancestor, Luca.
Why last? Last universal? Because the earlier universal,
it also had trees, but they all died off.
We call it the last because it is sort of the first one that we can track,
because we cannot, we don't know what we cannot track.
There's one organism that started the whole thing.
I would think of it as more like a population, a group of organisms.
Hold on a second. I tweeted this so I want to know the accuracy of my tweet.
Sometimes early in the morning I tweet very pothead-like things.
I said that we all evolved from one common ancestor that was a single cell organism
3.5 billion years ago, something like this.
How true is that tweet? Do I need to delete it?
Actually, correct. I think, of course, there's a lot to say,
which is like we don't know exactly, but to what degrees
the single organism aspect is that true versus multiple organisms?
Do you want me to be brutally honest? Yes, please.
There's still time. This is how we caveat the tweets.
First of all, it's not 3.5 is still a very conservative estimate.
In which direction?
I would say it's 3.8 is probably safer to say at this point.
A bunch of people said probably way before that.
If you put it in approximately, I'll take that.
I didn't. I just love the idea that I was once, first of all,
as a single organism, I was once a cell.
Well, you're still a group of cells.
No, but I started from a single cell. Me, Lex.
You mean like you versus Luca? Are you relating to Luca right now?
No, no, no. I'm relating to my Lex.
Your own development.
My own development, I started from a single cell.
It's like built up a stuff.
That, and then so that's for single biological organism.
And then from an evolutionary perspective, the Luca,
my ancestor is a single cell, and then here I am sitting,
half asleep, tweeting.
Like I started from a single cell, evolved a ton of murder along the way
to this brutal search for adaptation through the 3.5, 0.8 billion years.
So you defy the code of Douglas Adams.
You are proud of your ancestors and you invite them over to dinner
and you invite them over to your Twitter.
And it's amazing that this intelligence,
to the degree you can call it intelligence,

emerged to be able to tweet whatever the heck I want.
Yes, it's almost intelligence at the chemical level.
And this is also probably one of the first
chemically intelligent system that evolved by itself in nature.
Yeah, so you see that translation as a fundamental intelligent mechanism.
In its own way, and again, if we manage to figure out
how to drive life's evolution, if it can evolve
a sophisticated sort of informatic processing system like this,
you may ask yourself what might chemical systems be capable of
independently doing under different circumstances?
Yeah, so like locally, they're intelligent locally.
They don't need the rest of the shebang.
They don't need the big picture.
So that's a great segue into what makes this biological, right?
The hearts of the cellular activities are translation.
You kill translation, you kill the cell.
Not only the translation itself,
you kill the component that initiates it, you kill the cell.
You remove the component that elongates it, you kill the cell.
So there are many different ways to disrupt this machinery.
All the parts are important.
Now, it can vary across different organisms.
We see variation between bacteria versus eukaryotes versus archaea.
So it is not the same exact steps,
but it can get more crowded as we get closer to eukaryotes, for instance.
But you are still computing about 20 amino acids per second, right?
This is what you're generating every second.
That single machinery is doing 20 a second?
21 for bacteria, I believe 8 for eukaryotes or 9.
21 a second.
I mean, that's super inefficient or super efficient,
depending on how you think about it.
I think it's great.
It's way slower than a computer could generate through simulation.
I think, if you can't show me a computer that does this, we are done here.
Well, this includes the five things, not just,
but I could show you a computer that's doing the informatic, right?
Yes, you can show me that, but you cannot show me the one that has all.
For now.
For now.
I will ask you about, probably, what, alpha fold, right?
I think the more we learn about, and this is why early life and origin
is also very fascinating and applicable to many different disciplines.

There is no way you see this the way we just described it,
unless you think about early life and early geochemistry
and earliest emergent systems.
But going back to the biological component,
all of these attributes that we think about life
or that we associate with biology stems from translation
as well as metabolism.
But I see metabolism as a way to keep translation going
and translation keeps metabolism going.
But translation is arguably a bit more sophisticated process
for the reasons that I just described.
So metabolism is a source of energy for this translation process?
It's a way to process materials, and it is inherently dynamic,
and it is flexible, but it is not focused on reputation as translation does.
So that's the main difference.
Translation is kind of, in a way, just repeats, right?
So you have the metabolism that can synthesize materials,
creates or benefits from available energy,
and again, it's a dynamic system.
And then you have computation that is inherently repetitive, right?
Needs to carry out repetitive processes,
and it does the tasks, and it implements an algorithm,
but it is not dynamic.
So you see both of those attributes in translation combined.
It is repetitive, and it is dynamic,
and it also processes this information.
So they are fundamentally different.
I don't know if you can get life if you don't find a way
to process the information around you.
In a repetitive, dynamic way.
Yeah, and somehow that's what got selected, maybe not selected.
I don't know if it was accidental,
but that's what seems to be conserved for four billion years.
That's what life established upon.
What's the connection between translation and the self-replication,
which seems to be another weird thing that life just started doing,
wanting to just replicate itself?
I think when we truly understand the answer to that question,
we may have just made ourselves life, right?
I don't think we know quite how translation machinery
as a whole fits into equation,
because so we try to understand ribosomes, RNA,
how the linear information is processed,

or the genetic code, why this codon's not others,
why 20, not more, not less.
And we are sort of moving towards translation.
That's what we're working on anyway,
to finally look at the patterns in which this system operates itself.
And if you understand that,
you're really unlocking a very emergent behavior.
One of the things you didn't mention is physical.
Is there something to mention about that component that's interesting?
There's actually a paper published in 2013,
I want to say the first author, Zirnoff.
So they surveyed a computational engineered systems level
computation energy consumption.
And they tried to understand whether the universe is using its own,
or life is using its full capacity of energy consumption.
And if different planets in the universe had life,
the capacity would increase or decrease.
Does life operate at its energy maximum?
And they think that it does,
that it actually operates at an efficiency
that is far more above and beyond a computational system.
How is that possible to determine at all?
You tell me.
That's why I dropped the citation.
I found the citation.
It's quite an interesting paper.
Obviously, you can only calculate and infer these things.
It's a good question to ask.
Is the life that we see here on Earth
and life elsewhere in the universe,
is it using the energy most efficiently?
Yeah.
It seems to be very efficient.
Again, if we compare it to computers,
it seems to be incredibly efficient at using the energy.
Yeah.
I think they look at the theoretical optimum
for electronic devices,
and then try to understand where life falls on this,
and life is certainly more efficient.
And that's ultimately the physical side.
How well are you using for this entire mechanism
the energy available to you?

And so given all the resilience to errors
and all that kind of stuff,
it seems that it's close to its maximum.
And this paper aside, it does seem that life,
obviously, that's the constraint we have on Earth, right,
is the amount of energy.
Yeah.
So that's one way to define life.
Well, the input is energy, and the output is what?
I don't know.
Self-replicating.
Wait, okay, let's go there.
How do you personally define life?
Do you have a favorite definition
that you try to sneak up on?
Is it possible to define life on Earth?
I don't know.
It depends on what you are defining it for.
If you're defining it for finding different life forms,
then it probably needs to have some quantification in it
so that you can use it in whatever the mission
that you're operating to be more like.
Do you mean like it's not binary?
It's like a 7 out of 10 on the...
Life, life, life, life.
I don't know.
I don't think that defining is that essential.
I think it's a good exercise,
but I'm not sure if we need to agree
a universally defined way of understanding life
because the definition itself seems to be ever-evolving anyway, right?
We have the NASA's definition.
It has its minuses and pluses,
but it seems to be doing its job.
But what are the different... If there is a line
and it's impossible or unproductive to define that line,
nevertheless we know it when we see it
is one definition that the Supreme Court likes.
And that's a kind of an important thing to think about
when we look at life on other planets.
So how do we try to identify if a thing is living
or we go to Mars when we go to the different moons
in our solar system or go outside our solar system

to look for life on other planets?
It's unlikely to be a sort of smoking gun event, right?
It's not going to be, hey, I found this.
You don't think so?
I don't think so.
Unless you find an elephant on some exoplanet,
then I can say, yeah, there's life here.
No, but isn't there a dynamic nature to the thing?
Like, it moves, it has a membrane
that looks like there's stuff inside.
It doesn't need to move, right?
I mean, like, look at plants.
I mean, they grow, but there are plants
that can be also pretty dormant.
And arguably, they do everything that...
One of my favorite professors once said
that a plant does everything that a giraffe does
without moving.
So movement is not necessarily...
But on a certain timescale, the plant does move.
It just moves slower.
Yes.
It moves pretty...
I would say that it's hard to quantify this
or even measure it, but it is...
Life is definitely the chemistry finding solutions, right?
So it is chemistry exploring itself
and maintaining this exploration for billions of years.
So, okay, so a planet is a bunch of chemistry
and then you run it and say, all right,
figure out what cool stuff you can come up with.
That's essentially what life is.
Given a chemistry, what is the cool stuff I can come up with?
If that chemistry or the solutions that it embarks upon
are maintained in a form of memory, right?
So you don't just need to have the exploring chemical space,
but you need to also maintain a memory of some of those solutions
for over long periods of time.
So that's the memory component makes it more living to me.
Because chemistry can always sample, right?
So chemistry is chemistry.
But are you just constantly sampling
or are you building on your former solutions

and then maintaining a memory of those solutions
over billions of years, or at least that's what happened here?
Chemistry can't build life if it's always living in the moment.
The physicists will be very upset with you.
Okay, so memory could be a fundamental requirement for life.
Life is obviously chemistry and physics leading to biology.
So this is not a disciplinary problem of one discipline,
trying to bring other disciplines.
But what you need to have is definitely...
Chemistry is everywhere, right?
I tend to think you can be a chemist.
You can study chemistry, you can study physics,
you can study geology anywhere in the universe.
But this is the only place you can study biology.
This is the only place to be a biologist.
That's it.
So definitely something very fundamental happened here.
And you cannot take biology out of the equation.
If you want to understand how that vast chemistry space,
how that general sequence space got narrowed down to
what is available or what is used by life,
you need to understand the rules of selection.
And that's when evolution and biology comes into play.
So the rules of natural selection operate to you on the level of biology?
Rules?
I don't know if there are any rules like that.
It would be fascinating to find in terms of the biology's rules.
That's a very interesting and...
It's a very fascinating area of study now.
And probably we will hear more about that in the decades to come.
But if you want to go from the broad to specific,
you need to understand the rules of selection.
And that is going to come from understanding biology, yes.
Well, actually, let me ask you about selection.
You have a paper on evolutionary stalling
where you describe that evolution is not good at multitasking.
Or like in populations that evolve quickly.
It's a very specific thing, but there could be a generalizable, fundamental thing to this,
that evolution is not able to improve multiple modules simultaneously.
I guess the question is,
what part of the organism does evolution quote unquote focus on to improve?
Yeah, that was the driving question.
We meddled with the part where you shouldn't be messing up with translation.

This is the...
Should or should not?
You shouldn't.
As I said, there are many ways to break it and all life needs it.
That's one of the things...
Your favorite thing to do is to break life, see what happens.
It's...
Yeah, because that's how kids learn, right?
So you have to break something and you see how it will...
Then you do it over and over again to see if it will fix itself in the same ways.
Yeah.
So it's our...
I don't know, it's the most fundamental properties of ourselves as human beings.
So if we shouldn't break translation, then we should try to break it.
Yes.
To see how it will repair.
So which part did you break?
I broke elongation.
What's the role of elongation in this process?
So we have four steps of the translation to initiate elongate.
So elongate the chain of the information chain that you're now creating, the peptide chain, or let's say broadly polymer chain.
And there's the termination step and there's the recycling.
So all of these steps are carried out by proteins that are also named after these steps.
Initiation is the initiation factor protein, elongation is the elongator protein.
We broke elongation.
So the cell, the starting codon could still arrive to where it's supposed to go.
But the following information couldn't get carried out because we replaced elongation with its own ancestral version.
We inserted roughly 700 million year old elongation factor protein after removing the modern gene.
So we made this ancient modern hybrid organism.
And that essentially creates in some way the ancient version of that organism?
I wouldn't say so.
It's a hybrid organism.
Because the rest of the cell, the rest of the genome is still modern.
And that goes back to the difference between Jurassic Park.
There are many differences obviously given that this is not fiction, we're doing it.
But also we are not necessarily, I think in Jurassic Park they are taking an ancient, they find an ancient organism and then put a modern gene inside the ancient organism.
In our case, we are still working with what we got, but putting an ancestral DNA inside the modern organism.
So you're like taking a new car and putting an old engine into it?
In a way, yeah.

Yes.
Seeing what happens.
Yes, but in our case, it's more like a transformer than just a regular car.
It is doing things.
Yeah, so it's a more complicated organism than just a car.
I got it.
So what does that teach you?
We wanted to understand multiple things.
One is how does the cell respond to perturbation?
And we didn't just put the ancient DNA.
We sampled DNA from currently existing organisms, so the cousins of this microbe, and collected DNA sequences from the cousins as well.
So both ancestor and the current cousin DNA, so to speak.
They engineered all of these things to the modern bacteria and generated a collection of microbes that either have the ancient component or the variant elongator component that's still alive today, but coming from a different part of the tree.
So you broke elongation.
Was that something you did as part of the paper on evolutionary stalling to try to figure out how evolution figures out what they tried to improve?
Did that help?
Yes, because we were not supposed to mess with the translation.
That's exactly what we did.
And we altered elongation by changing it with different versions of elongation that are either coming from species that still are around today.
You can imagine them as sitting on the tips of the tree near branch, far branch, compared to the organism that we're working with, cousins, distant cousins, as well as the ancestors of the bacteria that we are now modifying.
How much different variation is there in that elongation step?
What are the different flavors of elongation?
That's a very good question.
So mechanistically or mechanically, it's the same, it's very conserved.
So all life elongates the same way.
It's nothing but a shuttle.
You just carry a chemical with you, the bit, to the heart of the machine.
Is that essentially doing a copy-paste operation?
It has its tail that's attached to the code, which is then carried biochemically to the linear chain to the core of ribosome.
And it sits on there.
It's released in the peptides click, the codes rather click.
Once that chemistry that the tail end occurs, the protein leaves the center.
So you can imagine it's like it hops in there and hops out.
And when it hops and hops out, it leaves the information behind.
That's all it does is bring the information, get out of there.

And it's all triggered by biophysics, biochemistry, because of the way the enzyme
choose energy, in this case, GTP, how the phosphor leaves the center,
that kicks, that gives the additional kick to the enzyme to leave the center.
So which parts are different then?
Where's the flavors of different flavors of elongation?
So usually the parts that matter don't change over time.
Nature conserves the sites of these proteins that are important for its job.
If there's a difference, then we want to know, especially if there's a difference between two cousins.
And we look at the sites that interact with the most important parts of this machinery.
If we see any difference, we tend to mutate or we revert, we engineer that part,
we alter that part because it gives us a clue that there must be something interesting going on here or not.
Okay, so that's not the fundamental part of the machinery,
but it's some flavorful characteristic that you can play with.
So now you stripped the machinery down to its parts and now you're looking at the parts of the parts.
And it depends where you're looking and how you're looking and what you're looking at.
But usually we see up to 70% level conserved identity across all modern versions.
When you travel back in time, the identity decreases.
So elongation likely existed.
We have good reason to think that it existed at the dawn of life.
So you're looking at a 3.8 billion year old mechanism.
And when we look at the ancestors that we resurrect, we see about 40% identity.
So the identity definitely decreases as you go back in time.
But still 60% shared information over 4 billion year is pretty good.
Is that just for elongation or for the entire translation?
It depends on what you do.
So for initiation, we've also recently published this.
It's a different story.
But overall, you see high level of identity that is kept intact,
especially if the component is essential for life.
So 40% and 70% you said.
But from generation to generation, how does evolution,
and presumably that's what that paper is looking at, is the parts of the parts.
How does it able to say, like mess with the parts
and try to come up with a cooler improved version of the organism?
So let me describe to you what we did in that experiment.
We took bacteria.
We perturbed the elongation in all of these with different variants.
So we had an initial set of a group of bacteria that we had.
We then subjected these bacteria to evolution in the lab.
So first of all, we knew we broke it because upon engineering,
we measured what's going on with the cell.

It's not growing as well.
They are not healthy.
We can see it with our eyes.
We can measure it that if they were generating and offspring every 20 minutes,
now it is 40 minutes.
So we really messed them up.
They don't want to work with this thing.
They don't want each other, but they need each other.
So we created that situation for them, which is good because we wanted to see how
we wanted to see how they will cooperate with each other to fix this problem.
Because we know that that's not the condition that they want to live in,
especially when they know what they can do.
So with that, we subjected these organisms to evolution in the lab.
We refer to this as experimental evolution.
We subject bacteria to different selection pressure, project them through bottlenecks.
Every day, we randomly collect a handful of bacteria from the flask,
put them in a new fresh environment with fresh food,
keep them in this environment for 24 hours until they reach a more dormant state,
and then we subject, introduce them to an even environment.
So we repeated this for about it.
I will say 150 days.
So every day, nonstop, we repeated this experiment.
So how many different kinds of environments are there?
We kept the environment to the same, because we had different initial conditions.
We kept the environment constant.
Same temperature, same food, same source of carbon.
But we created replicates for each lineage.
So in some ways, we created our own fossil record in the lab
by evolving and generating these flasks.
And every step of the way, we also froze these cells
and took stocks of them in the cryo-freezer.
How long does it take to go from one generation to the next bacteria?
For E. coli, it's usually 20 minutes.
Okay, great.
So that's the experiment.
That's the experiment.
And you're always messing with it in the same way for the initial condition?
It's the same way.
So we introduced variation at the elongation level,
because we perturbed it with different elongations.
We found that if we introduce a different protein that is very different,
the cells don't like that, right?
So if the distance is larger, the consequence is also large,

meaning that you hit them harder.
If you introduce a variant that is really foreign to them,
that's really distant.
In our case, it was the ancestor.
They really did not like the ancestor,
but they were okay with their nearest cousin.
Right.
Okay, great.
So you did vary in the distance?
We varied at the evolutionary distance,
and then we kept the experimental conditions the same,
and we propagated these populations every day for 150 days.
And we collected bacteria at every step of the way
and looked at the sequence.
We wanted to understand what sort of changes may have happened in the genome
to respond to the variation that we've introduced.
So what kind of changes would you be seeing,
depending on the evolutionary distance of the thing you shoved into it?
Exactly.
So we knew where we punched, right?
We punched right the heart, right?
We punched the translation.
So we expected, is it going to be a translation?
Are we going to see a change?
Will translation respond to this by fixing itself right away?
Or will it be another outside of translation,
something completely different, a different module?
Because translation itself is a module.
Or would it be within elongation,
a really sub-protein level thing?
So we had a strategy to identify the mutational pathways
by categorizing what we expected to find or where.
Okay.
So why does it not do multitasking?
Why is it not improving multiple things simultaneously?
It turned out that what we observed in general
is that first of all, the harder we hit the cells,
the more likely they were to respond by changes,
right, at where we hit it.
When you say hit it, you mean like changing something?
I like to think of it as hitting,
because I like to think there's breaking the cell, right?
I mean, not breaking enough to kill it,

but we still, because they're still alive,
they're not doing their job well.
So the bigger the evolutionary distance of the thing
you put in there, the harder the hit is how you think about it.
Exactly.
The bigger the hammer.
Bigger the hammer, exactly.
You hit it with, okay.
That's what it turned out to be,
because that's what the data told us,
that if the variation is higher,
then the consequences will also be higher
in the sense that the cells will not grow
as healthy compared to a variant that is coming from a near,
or a variant that is coming from a near evolutionary distance.
Is it wrong to think of this kind of hitting
as akin to a mutation?
Or no.
What are we supposed to learn from this hitting?
How the thing evolves after it's being hit in this way?
What does that teach us?
Because we see translation machinery as almost,
it is so conserved and so essential.
It is not even clear whether we can remove some of the parts,
or whether the entire translation will need
all of the same parts in the same efficiency.
We don't understand the rules of this machinery.
So the first thing we understand is that
what is the resilience?
What are we really talking about here?
You cannot mess with this translation.
Is this true?
Because it is so conserved and so similar
and functions in the most conserved ways.
That was the first thing that we wanted to understand.
Did you learn anything interesting about the resilience
at the chemical, physical, informatic computation?
No, I wouldn't say that.
In the biological level, yes.
Because we found that the different modules
started responding to the changes that we've introduced,
and that we could never recover the translation
as effectively as it used to be.

So that it never reached to its optimality,
that it was always suboptimal.
It needed, say, one more mutation perhaps to get there.
It accumulated four mutations.
We did a lot of experiments to understand this, of course.
It was accumulating mutations.
It was getting better at its task.
Maybe it needed a couple other mutations
to get really good at it,
but somehow those mutations never happened.
And before those mutations happened,
we saw another module emerging through mutations
and getting better at its own different task
that is not translation.
You can think of cell as a web of networks, right?
We think of these as multiple, almost, airports
that are proteins that are more central hubs
versus they're proteins that maybe are not as important hub.
If you introduce a problem in the most populated hub,
you're going to mess up the traffic system more drastically.
And that's what we were messing with in the biological terms as well.
So when we say module, like translation would be one of the modules.
Translation would be one.
So you're basically saying when you mess with translation,
the organism would choose to either try to fix that module
or another module, depending.
Exactly.
But it wouldn't do multiple modules.
It wouldn't do multiple modules.
It focused on one module at a time.
And right before that module maybe reached to its own maximum,
it stalled its optimality at a certain degree.
So you never get to a degree that is more optimal than you can achieve,
even though perhaps another mutation could get you there.
Since you messed with the translation from a sort of optimal perspective,
wouldn't it make sense for the cell to try to start fixing the translation?
That's exactly what we thought.
And it was not the case for all the broken translation missionaries.
For instance, if the variant was coming from a near ancestor, that didn't happen.
It was almost cruising around, trying different modules
and sort of living its best life still,
because there is no real urgency in the system to fix the most important problem.
And there's also not a direction.

Maybe to you it's obvious that's the problem,
but to the cell maybe you're the problem.
I'm living, like you said, my best life.
I mean, I guess that's the thing about evolution is we don't know
what the right direction to...
Yeah, it's almost like you can imagine that you have this messy closet.
Go on.
It happens to be an accurate representation of my life.
So you take a look at it and you see all the sweaters or jeans all over the place.
And then you look at a drawer that has socks coming out of it
and you think that's the most important one, I'm just going to fix that one.
And then you fix that one and you think you will get to the other one,
but you don't because you just fix the most important one.
That is whatever that was getting into your way.
That's really what evolution is.
It's quite lazy.
It fixes the problem that seems to be the most immediate
and it doesn't go beyond what it really needs to.
It seems like at least for our experimental setup, that was the case.
Especially for rapidly evolving systems.
So is the environment they're operating in pretty constrained?
Is there urgency?
I would say that we definitely constrained the environment.
It's definitely removed from their natural setup.
We're not evolving them in a gut.
It's a very homogeneous system, very controlled temperature, controlled food, controlled carbon.
So just looking at that, let me ask the romantic question.
How did evolution create so much beautiful, complex variety on earth?
Like from that, you're saying that we're talking about improving different modules,
but if we step back and look at the entirety of the tree,
the different organisms that created all throughout history.
The stuff that's fun to you with the first few billion
and the stuff that's fun to me when I watch on YouTube,
which is like the lion versus gorilla fights and so on.
But the whole thing is fun.
So all that beautiful variety from the predator and the prey,
from the self replicating bacteria and all that kind of stuff.
How did it do it?
How is a very difficult question,
especially when we don't understand the past with clarity at all.
I can tell you that there seems to be very critical innovations
that happened throughout the history of life that are each themselves
very sophisticated singularities that emerged once and then they set the tone.

One of which is emergence of translation.
It seems like it happened once.
It had to happen once.
It seems like that's all it took.
3.8 billion year, maybe older,
clearly subjected to a lot of chemical evolution even prior to last universal common ancestor.
And then you jump and you see emergence of cyanobacteria
that's undeniably changed the course of this planet
in the subsequent aerobic photosynthesis that life learned
how to utilize what's available in this environment in the most profound way.
And then you move forward, you see the emergence of eukaryotes,
endosymbiosis, also another singular event.
And then you move forward and then comes the plants.
So these are, I counted I think six different things
that seems to have happened just once.
The singularity events in the history of evolution of life on Earth.
So what's really fascinating here is that there seems to be two different courses,
the time course.
Evolution is operating at the molecular level.
We're talking about seconds.
We're talking about mutations that happen every second.
We're talking about selection that's also happening under a minute.
So that is a very fast process.
The fact that I can evolve bacteria in a lab
and I say almost complainingly, oh my goodness, it took me 150 days.
I mean, that's pretty rapid for a change to be seen.
But then the big changes and the ones that I'm talking,
the really big innovations that caused an increase of oxygen on this planet
or even its own mere presence are due to these molecular innovations.
Seems to only happen at a handful of times over billions of years of time scale.
Let me ask you this question having to do with my half asleep tweet.
So saying that we all originated from one common ancestor,
that's just one of the miraculous things about life on Earth.
Of course, you could say there's multiple common ancestors in the beginning,
multiple organisms and so on.
But the other stuff that you're talking about is these singular events,
these leaps of invention throughout evolution in history.
Now, there's a bunch of people who were commenting,
a bit surprising to me, who were basically skeptical of this idea.
The idea of?
Well, I would say evolution, honestly.
The process of evolution, but when you just actually focus in on like holy crap,
eukaryotes were invented.

Holy crap, photosynthesis were invented.
Those are incredible inventions.
And also, we can even go to Homo sapiens like intelligence.
Where did that come from?
These mysteries, I think where that skeptical comments are coming from
were also just the general skepticism of science.
I think from the pandemic, people may be a failure of institutions and so on.
They've been a growing distrust of science.
And it's not so much that it's anti evolution.
It's more of a stepping back and saying, wait a minute,
maybe scientists don't have it all figured out.
And I think to steelman that case is almost a step back
and to realize there's so much mystery to each of these leaps.
So it makes you wonder, is there something that in 100, 200 years
will figure out that we totally don't understand yet?
Like some, you know, there's, I talked to a bunch of people about another mystery,
which is consciousness, right?
People called panpsychists who believe consciousness
is one of the fundamental laws of the universe.
So there could be, you know, like we have laws of physics
that could be something that's like a consciousness field or something
that permeates all matter.
And so like there might be, it's kind of like Newtonian physics versus general relativity.
Like we have a good understanding of how things happen,
but we need another layer of understanding to fill in the gaps of the mysteries of it all.
And that sort of is a sobering reality that maybe there is something
we really deeply don't understand.
Do you have a sense of where the biggest mysteries here are?
Is it the origin of life itself?
Is it the leaps that we're talking about?
So you see the beauty, you're fascinated about the translation mechanism.
What are the deep mysteries there to you?
We are nothing but chemical systems capable of formulating
or answering questions about our own existence.
We humans or all of life, you think?
Humans are, I mean, the fact that we can, we even have this conversation
about our place in the universe is, at least to our knowledge,
is quite specific to our own chemical species.
Yeah, it's kind of wild.
We're introspecting on our evolutionary history
and we're just a couple of organisms.
We're like another organism listening to this and like their mind blown.
There's like three organisms, two of them talking

and the third one is like, holy shit.
I think that understanding the,
what I really find interesting about understanding the origin of life
or even contemplating about our own place in the universe,
if at the end of this would come down to appreciating,
or even before appreciating, really truly comprehending what it is that we got here.
That, to me, is a huge gain,
because there's no single question in biology, I think,
that will deliver the magnitude of that message and understanding,
but understanding how life here started at first place,
if we truly comprehend that.
This is not a concept that is well thought in schools.
We ask students to memorize these concepts,
if they are lucky they learned RNA world, chicken and egg problem, etc.
That's the extent to which maybe their biology teacher
was personally interested in the subject matter, if they're lucky.
You know the saying that the brains are evenly distributed
across any metric you can imagine, but opportunities are not.
So, if people aren't understanding the importance of this,
because that's a lack of opportunity right there,
that was skipped through the proper education and training,
then the delivery of why science matters, or how science actually works.
Yeah, but how do you even begin to seriously think about the origin of life?
I mean, every problem of existence, of life has its time.
So, I don't know if it's time to understand consciousness yet.
We might be a hundred years away from that.
The origin of life, I don't know if it's time for us to understand that yet.
Maybe we need to solve so many more problems along the way.
It's not a competition of problems, right?
So, there are all kinds of problems and it takes a lot of people to make the world.
So, you will always have some interesting brain going after an interesting problem to their own.
The issue here is that we need to first of all understand that what we have going on on this planet is pretty good.
Good planets are hard to find.
If we are alone in the universe, that's huge.
We need to take care of what we got here.
We are incredibly vulnerable to the changes that our own species also helped create at the biosphere, at the ecosystem level.
We take it for granted.
We take what we created for granted because of the fact that we think we are some sort of ultimate endpoint,
the most sophisticated, amazing thing that nature could generate.
I think understanding, not even understanding but asking these questions of where did this even

come from?
How did this even begin?
And attempting to understand that using chemistry and physics and biology and because we can, that's the ultimate gift we can give back to the entire species on this planet.
Yeah, I mean it's humbling. It's humbling to realize the complexity of this whole mechanism.
It certainly puts humans in their proper perspective that we're not,
just because we have brains and brains are intelligent doesn't mean we're the most intelligent thing because ultimately the whole mechanism of nature seems to be orders of magnitude more intelligent.
We're like a hierarchy of organisms that have a history of several billion years
and that all somehow came together to make a human and there'll be life after us just as was life before us
and something that comes after will be perhaps even more fascinating.
I think when you understand the magnitude of what happened here, there is no room for arrogance.
It should overwhelm you and humiliate. It's pretty humiliating.
It's quite amazing what happened here and there is no other discipline that will deliver that
but exploring our own origins and looking at life as a more planetary system phenomena
rather than one single species at a time, a collective look.
You mentioned this question in your TED Talk is the two possibilities of the universe being full of life and the universe being empty and we're the only life in the universe.
How do you feel about both options?
Just actually you as a single chemical organism introspecting about its existence in this world.
Having a planet flow of life is interesting because we talked about life being all about chemistry exploring solutions
and having solutions in front of you is great. It's beneficial, right?
Solutions being different organisms like other humans. You see them as the solutions to a chemistry problem.
That's an interesting solution. That's not next time. We're in Austin so there's a bunch of weirdos.
Every time I see a weirdo, I'd be like, oh, that's an interesting solution to this chemistry problem.
Now you think like an origin of life science.
Funny that that one worked out. Let's see where else it goes.
But having this emptiness and unpredictability of uncovering a novel solution can also have its own benefits
and we should be open to what other solutions might be out there and exploring those solutions.
Oh, to different chemistry problems. So that's where you see the other planets out there as different chemistry problems.
To their own local environment, yes.
So how many chemistry problems have solutions that are lifelike to you out there in the universe?
It's a wide open palette. If you think about it, I don't quite know.
We know the chemistry is chemistry. I don't think the chemistry will be different elsewhere.
But again, what is selected by chemistry will be determined by the environment most likely.
See, I think there is life everywhere out there.
So there's a guy named Nick Lane whose gut, and it's interesting to me.

I wonder what you think about it. His gut is there's life everywhere out there, but it stops at the bacteria stage.
So he says the eukaryotes is like the biggest invention and the hardest one.
I wonder if he thinks that's an accidental outcome. If he thinks that's inevitable, I wonder what that means.
But it's a likely possibility that the bacterial or microbial life is definitely more attainable.
So that's a weird world where our entire galaxy just has bacteria everywhere.
So if you don't like microbes, you aren't on the wrong planet.
No, I know. Yeah. And viruses. I don't know which one there's more of, but they're both, and most of them are productive.
They're fascinating. They do everything for us.
If you don't like microbes, you're on the wrong planet. You're full of good lines.
Okay, right, right. I just can't. There's like an imperative to the whole thing. To me, the origin is the hard question.
But once it gets going, I just don't see.
Wait, go ahead.
It seems like it's constantly creating more intelligent things, more fascinating, complex things.
They're able to solve complicated problems.
That's a very interesting, I definitely agree that the initial steps may be the ultimate determinants.
You cannot stop it once it starts. It's possible, right?
I just have never on Earth, but maybe, whenever I see life, it seems to flourish everywhere.
The thing is, the only thing I haven't seen is the start of it.
Exactly. And how are we going to understand it if we don't know the origin of life science?
The question here isn't exactly our ability to recapitulate everything that happened in the exact way that it happened.
This is about what can happen, rather than, or maybe how.
You think it's possible to study the origin of language using English.
There's a very particular chemistry here. There's a particular set of assumptions, understanding about what life is,
what everything is, our perception of reality is very specifically constructed through the evolutionary process.
I wonder if it's possible to get to some first principles, deep understanding of how life originates in such a way that you can actually construct it on other planets.
Ultimately, it feels like if you're doing it in a lab on Earth, you're always going to be using some aspect of the life that's already here.
That's what I sort of talked about in my talk as well.
Everyone should go. Watch the TED Talks. Very good.
The annoying thing to me about TED Talks, I guess this by design, is they're too short. It's like, come on.
Did you know that? There's no promptor involved?
There isn't.
You have to memorize stuff.
Thanks to my amazing editor who probably is watching this too, David Bielow. It was very, very

helpful.
I like this podcast. It's a very professional organization. I respect that medium.
In the TED Talks, life, creating life.
So it's a likely scenario that once we understand how life as a chemical system is capable of formulating its own expression
and generating a memory and manages its existence on a planetary body for billions of years,
once we understand what conditions gave rise to that,
we may be very likely to understand whether a different planet also be likely to instigate its own chemical revolution
if it was provided through some missing ingredients.
We may be able to think of it as a sending fertilizer to a different planet that is missing its own chemical composition or lacking,
or that it needs more of what it has.
The difference between making that planet Earth-like, which is not what that's about.
We're not talking about terraforming or we're not talking about turning that planet into Earth-like system.
We're not talking about first understanding that planet, studying its chemistry, studying its properties well enough
to understand whether it is close to its own chemical revolution and maybe giving it that extra nudge.
So this is obviously a pretty big speculation and suggestion.
It's a very interesting proposition because this is a yes or no question.
I think it says a lot about the perception of the person who's answering this question,
that if the answer is no, no, no, absolutely not, that's not something we want to do.
I want to know why that is the case.
So just to be clear, what we're talking about is looking at the chemical cocktail of a particular planet and tasting it and seeing what's missing.
So having a very systematic, rigorous scientific process of understanding what is missing,
not what is missing in terms of to make it Earth-like,
but what is missing in order to be sufficiently have the spark or the capacity of the spark
to launch the evolutionary process.
And then the question is, do we want to then complete the cocktail?
The proposition is to also make us think that we will likely have this capacity at some point,
especially when we understand origin of life better and better.
So we will be asking ourselves this question.
I guess I wanted to bring this to daylight a little bit because maybe in 10, 20 years, maybe more.
So you wanted to ask the ethical question, should we basically start life elsewhere on another planet?
Or enable the chemical capacity of that planet that it may one day itself get there.
Okay. So for me, the answer is yes.
So if you were to try to argue against my yes, what would you say?
What's the worst that can happen if we seed another planet with life?
What are the things we should think about?

Is your main concern a chemical biological one or is it an ethical one?
What do you think about?
Well, the worst thing that can happen is that it wouldn't work, right?
So that it's not likely that an attempt like this would work.
That's probably because you have to have an understanding that I don't think we have just yet.
I see because if it doesn't work, then we could try again, right?
To me, the worst case, the thing I would be worried about is we create life.
I mean, the same stuff I worry about with plants is things that might have a conscious experience.
And then the dark aspect of life is life is increasingly complex life.
Maybe I'm anthropomorphizing, but it seems to have the capacity to suffer.
And so we're creating something.
It's like when you have children, you put creatures into this world that will suffer,
can't suffer and may suffer depending on how you view life, may likely suffer.
And so now you carry this responsibility for doing your best to alleviate any suffering that might go through.
Perhaps that's a romanticizing this notion of life, perhaps bacteria are not capable of suffering,
but perhaps it'll create more complex life forms that would be able to suffer.
And that feels like a responsibility as well.
Of course, other people would be concerned.
The more obvious concern is like, well, you just created a life form.
How do you know it's not going to be a super deadly virus that somehow is able to hurt humans?
Yeah, my concern is more, I feel like that's a solvable problem.
The problem of creating conscious beings that are able to suffer, that's a tricky one.
Yeah, I can see why.
Because it goes back to, again, would we, first of all, do we have a responsibility to propagate more of this chemistry that we have on this planet elsewhere,
given that we know ultimately we will be vanished by the entire planet?
And if this is, in fact, a very rare chemical event that happens because all the right circumstances came together and we were the lucky one,
do we have a responsibility to sponsor it?
If we were to back up...
Sponsor, I like it.
That's a good way to put it.
We try to back up remnants of our civilization, right?
So we want to potentially create conditions on the different planets so that humans can survive,
given that we know what we want to, just for the sake of growing.
Yeah, propagating.
Becoming multipartiary species.
Exactly.
And really, as at stake here, I think it's actually, or what is really more interesting is what we don't see,
which is, again, the chemical behavior that enabled everything at first place.
That's different than sending potato crops or engineering bacteria to live on a different planet.

That's very different.
You're really stripping it down to what is possible at the chemical level.
So even if you are instigating the chemistry on different planets,
you are letting that very planet to do its thing.
You're not necessarily contaminating this planet with different chemistry
because the idea behind this, the way I thought about,
is that you understand that planet, you understand the conditions,
you understand the chemistry of the planet really well
before choosing the planet as a candidate at first place.
And then it's not about sending a missing ingredient per se,
but again, just sending more of what it already has.
That will be respecting that planet's condition too.
So I'm not suggesting any occupation.
I'm not suggesting any colonization.
I'm not suggesting any, like, let's just strip everything and make everything Earth-like.
That's not what I'm saying.
It's more about empowering that place.
What you are saying is likely to be the motivator behind all this.
That's not because I see suffering, I see pain.
It's very interesting.
I think this is a question that really reveals a lot about the person who's answering it.
Well, okay, so the pushback on my pushback.
If I saw him deeply troubled by suffering, then I should be probably paralyzed
about the history of life on Earth.
And, you know, there's...
Can you elaborate? What do you mean?
Most of life who's ever lived suffered in ways that are almost unimaginable to me.
You mean your own species?
Our own species and before.
And animals living today.
And we're not even talking about factory farms.
We're just animals living in extreme poverty in the jungle.
People think, like, in a natural environment, animals live in a happy place.
No, it's a brutal place of desperately trying to survive, of desperately trying to look for food.
And it's just, like, all of that life, that's just mammals.
I don't understand mammals, but, like, throughout, like, trillions of organisms that led up to those mammals.
And the organisms living everywhere, like even bacteria, there's death everywhere.
So maybe this idea of death, this idea of suffering, is actually...
This thing that we see as a bug is actually a feature.
I don't think suffering is a linear property like that with life.
And I may be with Nick Lane on this one, that the likeness of anything similar to what we got here, evolving in another planetary body, I think is quite low.

Where would you say is the biggest unlikely thing?
Do you mean humans, or do you mean even multicellular organisms?
Probably multicellularly.
But I understand both sides of the equation, right?
In one level, I can see that we may not have any other choice but to back up this chemistry somewhere else.
So you would be saving, it's the ultimate saving, or our own record.
It's not about, you know, yes, let's also save Beatles and all the amazing songs,
but this would be the ultimate repository of life.
But I can also see your point of view, for sure.
It's really interesting, so like, don't see the plan with the missing ingredient.
Try to understand what the ingredients it has, is it possible to construct life?
For me, from a computer person, it just feels like something that could be solved computationally.
We can learn from the mistakes that we've done here and aspire not to repeat them.
It is possible.
We do amazing things as humans.
There's a lot of suffering, but there's also a lot of beauty.
And we could choose what we want to be or what we want to see, right?
So these attempts don't need not to come from a place of fear,
but it can be ultimately, it can come from a piece of hope and love.
I think we're just very recently figuring out stuff.
Like we've even just a century ago, we're doing atrocities that weren't seen as atrocities at the time.
I mean, I think we're learning very quickly of what is right and wrong.
Yes, and I work with a lot of, maybe because I'm at the university,
I get to teach young people every day.
Even at the time of four years or three, few years, you see generational difference already unfolding in front of you.
And maybe that's why I see hope, because I think what we get to interact with in classrooms every year is just getting better.
They are aware of issues in a way that I sure wasn't at their age.
Some levels I was, but in many levels I didn't think about.
I wasn't concerned of the problems.
Well, they maybe have to be concerned because it's hitting the reality, it's hitting them hard.
But younger people are not afraid of these things.
An 18-year-old can face these brutal facts about the planet in ways that I don't think any other generation before them did.
Yeah, it's super cool. There's all these cool technologies that aid in the process of a human being, being able to see the truth at deeper, deeper levels.
Wikipedia and just the internet in general is enabling education at a level that was unimaginable before the internet.
Yes, and I think space exploration, even contemplating about these possibilities,
ultimately, and I will emphasize this again, should make us think about our own place in the universe.

If we are alone, that is quite fascinating.
And we definitely have a responsibility to guard what we got better and protect it better and don't take it for granted.
If we are not the only one, that's also a lot of responsibility to understand what else is out there.
So either proposition, as famously being told, is fascinating. But as a scientist, I think,
and I think that's the general behavior, maybe not my fellow scientists listening to this can correct me if they aren't like this,
but you need to have a level of optimism and hope.
That's something that things are worth working for, worth dreaming, worth imagining.
And we cannot just have fear of suffering or fear of pain stopping us from doing marvelous things.
I've talked to quite a few people in my life who've gotten a lot of shit done, have helped a lot of people,
and I don't know a single one of them who's not an optimist.
Now, there's a place for critics and cynicism in this world,
but in terms of actually building things and creating things in this world that help a lot of people,
I think optimism is a requirement, is a precondition in almost all cases in my limited, humble human experience.
But I tend to, when I look out there, I think that aliens are everywhere.
I think there's, to me, I have a humility about, I tend to see us humans as being very limited cognitively.
Like, there's so many things we don't understand.
I think eventually we'll understand, of course we don't know this, but my gut says,
we'll understand that alien signals and life has been all around us, and we're too dumb to see it.
Like, whatever life is, whatever the life force is, whatever consciousness is, whatever intelligence,
whatever the mechanism that led to the origin of life on Earth was everywhere,
and we're just too dumb to see it.
It's in the physics, it's somewhere, we'll find it somewhere in the physics.
I think that's one of the most humbling parts of also being a scientist that we know, that we never know, for sure.
And for the outsiders, perhaps, that may be a very strange way of living,
especially when your pursuit is about creating knowledge,
and that you'll know that what you created can also be, and hopefully will be disproven,
so that another level will rise.
And I think we've seen that this lack of maybe connection between the approach to science or knowledge
versus folks who are maybe not thinking about these problems every day, that we are okay with being wrong.
In fact, we know that that's the only way to push the limits of knowledge.
How do you think life originated on Earth?
We've talked about this, but do you have a gut feeling about...
First of all, actually, even to step back, do you think, because you were flirting with this idea,
the translation mechanism came before life?
I think that you cannot separate from emergence of translation machinery from emergence of life,

or something like translation machinery, this whole informatic chemical computing system
that is also capable of dynamism and evolvability that comes with biology, biological behavior from emergence of life itself.
We've definitely took a lot of steps towards understanding origins.
We are able to create molecules from environments, lightning, heat, and you make amino acids.
So we are able to create the building blocks, the Miller Ure experiment.
That's now 60 years ago.
We are able to create the building blocks.
We are able to make them interact with one another.
They can get more complex.
Some call this messy.
There's all this chemistry that's going on.
We are able to have these chemicals interact with one another,
maybe have even some emergent properties that we can quantify.
Definitely, there is this trend towards more systems-level approach to origins,
with more introduction of systems-level chemistry, more network-level chemistry,
and complex system integration in order to understand how...
Now that we can make these building blocks, we can make them interact with one another,
but how do we make them interact with one another in more intelligent ways
that will have the properties of a biological system, will be heritable,
it will be responding to the environment, it will mutate, and it will sustain itself.
That is the final bit, I think, in our original life adventure.
And we are extremely close.
I'm very optimistic that our community will get a handle of this problem in this decade.
This is, in fact, I think, one of the most exciting times to be doing this work.
What would be super convincing to you, like, incredibly amazing, would blow your mind
if X was done in a lab?
I don't know if you would call it origin of life,
but something really truly remarkable and special done in a lab.
What would that look like to you?
The properties that I listed, the five properties that I listed about in machinery
that is capable of sensing and responding to the environment,
if we can...
I would imagine, similar to Miller-Yuri experiments,
where they only sparked in particular environmental forces
and were able to produce a chemical that is important for life,
or a mix of chemicals important for life, or building blocks, rather.
If I saw that a similar experiment there, and well-defined geochemical parameter,
was subjected on a mix of chemistry,
which led that chemistry to form some level of computation informatic biological property,
and by biological I'm going to keep it to very minimum, as I defined early on.
That would be super exciting to me, as self-organizing chemistry
that we can create experimentally in a flask by simulating the conditions of early Earth,

be it radiation, be it temperature or mix of both, that would be very cool.
And doing all the five, the chemical, physical, informatic, computational, biological?
Yes.
So like simulation and a computer would not be good enough?
It would be great, because they help to understand the parameters,
maybe formulate, maybe quantify, create models, but ultimately you need to experiment.
Unless it's quantum mechanical simulation, but that's going to be extremely difficult.
So simulating from the physics up, that's going to be very difficult.
Because you're going to have to simulate the physical, the chemical, the informatic.
I mean, honestly, it's very difficult to start the quantum mechanics
and end up in biology all through simulation.
But the stuff that DeepMind did with AlphaFold and protein folding is really inspiring.
It's inspiring in that you're able to solve a difficult biology problem.
Yeah, absolutely. That's why there's definitely a lot of benefit to those models' predictions,
because they at least help the experimentalist to come up with the priors
and parameterize things better, maybe eliminate very obvious dead ends early on,
given that experiments take such a long time and it's a huge investment.
And no one's a better experimentalist than nature.
Let me ask you perhaps a depressing, sad for you question.
You really want to make me sad. You're not going to win.
No, I know. There's a flame of optimism in you that will never be extinguished.
Okay, the idea of past Bermuda, you mentioned would we seed another planet with life.
Is it possible that our planet was seeded with life from elsewhere?
So what the proposition I made, I like to think of it as proto-Spermia rather than pan-Spermia,
because it's even more proto-state than acknowledging.
Because in pan-Spermia, you still have a cell, right?
You still have something that is very, even a cell to me would be very Earth-like.
I'm talking at sub-sailor level in the proposition of spreading chemistry.
So spreading chemical ingredients, not spreading life.
Exactly. It would be more like the fertilizer that is well-adopted and compatible with that planetary body.
In pan-Spermia, you're still imagining either an entire bacteria or microbe or a cell,
or something that is DNA, which is still taren.
So in that sense, that doesn't matter to you, because it's chemistry.
That's the initial conditions. It doesn't matter how the initial conditions came to be.
They are what they are, and let's go from there.
Yeah.
And there's all kinds of fascinatingly different initial conditions in terms of chemistry
and different planets.
Yes, but in terms of pan-Spermia, obviously there's going to be always room for those sort of discussions.
Those discussions will always be present, I think, in any life in the universe debates.
But the problem I have with pan-Spermia is that it removes the problem from the planet to

somewhere else.
It makes it very difficult to answer scientifically.
You just took the problem away from this planet and formulated in a way that I cannot go
and try to understand in the lab doing experiments or even through models.
Does it though?
So I've heard brilliant biologists like yourself say that, but to me, okay, here's how I think of Earth.
I actually am able to hold all these possibilities in my head, and all of them are inspiring to me.
I kind of think there's a possibility that Earth is just an experiment by a graduate student, by an alien graduate student.
So I know the exact episode of Star Trek you're talking about.
To me, that's inspiring.
But that's not what pan-Spermia is about.
You're talking about my proposition.
That's not what pan-Spermia is.
What's pan-Spermia?
Oh, life just came from elsewhere.
Still that's interesting because there's still giant leaps that happened on Earth, it seems like,
beyond the initial primitive organisms, like eukaryotes.
I don't think pan-Spermia usually articulates at the level of eukaryotes.
I think they talk about bacteria primarily.
I think so.
Right.
So that's still interesting because all the different leaps of evolution still happen here on Earth.
That's still interesting.
Yeah, but it's definitely interesting to listen to,
but I wouldn't know how to place it in the studies of origin of life, I guess.
Here's how we place it.
You have the initial conditions for the origin of life,
and you try to create life in that way that you've described in the five components,
and it keeps failing.
So what pan-Spermia allows you to do is to also consider the question,
maybe there's missing components.
How do you answer that question?
Through exploration and through science, looking outside of Earth,
looking at the fundamentals of chemistry and physics.
How do you understand that with fundamentals of chemistry and physics?
How do you understand gravity?
But you're talking about pan-Spermia, right?
I don't understand how would you...
It's different than...
If you think it's similar to looking for life in the universe,
is that what you're thinking?
No, I'm saying there's a missing component that came from elsewhere.

But a whole entire organism is not a missing component like that, right?
I mean, when you're thinking about origin of life.
No, no, no.
That's an assumption.
Your assumption is all the ingredients for the origin of life are here on Earth.
Now, I tend to believe that most likely that's the case.
I'm just saying it's inspiring to think that there is some ingredients.
You're going to push back because that's not pan-Spermia.
That's probably...
See, okay, so think...
It's also kind of fun to push back on you.
No, I understand.
I understand.
I understand if actually a living organism ended up here from elsewhere.
That means a lot of the exploration we're doing here with the ingredients that we know
will not give us the clues to the origin of life.
But it just seems like it's still very useful to try to create life here.
And then we'll see, wait a minute.
Don't you think we'll be able to prove, not prove, but show that pan-Sperma is very likely?
If we just keep failing, we understand biology deeply.
I understand chemistry deeply.
See, that's the thing.
I don't think so.
The failure is not going to indicate that this must have been...
I don't think anyone will put the problem to something else just because our failures,
our experiments failed.
So failure means we don't understand the chemistry deeply enough?
Yeah, and given the progress we made and how many brilliant people are working on this right now,
and it's definitely more, I would say that we are approaching this problem in more broader ways,
in different ways possible.
I'm confident that we will get there.
For us, again, we are interested in early cells and first cells and what follow the origin of life,
but given that it's a continuum that's between the origin and emergence of first cells,
it's hard to separate these two ends from one another.
So given that life is a solution to a chemistry problem, if we re-ran Earth a million times,
how different would the results be?
If we look at that wheel, how different would be the tree of life, do you think?
What's your gut say?
My mind asks, are you imagining, if we are repeating the planet one million times,
are we seeing, are the things that happened, I'm not talking at the chemical level,
but at the environment level, do they happen at the same time, at the same frequency,
at the same intensity every time you're running this tape over and over again?
Yes, you mean like geological stuff.

Yeah, like so.
So you're saying those are important.
The fact that you would ask that question is also fascinating, so that's important.
The timing, the frequency, the intensity of geological events.
Yeah, so when we run this imaginary rewind and play experiments in our minds,
I want to know whether we are positioning all the same geologic events at the same chronological order as well,
or whether we are also giving them more randomness.
So if they volcano erupt, is it happening at the same time?
If you have our dinosaurs getting wiped off every time with the same meteorite that's hitting the same.
But also like temperature changes and all that.
Temperature changes, everything.
That's actually, I've heard you say somewhere that one of the things that's fascinating to you about this whole process of evolution is that
the process of evolution, all the mechanisms were invented and developed
despite all the variation geologically through the hardship that Earth has gone through.
That the biological innovations persisted despite that?
Yeah, despite that, which is interesting.
You kind of think of the biological innovations kind of happening in their own.
So we actually have a center exploring this problem.
We want to understand whether it's almost like judging a book by its cover.
Do you just look at an environment and then see whatever is present or scares in that environment and then think that, okay, the life form that will exist in this environment will obviously have a lot of molybdenum in its system.
Look at all this molybdenum around here.
Because if you say that, you are now putting the environment in the more prime driver role, right?
You're saying that environment will determine what biology will or will not use.
But we've done studies that show that it's not necessarily straightforward.
For instance, we looked at going back to nitrogen.
One thing that's fascinating about the way cells fix nitrogen, the ones that can do,
is that they also do this through a lot of help of a lot of metals, a lot of elemental support, really.
And which geologists use to understand where did this metabolism even evolve where at first place?
So we look at ancient oceans, we try to understand the elemental composition of ancient oceans.
And what we see is that in some cases, the metabolisms, even though they prefer a certain metal or an element that is in the environment,
that metal wasn't abundant in the environment, but still life chose that.
So it's not that straightforward as though you are what you eat, but you don't necessarily eat what is obvious to you.
Just because there's a lot of that food around you doesn't mean life will ultimately go there.
Maybe most of the time it will.
But it seems like in the case of nitrogen fixation, it didn't, and maybe that made the difference.
It's so cool that, right, it's not the abundant resource that's going to be the definition of what kind of

life lurishes.
So it's not a straightforward thing.
Yes.
But your sense is that the different timing, the different conditions of the environment would change the way evolution happens.
Yeah, for instance, I think it's in the 80s, maybe earlier than that, the Stephen Jay Golds book, Wonderful Life, which changed, I think, a lot of scientists' life, including mine.
He contemplates on this notion of the tape of life.
Of course, I hope people still know what tape is, but I think your listeners will know what tape is.
I don't know.
It's the tape.
Go on, tell me about the tape.
Is there like a TikTok?
Can you swipe on it?
I'm sorry, go ahead.
I apologize for my rude introduction.
I can't ask for it.
But he speculated or suggested this hypothetical experiment, whether if life was recorded on, or can be imagined to be recorded on a linear, is a linear chain of events recorded on a tape.
And if we were to rewind this tape, would we listen to the same song?
And in his proposition, I also thought, yeah, but are we replaying the tape in the same exact manner?
Or are we meaning all the geological and environmental events are they happening at the same time?
Because then you removed the randomness from equation a little bit, right?
You just removed it because you're assuming everything will happen at the same time, at the same intensity.
So that's not too contingent.
That means that the natural selection you're thinking is really operating at more, or evolution is operating at more, under more random forces, then that can be dictated by the environment.
So in our way of understanding or thinking about rewinding, replaying, I don't think we're thinking about the role of the environment as clearly or don't seem to be integrated as much.
But I also wonder if it's possible that the chemistry ultimately defines the destination that despite all the environmental changes, despite all the randomness, will end up in something.
But we are not talking about whether life will emerge and sustain itself.
We are talking about whether life will emerge and sustain itself in the shape and form that is similar to what we have right now.
So you are chemistry, I'm chemistry, we're having this conversation and your plants are chemistry too.
They are also having their own conversation.
These plants are fake, but yes.
I didn't want to say that, but they are fake.
Do you look at my place?
Of course they would be fake, otherwise they would die.

What's wrong with this place?
It's wonderful.
I'm Alice and this is Wonderland.
This is great.
It's just that this is a place where robots flourish and those plants are fake.
Are you saying that you and I are the only living organisms?
Obviously there are microbes in this room.
Yeah, we are the only living organisms.
Let's take care of getting a dog.
This is not a clean room, so you have microbes here.
Yes, many, millions.
So you and I and all the microbes in this room, your chemical systems that are operating in a way that we can respond and sense and our environments and whatnot.
But if you're asking if you're going to be here, then you're imagining that another solution is also possible, which is different than the fundamentals of life.
Because life will do always. Life will do its life thing.
I guess it goes all the way back to the things we were talking about, translation and the stuff you were messing with,
is figuring out what is the important stuff and what isn't. It makes me wonder about, just like with the translation machinery,
with human beings, I wonder what's the important stuff. Is it important to have two limbs?
Is it important to have eyes?
It was obvious that the sensory mechanism of eyes, like sight, were to develop.
Sometimes, if you were here on Earth, would the sensory mechanism of sight develop? And what would it look like?
Would it be one giant eye or would it be two? What's with the symmetry? Why are we so damn symmetrical?
In response to Steve J. Gold's proposition, most people who argue that life is convergent and it will in fact lead to a few determined outcomes.
It's not that the outcome is determined per se, but the pathways are restricted,
and the mutational trajectories that life can act upon are already very limited so that the final outcomes are a few,
and eyes being one of them.
So the convergence at the eye level was presented as an example of why life may actually embark on the same solution over and over again,
given that many species evolved independently from one another.
Do you think there's any inkling of truth? Is it just us humans thinking more special?
I think those innovations came again so far after the... I know it's the fun stuff, yes.
Thank you. We humans tend to talk about the later stuff, but without the earlier stuff.
When we think of earlier Earth, I ask this to my students too. I want them to close their eyes and think about just nothingness but dust.
We don't have trees, we don't have plants. When we say an empty place, or visually at least, we are talking about a planet that is really alien.

So understanding our own past is similar to understanding an alien planet altogether.
Given that it is a very different planet that did not have any oxygen for two billion years,
there's nothing that is familiar to us that we would even think about when we think about life that is present in our past, yet here we are.
So cool that from that came this, like houses and people...
And we are very, very... we are the super later rivals to the party, right?
So this is definitely not our planet. It's the microbial planet that we live in.
But the potential to create us was always there.
How did you know that?
Because we were created. Oh, I don't know. You think it's possible this, even for the early stuff.
Yeah, maybe if it's super unlikely, yeah, that we just got super...
This is the planet that got really lucky given the chemistry.
Like maybe to create the bacteria is not so lucky.
But to create complex organisms all the way up to mammals, that's super lucky.
Yes, and it may all come down to a few innovations that happened at the molecular level that may or may not be inevitable.
So all these molecular tricks may have enabled the mere existence of whatever you are able to define as familiar to yourself.
And you have a hope that science can answer these questions to reconstruct?
Science is answering these questions. I mean, we are limited to going back to the beginning in our ways, right?
So we rely on biology. It says overwritten. You're talking about four billion year old records that is ever changing.
Again, it makes it beautiful, but also makes it difficult. It's not tractable.
Geology has, to some degree, it has a record of a more static frozen state record that is embedded on itself, on the surface of this planet, if we can find them.
And that's the key that most of these recorded remnants are, if we are lucky, we find them. They are not naturally selected.
They are found, they need to be found for us to read them.
So we work with a very handful set of samples, especially when we talk about the deep past, the planets with no oxygen,
when we passed the Great Oxidation Event threshold, that is about 2.5 billion years.
So the earliest life is even harder. You are trying to write the story of life based on a handful of rocks and what is recorded on them.
Speaking of finding select remnants of our deep past, you said that you've been thinking about Nick Nieland's essay on scientific knowledge and scientific abstraction.
So let me ask you, what do you think scientific questions and answers or in general ideas come from?
You're a scientist. You ask very good questions and try systematically and rigorously to answer them through experiment. What do you think ideas come from?
So ideas come all the time. There are all kinds of ideas. There are good ideas. There are not so good ideas. There are really exciting ideas, maybe some boring ones.
But if you are really interested in doing something different, then you need to be willing to take the

risk to be wrong.
And that's incredibly difficult, even though we talked about the idealist notion behind science that we ultimately want to be rejected,
or our ideas need to be rejected for the entire infrastructure to move forward.
There is a level of risk-taking, I think, behind any creative idea.
And I mean that in a true sense. If you are disappointed that your idea didn't work, then it wasn't a risk, because you still hoped that it will work.
True risk is that you accept that it may not work, so that the failure shouldn't also surprise you.
Yeah. When you embark on stuff, when you embark on an idea, do you actually contemplate and accept failure?
Not consciously, I wouldn't say so, but I eliminated a lot of the things out of my work line by simply not feeling like studying them.
I was bored chasing certain questions.
So you trusted the signal of boredom as a good sign that it's not a good question.
Yes. It should definitely be, whatever you're doing should be exciting.
If there's only one person that should be ever excited about what you're doing, that should be you.
And that's enough for that idea to go somewhere, I think, that you need to believe in the idea.
But at the same time, I think it's important to not fall in love with your mistakes.
If something isn't working, you should let it go.
Instead of trying to fix it, even though you feel that this is a mistake or you know that it's a mistake, instead of trying to fix it, you should wrap it up and move on to something else, which is incredibly hard.
Good advice for science, but also good advice for relationships.
Okay, so that's actually really hard, especially if you sink in so much of your time, not even PhD, the entire scientific career, it's really tough to let go.
Yes, and there's not a lot of room for true freedom, maybe at this certain degree.
But you need to be trained, right? It's not that scientists are just brilliant, amazing humans, they just know and learn how to do science,
because they're trained in how to do science.
So that is important, because as someone who wants to definitely, I'm giving the message that this is for everybody,
and there's this notion of scientists being super smart people, that's definitely not true, right?
It is a method that you learn to solve a problem, that's really what science is.
And some are really good at it, and they get better at it under really good guidance, maybe good mentorship.
And ultimately, everyone finds their own style of problem solving and what sort of problems they solve,
and not met a scientist that finds their own pursuit boring.
Well, it can happen, but they're not going to be affected, just like you said, I think.
It's kind of interesting, because in the age of social media and attention economies and stuff like that,
I've interacted with a lot of folks, like YouTubers and so on.
I think a lot of their work is driven by what others find exciting.

And I think that ultimately leads to a life that's not fulfilling.
I can see the reason behind it, or perhaps there's a fear of failure that can be a major determinant of that pattern, right?
So you try to do something that is accepted by others, because that's maybe unlikely to give results right away.
But it's a long game, it's a very long game, and if you are aiming a long-term change and long-term impact,
you've got to be very, very patient about it, and you better tame your ego.
I mean, on YouTube and those kinds of places on the internet, on social media, you get feedback right away.
So it's even harder to be patient.
Because change and ideas develop over a period of months and years, not decades.
And the response from social media and so on is on the rate of seconds, minutes and hours.
So I recommend actual physical libraries for people who may want to appreciate or remember the sense of time
and how long it takes to build something.
I think it is, you're right, that's the immediacy and the right response.
And the fact that these places, the algorithm wants you to respond right away and interact with itself, right?
So I can see the appeal, but through innovation, I think it doesn't even scream.
It's not shiny, especially in the beginning.
But it's also important to not fool ourselves and think that everything that people criticize has some super important meaning behind it.
So it's a mix of the technique, the methods, and your gut feeling.
Yeah, and a weird dance between learning and accepting the ideas of the current science and at times trusting your gut and rejecting those.
Because science progresses by sometimes rejecting the ideas of the past or sometimes building on them in a way that changes them, transforms them.
Yes, and I think what is hard is to really drill down into a concept, right?
So you can create a new thing and then it may be appealing and gain a lot of traction.
But to sustain that, to continue that, you really need to show the true expertise.
And so it's not only about defining a problem, but then really systematically solve that problem maybe over the course of decades.
You mentioned the library.
I've also saw that you've translated scientific documents, or at least like mentioned that you did it at some point in your life.
So let me ask you, how much do you think is lost in translation in science and in life?
How many languages do you speak?
Two.
Two.
How much is lost in translation in science and in life between those two?
Well, it's actually three because science is like another language, right?
It is.

I speak Russian, a little bit of French, and it's always fascinating to see how much is lost.
And the Soviet Union has a tradition of science and mathematics and so on.
It's interesting that a lot of the wisdom gained from that part of the world is lost basically because it was never translated.
Well, I'm not sure if it is lost per se.
Maybe it's more like a gain in some sense, right?
Because you understand and science is ultimately a human pursue.
You cannot separate as much as maybe it's the best system that humans ever came up with to seek knowledge, to generate and make sense of the world.
It works most of the time.
It doesn't mean it's perfect.
Did the kind of translation do, by the way, was for scientific work?
I directly translated for scientific work, yes.
I think that, again, brains are equally distributed, but not opportunities are not, right?
So if you want to benefit from all human power, whatever we can generate as human beings, you need to include everybody on the table.
And that is by extending the opportunity.
I think most of us that make it tend to think that we did because of something special about ourselves.
But it is important to know that, no, we were given opportunities and that's why we are here.
Not because there was something inherently special about us or that the system truly selects for the ones that really are...
Yeah, and language is a part of the opportunity.
Language is an opportunity because it comes with, similar to bacteria, right?
They speak these languages.
They have, even we call this, we call culturing the bacteria, we call it culturing, right?
When we grow bacteria that we isolate from the environment in the lab,
meaning that you create an environment for them to grow and thrive and sustain themselves.
That's what we say, but culture is for microbiologists.
For language, with language comes a different culture, a different perspective.
And you bring that to the table.
It brings the sense of diversity that can only be achieved by clashing perhaps two different cultures, two different languages, two different approaches, maybe in some cases four different approaches.
Yeah, I think language is not just a mechanism of communication, it's a way to, it's a dynamic system of exploring ideas.
And it's interesting to see that different languages explore ideas differently.
Yes, and I think that, so when I said science is like a language itself, I said it in two different ways.
One is very literal meaning that you can speak English, but that doesn't mean you will understand the scientific paper.
It's a different level of English that you need to learn to understand.
Even not just for scientific papers, even from discipline to discipline,
I challenge any chemist to read an evolutionary biology paper and vice versa.
It may sound extremely different, a different language altogether.

But there's also the language of communicating and because words matter, how we talk matter, how we represent our science matters.
So yes, just learning English as a second language alone is not going to make you fluent in science either.
And it's interesting because in that sense you speak many more than three languages because you're pretty cross-disciplinary.
It seems like you have a foot in a lot of disciplines.
I mean, biology, biology, evolutionary biology, I mean there's chemistry.
Biochemistry, biophysics, even we do a lot of statistics.
So there's a lot of mathematics to what we do as well.
Yes, we like to think of it as an astrobiology program.
I repeat it because it's fun that it is not a fruit salad, but it's a smoothie.
That that's what we're generating.
It's not a fruit salad, so a smoothie is a successful combination of those fields and a fruit salad is not.
I wouldn't say it's a success unnecessarily.
If you put the wrong ingredient and then you press the blender and you've made it a smoothie, you mean it can ruin the entire mix.
Can it though? Because I feel like...
Yes, I can definitely assess that for ginger. It ruins every smoothie.
Ginger?
I think so.
It's just a personal thing and also I don't like cinnamon, but...
Ginger has a cinnamon taste because I thought ginger was...
No, I don't think they do, but I also don't like...
Wasn't that a thing they add in a lot of smoothies?
I was forced a smoothie.
I went to Malibu with a good friend of mine, Dan Reynolds, and he forced me to consume a smoothie.
It's probably the first smoothie I've ever had because I always had...
It was very judgmental of the kind of places and people that drink smoothies, but it was good.
Well, smoothie is very American, so I...
Yeah, it is an American thing.
I wouldn't say success per se, but it is true that when you dance at the edge of different disciplines, that's when inevitably the innovation will rise because you will see things maybe a little differently when you're on the edge, right?
But it will probably take longer and it may not be understood right away.
It may not come into final form quickly given that it is a new concept rising.
So, therefore, the patients will make more sense...
I'm sorry, patients will be even more important.
So, if you are...
In other words, if you are into immediate appreciation, that's probably not the way to go.
You're one chemical organism, so let me ask maybe a little bit more of a personal thing.
Where did your life form originate?
And what fond memory do you have from the early days of childhood that are representative of your

bacteria culture?
I was born in Istanbul, so I grew up in Turkey.
It's a city that has two continents, which is quite interesting.
You see a welcome to Europe sign and then welcome to Asia sign the same day, depending on which part of the bridge you are.
So, that's where I was born and I spent roughly 20 years of my life and then I immigrated to the United States.
It's a very proud culture, it's a beautiful culture, it's a very flavorful culture.
What aspects of it is part of who you are?
What are the beautiful aspects that you carry with you in your heart?
I think we are very sincerely human as a culture.
I think we have the saying that don't go to bed full if your neighbor is hungry.
So, you know, you wouldn't eat any food in front of someone where I come from without offering to share the bite.
So, I think those things, however small they may sound, a really big deal,
especially when you are put in or moved to a place that may not have those attributes.
So, I think that culturally, we are a lot of conscious and just role deep human.
The connection, the connection between human beings.
I think so, yeah.
I think I definitely carried that with me.
We talk a lot about biology.
Let me ask you about the romantic question, what role does love play in the human condition
or in the entirety of life on earth?
It's not easy to learn how to love if you're not loved, okay?
So, it's something, but the good news is that it is something that you can learn.
I think that you can practice and teach yourself how to maybe give yourself the thing that wasn't given to you
and then ultimately give it to others.
I think it would be quite arrogant to think that we will be capable of loving.
It could be anything really.
So, just like translation, it's a repeating and a dynamical process.
That you can learn.
Yeah, that you can learn.
Yes, and you should learn.
There is no excuse to not learning to love because that's a deeply human thing.
It is a deeply human thing.
It is a very sad thing if one of us passes this planet without knowing what love is.
And that could be a love to a pet, a love to a plant.
To a robot.
Just kidding.
Or a fake plant.
We love, we can't help who we love.
What advice would you give to a young person today?

High school, college, how to have a career they can be proud of or how to have a life they can be proud of?
You said an interesting thing about brains being distributed evenly, but opportunity is not.
It's really interesting to think about.
I've talked to folks from Africa.
You realize that there's whole areas of this earth that have so much brilliance, but unfortunately so little opportunity.
And one of the exciting things about the 21st century is more and more opportunities are created.
And so the brilliance is unlocked in all those different places.
And so all these young people now have the opportunity to like do something to change the world.
I had a chance to visit Bosnia.
So I was invited to give a talk in a very northernmost part of the country that was impacted by the war tremendously.
And it was a public talk.
It was open to everybody in the village.
And people drew from Sarajevo to attend.
Whenever I think about our role as a scientist or the beneficiaries of the knowledge that we create,
I always think about that night, that's how many people were in that room.
It was incredibly crowded and lots of young people who were trying to start everything new and not carry a place, whatever,
maybe the feeling that was taken from them with hope and love starts a new beginning, be deceit for the next generation.
And it moved me so much that they all came to hear about early life space, something maybe different for them.
Maybe they were always interested in and never thought about.
But what stayed with me was just the look and the feeling, the look on their faces and the feeling in the room.
The energy just was really moving to me.
Their willingness to be the seed, the first of their family and generation to do that big new thing.
And that's exactly why I'm telling this whole story, because for most of us, we may have to be that seed in our families,
that the first one to do something new, to break that cycle, whatever it is that you want to break free from.
I would want the young people to know that you can be that, that there are just wonderful things to learn from this life.
And it's just incredible to be living.
And I would want them to know that their voice matters and they need to use it, especially those who think that their voice doesn't matter.
And ultimately, I think what it comes down to is to trusting yourself, trusting and respecting your voice.
If you're not loved, learn how to love.
If you are not respected, start by respecting yourself. Learn how to respect yourself.
You can teach yourself things.

Yes, really difficult when you're surrounded by people that don't believe in you.
Yes, I definitely know the feeling.
And I would just want them to know that they don't need to be defined by or reduced down to what others see in them.
Believe in yourself, have their respect.
Try to develop their respect and the love for yourself.
And then from that, it flourishes.
You'll find others that'll give you love.
It may not.
I mean, life is not fair.
It's true. Be prepared that it's not very fair, unfortunately.
And so I don't want to depict this Disney story that, and then yes, and everything will be just fine.
It's mostly isn't, but you learn a way.
Life does it all the time.
Speaking of which, what do you think is the meaning of all this?
What's the meaning of life?
Why are we here?
Why are we here?
All the beauty you've discussed.
Why is the translational mechanism machinery here?
Why?
I don't think there is.
Why so much beauty?
Why so much beauty?
It is because we choose to see it that way.
It's beautiful.
But there is no meaning.
I don't think no.
But why is it so beautiful?
Why did we choose?
From where is the imperative to see it, to see so much beauty in a thing that scientifically speaking or from a rational perspective is void of beauty.
It's just, it just is.
Not everybody chooses to see the beauty.
Hate is going to hate.
I mean, we have the capacity to see the beauty.
We have the capacity, so why not use it to the fullest, right?
We have the capacity.
But that capacity, isn't that fascinating that we developed that?
It feels like that was always laid in there in the whole process of life.
This ability to find, to introspect ourselves.
I mean, it's definitely soothing to think like that.
But I don't think there is a meaning like that way.

It's fascinating that we can understand it.
But why is it soothing?
There's a desire, there's a longing.
But soothing doesn't mean that there's a meaning.
Why is soothing a meaning?
Let me just put it this way.
Because there is just, I think, so much unfairness going on, I wouldn't even dare myself to think that there's a meaning out of respect to the ones that are suffering.
I see.
I think out of suffering emerges flourishing in beauty.
I mean, that's what I see.
I agree with you.
When I went to Ukraine, it's all the people suffering in their eyes and in their stories.
It's a hope for the future.
It's a love for the people who are still living.
It's a love for life, so it's there.
And that's the dark thing is the suffering and the law somehow intensifies your appreciation of the life that is the left.
That's a weird thing too.
I think that there is something about still doing your best and believing that there's whatever goodness is worth working for.
It's beyond, and to do that without a meaning, there is something more humbly humbling and profound about that.
And we have a, this will come out very random.
Okay, so just in Turkish bathrooms, there is this sign.
That says, leave it as you want to find it.
And I think that's a pretty good.
That's your meaning of life found in the Turkish.
There's wisdom to that.
There's wisdom to that, but it also is because however you leave defines you, right?
So I think there's some profound meaning to that too, that just leave it as you would want to find it.
So that your little scribble in the long story of life on earth is one that ultimately did a pretty good job.
You know, it at least kept it the same as you found it.
Or at least I left it in the way that I wish I found it.
Yeah, yeah, right.
Oh man.
Yes, that's a wisdom from Turkish bathrooms.
That's where I searched for wisdom as well.
And as we started with the origin of life and ended with the wisdom in a Turkish bathroom, I think that's a perfect conversation.
You're an incredible person.
The humor, the humanity, but also the brilliance of your work.

I really appreciate that you were talking to me today.
This was really fun.
Thanks for having me.
Thanks for listening to this conversation with Betul Kachar.
To support this podcast, please check out our sponsors in the description.
And now let me leave you with one of my favorite quotes from Robert Frost.
In three words, I can sum up everything I've ever learned about life.
It goes on.
Thank you for listening.
I hope to see you next time.