The following is a conversation with David Kipping, an astronomer and astrophysicist at Columbia University, director of the Cool World Lab, and he's an amazing educator about the most fascinating scientific phenomena in our universe. I highly recommend you check out his videos
on the Cool World's YouTube channel. David quickly became one of my favorite human beings. I hope to talk to him many more times in the future.
And now a quick few second mention of each sponsor. Check them out in the description. It's the best way to support this podcast. We've got Simply Safe for home security, Shopify for e-commerce, and ExpressVPN for privacy on the internet. Choose wisely my friends. And now onto the full ad reads. As always, no ads in the middle. I find those annoying. So I try my best to make sure we don't have any. But if you skip these, please still check out the sponsors. I mean without them, this podcast would not be possible. So it's a huge, huge thank you to them for believing this podcast, for supporting it, and they make good stuff, which is the reason why they're a sponsor. So maybe you might consider checking out their stuff. Maybe it will make you feel good as well. This show is brought to you by Simply Safe, a home security company designed to be simple and effective. I don't remember at this point how long it took me to set it up. But it must have been, it's certainly less than an hour, it's probably like 30 minutes. Everything just works. Everything is connected. All the sensors are amazing. Just super easy to use. And I think that first layer of security of physical security is essential. I take my security extremely seriously. There's many, many layers of both physical and digital security. And I think it's just just taking security seriously allows you to kind of take control of your life and take responsibility for being in this world, a world that's sort of full of dangers and risks and all that kind of stuff. And it's just really empowering, just like discipline is freedom. I think in that same way, taking your security seriously is the kind of freedom because it gives you freedom to freedom to take on the day. Anyway, go to SimplySafe.com to get a free indoor security camera plus 20%
off your order with interactive monitoring. This show is also brought to you by Shopify, a platform designed for anyone to sell anywhere with a great looking online store that brings your ideas to life and tools to manage day to day operations. I really, really should put out merch. I know as a fan of podcasts, shows, bands, everything. I love wearing the thing on my shirt just to make myself feel good. But it's also a nice way to connect with others to start a conversation. Like Metallica, I just wore a Metallica shirt to the gym. One guy said, yeah, Metallica. And I was like, yeah. And together through that, there's like, I don't know his life story. He doesn't know my life story. And I think there was a joint celebration of two lives that at least for time have enjoyed the hell out of some Metallica. So what can I say? Anyway, sign up for a $1 per month trial period at Shopify.com slash Lex, all lowercase. Go to Shopify.com slash Lex to take your business to the next level today. The show is also brought to you by ExpressVPN, a company that for many, many years brought happiness to my life with a big sexy button that I press and it takes care of everything. I think it's really, really important that you have a VPN and ExpressVPN has been my favorite is what I really recommend. The thing I love most about it is it does the thing it does extremely well without extra features that nobody needs. And it does it on every single operating system or device, Android, Mac OS, Linux, whatever. I love software that is designed simply or rather

the final thing is simple, but the underlying design doesn't matter what it is. They deliver a simple feeling. It's like Olympic gymnast or Olympic athletes, a gold medal is an effortless performance. Perfection seems effortless. But the path, the journey to perfection is one heck of a difficult journey. And so whatever the journey ExpressVPN took, I'm glad they did because they created an amazing piece of software. Go to ExpressVPN.com slash Lex pod for an extra three months
free. This is a Lex Friedman podcast. To support it, please check out our sponsors in the description. And now, dear friends, here's David Kipping.
Your research at Columbia is in part focused on what you call cool worlds or worlds outside our solar system where temperature is sufficiently cool to allow for moons, rings in life to form, and for us humans to observe it. So can you tell me more about this idea, this place of cool worlds? Yeah, the history of discovering planets outside our solar system was
really dominated by these hot planets. And that's just because of the fact they're easier to find. When the very first methods came online, these were primarily the Doppler spectroscopy method, looking for wobbling stars, and also the transit method. And these two both have a really strong bias towards finding these hot planets. Now, hot planets are interesting. The chemistry in the atmosphere is fascinating. It's very alien. An example of one that's particularly close to my heart is Trey's 2B, whose atmosphere is so dark, it's less reflective than coal. And so they have really bizarre photometric properties. Yet at the same time, they resemble nothing like our own home.
And so it said there's two types of astrophysicists, the astrophysicists who care about how the universe works. They want to understand the mechanics of the machinery of this universe. Why did the Big Bang happen? Why is the universe expanding? How are galaxies formed? And there's
another type of astrophysicist which perhaps speaks to me a little bit more. It whispers into your ear, and that is why are we here? Are we alone? Are there others out there? And ultimately along this journey, the hot planets aren't going to get us there. When we're looking for life in the universe, seems to make perfect sense that there should be planets like our own out there, maybe even moons like our own planet around gas giants that could be habitable. And so my research has been driven by trying to find these more tracheous globes that might resemble our own planet.
So they're the ones that lurk more in the shadows in terms of how difficult it is to detect? They're much harder. They're harder for several reasons. The method we primarily use is the transit method. So this is really eclipses. As the planet passes in front of the star, it blocks out some starlight. The problem with that is that not all planets pass in front of their star. They have to be aligned correctly from your line of sight. And so the further away the planet is from the star, the cooler it is, the less likely it is that you're going to get that geometric alignment. So whereas a hot Jupiter, about 1% of hot Jupiters will transit in front of their star, only about 0.5%, maybe even a quarter of a percent of Earthlight planets will have the right geometry to transit. And so that makes it much, much harder for us.
What's the connection between temperature of the planet and geometric alignment, probability of geometric alignment? There's not a direct connection, but they're connected by an intermediate parameter, which is their separation from the star. So the planet will be cooler if it's further away from the star, which in turn means that the probability of getting that alignment correct

is going to be less. On top of that, they also transit their star less frequently.
So if you go to the telescope and you want to discover a hot Jupiter, you could probably do it in a week or so, because the orbit up here is of order of one, two, three days. So you can actually get the full orbit two or three times over. Whereas if you want to set an Earthlight planet, you have to observe that star for three, four years. And that's actually one of the problems with Kepler. Kepler was this very successful mission that NASA launched over a decade ago now, I think. And it discovered thousands of planets. It's still the dominant source of exoplanets that we know about. But unfortunately, it didn't last as long as we would have liked it to.
It died after about 4.35 years, I think it was. And so for an Earthlight planet, that's just enough to catch four transits. Four transits was kind of seen as the minimum. But of course, the more transits you see, the easier it is to detect it because you build up signal to noise. If you see the same thing tick, tick, tick, tick, tick, the more ticks you get, the easier it is to find it.
And so it was really a shame that Kepler was just at the limit of where we were expecting it to start to see Earthlight planets. And in fact, it really found zero. Zero planets that are around stars like the Sun, orbits similar to the Earth around the Sun, and could potentially be similar to our own planet in terms of its composition. And so it's a great shame, but that's why it gives astronomers more to do in the future.
Just to clarify, the transit method is our primary way of detecting these things.
And what it is, is when the object passes, occludes the source of light, just a tiny bit, a few pixels. And from that, we can infer something about its mass and size and distance, geometry, all of that. That's like trying to tell what, at a party, you can't see anything about a person, but you can just see by the way they occlude others.
So this is the method. But is this a super far away? How many pixels of information do we have?
Basically, how high resolution is the signal that we can get about these occlusions?
You're right in your description. I think just to build upon that a little bit more, it might be almost like your vision is completely blurry. You have an extreme hyperscription, and so you can't resolve anything. Everything's just blurs. But you can tell that something was there because it just got fainter for a short amount of time. Someone passed in front of a light, and so that light in your eyes would just dim for a short moment. Now, the reason we have that problem with blurriness or resolution is just because the stars are so far away. I mean, the closest stars are four light-years away, but most of the stars Kepler looked at with thousands of light-years away. And so there's absolutely no chance that the telescope can physically resolve the star, or even the separation between the planet and the star is too small, especially for a telescope like Kepler. It's only a meter across. In principle, you can make those detections, but you need a different kind of telescope. We call that direct imaging. And direct imaging is a very exciting, distinct way of detecting planets. But as you can imagine, it's going to be far easier to detect planets which are really far away from their star to do that, because that's going to make that separation really big. And then you also want the star to be really close to us. So the nearest stars, not only that, but you would prefer that planet to be really hot because the hotter it is, the brighter it is. And so that tends to bias direct imaging towards planets which are in the process of forming. So things which have just formed, the planet's still got all of its primordial heat embedded within it and it's glowing.
We can see those quite easily. But for the planets more like the Earth, of course,

they've cooled down. And so we can't see that the light is pitiful compared to a newly formed planet.
We would like to get there with direct imaging. That's the dream is to have
the pale blue dot, natural photograph of it, maybe even just a one pixel photograph of it.
But for now, the entire solar system is one pixel, certainly with the transit method,
most of the telescopes. And so all you can do is see where that one pixel,
which contains potentially dozens of planets, and the star, maybe even multiple stars,
dims for a short amount of time.
It dims just a little bit. And from that, you can infer something.
Yeah. I mean, it's like being a detective in the scene, right? It's very,
it's indirect clues of the existence of the planet.
It's amazing that humans can do that. They're just looking out in these immense distances
and looking, if there's alien civilizations out there, let's say one exactly like our own,
we're like, would we even be able to see an Earth that passes in the way of its sun
and slightly dims? And that's the only sign we have of that alien human-like civilization out
there is it's just a little bit of a dimming.
Yeah. I mean, it depends on the type of star we're talking about. If it is a star truly like
the sun, the dip that causes is 84 parts per million. I mean, that's just, it's like the same as a
it's like a firefly flying in front of like a giant floodlight at a stadium or something.
That's the kind of the brightness contrast that you're trying to compare to.
So it's extremely difficult detection. And in the very, very best cases, we can get down to that.
But as I said, we don't really have any true Earth analogs that have been in the exoplanet
candidate yet. Unless you relax that definition, you say, it's not just doesn't have to be a star
just like the sun. It could be a star that's smaller than the sun. It could be these orange
dwarfs or even the red dwarf stars. And the fact those stars are smaller means that for the same
size planet passing in front of it, more light is blocked out. And so a very exciting system,
for example, is Trappist 1, which has seven planets which are smaller than the Earth.
And those are quite easily detectable, not with a space-based telescope, but even from the ground.
And that's just because the star is so much smaller that the relative increase in or decrease in
brightness isn't hampt significantly, because that's smaller size. So Trappist 1e,
it's a planet which is in the right distance for liquid water. It has a slightly smaller size
than the Earth. It's about 90% the size of the Earth, about 80% the mass. And it's one of the
top targets right now for potentially having life. And yet, it raises many questions about
what would that environment be like? This is a star which is 1 eighth the mass of the sun.
It's stars like that take a long time to come off that adolescence. When stars first form,
like the sun, it takes them maybe 10, 100 million years to sort of settle in to that main sequence
lifetime. But for stars like these late M dwarfs as we call them, they can take up to a billion years
or more to calm down. And during that period, they're producing huge amounts of x-rays, ultraviolet
radiation that could potentially rip off the entire atmosphere. It may desiccate the planets in the
system. And so even if water arrived by comets or something, it may have lost all that water due
to this prolonged period of high activity. So we have lots of open-ended questions about these
M dwarf planets, but they are the most accessible. And so in the near term, if we detect anything in
terms of biosignatures, it's going to be for one of these red dwarf stars, it's not going to be a
true Earth twin as we would recognize it as having a yellow star. Well, let me ask you. I mean,

there's a million ways to ask this question. I'm sure I'll ask it about habitable worlds. Let's just go to our own solar system. What can we learn about the planets and moons in our solar system that might contain life, whether it's Mars or some of the moons of Jupiter and Saturn? What kind of characteristics? Because you said it might not need to be Earth-like. What kind of characteristics might we be looking for? When we look for life, it's hard to define even what life is, but we can maybe do a better job in defining the sorts of things that life does. And that provides some aspects to some avenue for looking for them. Classically, conventionally, I think we thought the way to look for life was to look for oxygen. Oxygen is a byproduct of its synthesis on this planet. We didn't always have it. Certainly, if you go back to the Achaean period, you have this period called the Great Oxidation Event where the Earth floats with oxygen for the first time and starts to saturate the oceans and then the atmosphere. And so that oxygen, if we detect it on another planet, whether it be Mars, Venus, or an exoplanet, whatever it is, that was long thought to be evidence for something doing photosynthesis. Because if you took away all the plant life on the Earth, the oxygen wouldn't just hang around here. It's a highly reactive molecule. It would oxidize things. And so within about a million years, you'd probably lose all the oxygen on planet Earth. So that was conventionally how we thought we could look for life. And then we started to realize that it's not so simple because A, there might be other things that life does apart from photosynthesis. Certainly, the vast majority of the Earth's history had no oxygen and yet there was living things on it. So that doesn't seem like a complete test. And secondly, could there be other things that produce oxygen besides from life? A growing concern has been these false positives in biosignature work. And so one example of that would be photosynthesis that happens in the atmosphere. When ultraviolet right hits the upper atmosphere, it can break up water vapor. The hydrogen splits off to the oxygen. The hydrogen is a much lighter atomic species. And so it can actually escape certainly planets like the Earth's gravity. That's why we don't have any hydrogen or very little helium. And so that leaves you with the oxygen, which then oxidizes the surface. And so there could be a residual oxygen signature just due to this photosynthesis process. So we've been trying to generalize. And certainly in recent years, there's been other suggestions, things we could look for in the solar system beyond nitrous oxide, basically laughing gas is a product of microbes. That's something that we're starting to get more interested in looking for methane gas in combination with other gases can be an important biosignature. Phosphine as well. And phosphine is particularly relevant to the solar system because there was a lot of interest for Venus recently. You may have heard that there was a claim of a biosignature in Venus's atmosphere. I think it was like two years ago now. And the the Georgian jurist allowed on that. There was a very provocative claim and signature of a phosphine-like spectral absorption. But it could have also have been some of the molecule in particular, sulfur dioxide, which is not a biosignature. So this is a detection of a gas in the atmosphere of Venus. And it might be controversial on several dimensions. So one, how to interpret that? Two, is this the right gas? And three, is this even the right detection? Is there an error in the detection? Yeah. I mean, how much do we believe the detection in the first place? If you do believe it, does that necessarily mean there's life there? And what gives? How can you have life in Venus's atmosphere in the first place? Because that's been seen as like a hell hole place for imagining life. But I guess the counter that has been that, okay, yes, the surface is a horrendous place to imagine life thriving. But as you go up in altitude, the very dense

atmosphere means that there is a cloud layer where the temperature and the pressure become actually fairly similar to the surface of the earth. And so maybe there are microbes stirring around in the clouds, which are producing phosphine. At the moment, this is fascinating. It's got a lot
of us reinvigorated about the prospects of going back to Venus and doing another mission there. In fact, there's now two NASA missions, Veritas and Da Vinci, which are going to be going back in before 2030 or the 2030s. And then we have a European mission, I think that's slated now. And even a Chinese mission might be coming along the way as well. So we might have multiple missions going to Venus, which has long been overlooked. I mean, apart from the Soviets, there really has been very little in the way of exploration of Venus. That's certainly as compared to Mars. Mars has enjoyed most of the activity from NASA's rovers and surveys. And Mars is certainly
fascinating. There's this signature of methane that has been seen there before. Again, there, the discussion is whether that methane is a product of biology, which is possible,
so that happens on the earth, or whether it's some geological process that we are yet to fully understand could be, for example, a reservoir of methane that's trapped under the surface and is leaking out seasonally. So the nice thing about Venus is if there's a giant living civilization there, it'll be airborne, so you can just fly through and collect samples. With Mars and moons of Saturn and Jupiter, you're going to have to dig under to find the civilizations, dead or living.
Right. And so yeah, maybe it's easier then for Venus because certainly you can imagine just a balloon floating through the atmosphere or a drone or something that would have the capability of just scooping up and sampling. To dig under the surface of Mars is maybe feasible-ish, especially with something like Starship that could launch a huge digger basically to the surface and you could just excavate away at the surface. But for something like Europa, we really are still
unclear about how thick the ice layer is, how you would melt through that huge thick layer to get to the ocean, and then potentially also discussions about contamination. The problem with looking for
life in the solar system, which is different from looking for life with exoplanets, is that you always are in the risk of, especially if you visit there, of introducing the life yourself. It's very difficult to completely exterminate every single microbe and spore on the surface of your rover or the surface of your lander, and so there's always a risk of introducing something. I mean,
to some extent, there is continuous exchange of material between these planets naturally on top of that as well, and now we're sort of accelerating that process to some degree. And so if you dig into Europa's surface, which probably is completely pristine, it's very unlikely there has been much exchange with the outside world for its subsurface ocean, you are for the first time potentially introducing bacterial spores into that environment that may compete or may introduce spurious signatures for the life you're looking for. And so it's almost an ethical question as to how to proceed with looking for life on those subsurface oceans. And I don't think we've really have a good resolution for this point. So you mean ethical in terms of concern
for preserving life elsewhere and not to murder it as opposed to scientific one?
I mean, we always worry about a space virus coming here or some kind of external source,
and we would be the source of that potential contamination.
Or the other direction. I mean, whatever survives in such harsh conditions might be

pretty good at surviving all conditions. It might be a little bit more resilient and robust, so it might actually take a ride on us back home.
Possibly. I mean, I'm sure that some people would be concerned about that.
I think we would hopefully have some containment procedures if we did sample return. Or you mean you don't even really need a sample return. These days, you can pretty much send like a little micro laboratory to the planet to do with experiments in situ and then just send them back to your planet, the data. And so I don't think this is necessary, especially for a case like that where you might have contamination concerns that you have to bring samples back.
Although probably if you brought back European sushi, it would probably sell for quite a bit with the billionaires in New York City. Sushi, yeah. I would love from an engineering perspective just to see all the different candidates and designs for like the scooper, for Venus and the scooper for Europa and Mars. I haven't really looked deeply into how the actual engineering of collecting the samples because that's the engineering of that is probably essential for not either destroying life or polluting it with our own microbes and so on.
So that's like an interesting engineering challenge. I usually for rovers and stuff focus on the mobility aspect of it, on the robotics, the perception and the movement and the planning and the control. But there's probably the scooper. It's probably where the action is. The microscopic sample collection. So basically you have to first clean your vehicle, make sure it doesn't have any earth-like things on it, and then you have to put it into some kind of thing that's perfectly sealed from the environment. So if we bring it back or we analyze it, it's not going to bring anything else externally. Yeah, I don't know. That would be an interesting engineering design there. Yeah. I mean, Curiosity has been leaving these little pods on the surface quite recently. There's some neat photos you can find online and they kind of look like a lightsaber hilt. So to me, I think I tweeted something like, this weapon is your life.
Like don't lose it Curiosity because it's just dumping these little vials everywhere.
And yeah, it is scooping up these things. And the intention is that in the future, there will be a sample return mission that will come and pick these up.
But I mean, the engineering behind those things is so impressive. The thing that blows me away the most has been the landings, especially I'm trained to be a pilot at the moment. So that's the sort of, you know, watching landings has become like my pet hobby on YouTube
at the moment and how not to do it, how to do it with different levels of conditions and things. But with the, you know, when you think about landing on Mars, just the light travel time effect means that there's no possibility of a human controlling that descent. And so you have to put all of your faith and your trust in the computer code or the AI or whatever it is that you've put on board that thing to make the correct descent. And so there's this famous period course seven minutes of hell where you're basically waiting for that light travel time to come back to know whether your vehicle successfully landed on the surface of not. And during that period, you know in your mind simultaneously that it is doing these multi-stages of deploying its parachute, deploying the crane, activating its jets to come down and controlling its descent to the surface. And then the crane has to fly away so it doesn't accidentally hit the rover. And so there's a series of multi-stage points where any of them go wrong, you know, the whole mission could go awry. And so the fact that we are fairly consistently able to

build these machines that can do this autonomously is to me one of the most impressive acts of engineering that NASA have achieved. Yes, the unfortunate fact about physics is the takeoff is easier than the landing. And you mentioned Starship, one of the incredible engineering feasts that you get to see is the reusable rockets that take off, but they land and they land using control and they do so perfectly. And sometimes when it's synchronous, it's just it's beautiful to see. And then with Starship, you see the chopsticks that catch the ship. I mean, there's so much incredible engineer, but you mentioned Starship is somehow helpful here. So what's your hope with Starship? What kind of science might it enable, possibly? There's two things. I mean, it's the launchcast itself, which is hopefully going to mean per kilogram is going to dramatically reduce the cost of the sort of the level. Even if it's a factor of 10 higher than what Elon originally promised, this is going to be a revolution for the cost launch. That means you could do all sorts of things. You could launch large telescopes, which could be basically like JWST, but you don't even have to fold them up. JWST had this whole issue with the design that it's six and a half meters across. And so you have to, there's no fuselage, which is that large at the time. There is four wasn't large enough for that. And so they had to fold it up into this kind of complicated origami. And so a large part of the cost was figuring out how to fold it up, testing that it unfolded correctly, repeated testing, and there was something like 130 fail points or something during this unfolding mechanism. And so all of us were holding our breath during that process. But if you have the ability to just launch arbitrarily large masses, at least comparatively compared to JWST, and very large mirrors into space, you can more or less repurpose ground-based mirrors. The Hubble Space Telescope
mirror and the JWST mirrors are designed to be extremely lightweight. And that increased their costs significantly. They have this kind of honeycomb design on the back to try and minimize the weight. If you don't really care about weight, because it's so cheap, then you could just literally grab many of the existing ground-based mirrors across telescopes across the world, four meters, five meters to mirrors, and just pretty much attach them to a chassis and have your own space-based telescope. I think the Breakthrough Foundation, for instance, is an entity that has been interested in doing this sort of thing. And so that raises the prospects of having not just one JWST, JWST is a fantastic resource, but it's split between all of us, cosmologists, star formation, astronomers, those of us studying exoplanets, those of us wanting to study the ultra-deep fields and the origin of the first galaxies, the expansionary of the universe. Everyone has to share this resource, but we could potentially each have one JWST each that is maybe just studying a handful of the brightest exoplanet stars and measuring their atmospheres. This is important because we talked about this planet Trappist-1e earlier. That planet, if JWST edited it and tried to look for biosignatures, by which I mean oxygen, nitrous oxide, methane, it would take it of order of 200 transits to get even a very marginal, what we call two and a half sigma detection of those, which basically nobody would believe with that. And 100 transits, I mean, this thing transits once every six days, so you're talking about sort of four years of staring at the same star with one telescope. There'd be some breaks, but it'd be hard to schedule much else because you have to continuously catch each one of these transits to build up your signal to noise. And so JWST is never going to do that. In principle, technically, JWST could technically have the capability of just about detecting a biosignature on an Earth-like planet around

a nonsun-like star. But still, impressively, we have basically the technology to do that, but we simply cannot dedicate all of its time practically to that one resource. And so, Starship opens up opportunities like that of mass producing these kinds of telescopes, which will allow us to survey for life in the universe, which of course is one of the grand goals of astronomy. I wonder if you can speak to the bureaucracy, the political battles, the scientific battles for time on the James Webb telescope. There must be a fascinating process of scheduling that. All scientists, they're trying to collaborate and figure out what the most important problems are. And there's an interesting network of interfering scientific experiments, probably, they have to somehow optimize over. It's a really difficult process.
I don't envy the TAC that are going to have to make this decision. We call it the TAC, the Time Allocation Committee, that they make this decision. And I've served on these before. And it's very difficult. I mean, typically for Hubble, we were seeing at least 10, sometimes 20 times the number of proposals for telescope time versus available telescope time. For GDST, there has been one call already that has gone out. We call it cycle one.
And that was oversubscribed by I think something like six to one, seven to one.
And the cycle two, which has just been announced fairly recently and the deadline is actually the end of this month. So my team are totally laser focused on writing our proposals right now. That is expected to be much more competitive, probably more comparable to what Hubble saw. And so it's hard. More competitive than the cycle one, you said already?
Because that's already more competitive than the first cycle. So I said the first cycle of James Webb was about six to one. And there's probably more like 20 to one, I would expect. These are all proposals by scientists and so on. And it's not like you can schedule at any time. Because if you're looking for transit times, you have a time critical element.
Yes, time critical element. And they're conflicting in non-obvious ways. Because the frequency is different, the duration is different. There's probably computational needs. They're different. There's the type of sensors, the direction pointing, all that.
Yeah, it's hard. And there are certain programs like doing a deep field study where you just more or less point the telescope. And that's pretty open. I mean, you're just accumulating photons. You can just point at that patch of the sky whenever the telescope is not doing anything else and just get to your month, let's say a month of integration time is your goal over the lifetime of JWST. So that's maybe a little bit easier to schedule. It's harder, especially for us looking at cool worlds. Because as I said earlier, these plants transit very infrequently. So we have to wait, if you're looking at the Earth,
Transiting the Sun and Alien watching us, they would only get one opportunity per year to do that observation. The transit lasts for about 12 hours. And so if they don't get that time, it's hard. That's it. If it conflicted with another proposal that wants to use another time critical element, it's much easier for plants like these hot plants or these close-in plants.
Because they transit so frequently, there's maybe 100 opportunities. And so then the TAT can say, okay, they want 10 transits, there's 100 opportunities here, it's easier for us to give them time. We're almost in the worst case scenario. We're proposing to look for exoplanets around to cool planets. And so we really only have one bite of the cherry for each one. And so our sales pitch has been that these are extremely precious events. And more importantly, JWST is the only telescope, the only machine humanity has ever constructed, which is capable of finding moons

akin to the moons in our solar system. Kepler can't do it, even Hubble can't do it. Jurassic is the first one. And so there is a new window to the universe because we know these moons exist. They're all over the place in the solar system. You have the moon, you have Io, Callisto, Europa, Ganymede, Titan, lots of moons of fairly similar size, sort of 30% the size of the Earth. And this telescope is the first one that can find them. And so we're very excited about the profound implications of ultimately solving this journey we're on in astronomy, which is to understand our uniqueness. We want to understand how common is the solar system? Are we the way, are we the architecture that frequently emerges naturally? Or is there something special about what happened here? I think this is not the worst case, the best case, it's obvious, it's super rare. So you have to like, I would, so I love scheduling from a computer science perspective, that's my background. So algorithmically, to solve a schedule problem, I will schedule the rarest things first. And obviously, this is the JLST is the first thing that can actually detect a cool world. So this is a big new thing, you can show off that new thing, happens rarely, schedule it first, it's perfect. You should be in the tech business, I will file my application after we're done with this. I, you know, this part of me is the OCD, part of me is the computational aspect I love scheduling, computing device, because you have that kind of scheduling on supercomputers on that scheduling problem is fascinating, how do you prioritize computation, how do you prioritize science, data collection, sample collection, all that kind of stuff, it's actually kind of, it's kind of fascinating, because data in ways you expect and don't expect will unlock a lot of solutions to some fascinating mysteries. And so collecting the data and doing so in a way that maximizes the possibility of discovery is really interesting, like from a computational perspective, I agree, there's a real satisfaction extracting the maximum science per unit time out of your telescope. And that's, that's the tax job. But the, the tack are not machines, they're not a piece of computer code, they will make their selections based off human judgment. And a lot of the telescope is certainly within the field of exoplanets, because there's different fields of astronomy, but within the field of exoplanets, I think a good expectation is that most of the telescope time that JBCC have, will go towards atmospheric retrieval, which is sort of alluded to earlier, you know, like detecting molecules in the atmospheres, not biosignatures, because as I said, it's really not designed to do that. It's pushing Gider's T probably too far to expect to do that. But it could detect, for example, a carbon dioxide rich atmosphere on Trappist 1e. That's not a biosignature, but you could prove it's like a Venus in that case, or maybe like a Mars in that case, like both those have carbon dioxide rich atmospheres, doesn't prove or disprove the existence of life either way. But it is our first characterization of the nature of those atmospheres. Maybe we can even tell the pressure level and the temperature of those atmospheres. So that's very exciting. But we are competing with that. And I think that science is completely mind-blowing and fantastic. We have a completely different objective, which is in our case, to try and look for the first evidence of these small moons around these planets. Potentially, even moons which could be habitable, of course. So I think it's a very exciting goal. But attack has to make a human judgment, essentially, about which science are they most excited by, which one has the highest promise of return, the most highest chance of return. And so that's hard because if you look at a planetary atmosphere, well, you know, most of the time, the planet has an atmosphere already. And so there's almost a guaranteed success that you're going to learn something about the

atmosphere
by pointing judicious to it. Whereas in our case, there's a harder cell, we are looking for something that we do not know for sure exists yet or not. And so we are pushing the telescope to do something which is inherently more risky. Yeah, but the existence, if shown, already gives a deep lesson about what's out there in the universe. That means that other stars have similar types of variety as we have in our solar system. They have an Io, they have Europa and so on, which means there's a lot of possibility for icy planets, for water, for planets that enable planets and moons. I mean, that's super exciting because that means everywhere through our galaxy and beyond, there is just innumerable possibility for weird creatures, life forms.
You don't have to convince me. I mean, NASA has been on this quest for a long time, and it's sometimes called Eter Earth. It's the frequency of Earth like, usually they say, planets in the universe. How common are planets similar to our Earth? In terms of, ultimately, we'd like to know everything about these planets in terms of the amount of water they have, how much atmosphere
they have. But for now, it's kind of focused just on the size and the distance from the star, essentially. How often do you get similar conditions to that? That was Kepler's primary mission, and it really just kind of flirted with the answer. Didn't quite get to a definitive answer. But I always say, look, if we're looking, if that's our primary goal to look for Earth like, I would say, worlds, then moons has to be a part of that because we know that Earth like, from the Kepler data, the preliminary result is that Earth like planets around sun like stars is not an inevitable outcome. It seems to be something like a 1 to 10% outcome. So it's not particularly inevitable that that happens. But we do often see about half of all sun like stars have either a mini Neptune, a Neptune or a Jupiter in the habitable zone of their stars. That's a very, very common occurrence that we see. Yet we have no idea how often they have moons around them, which could also be habitable. And so there may very well be, if even one in five of them has an Earth like moon or even a Mars like moon around them, then there would be more habitable real estate in terms of exo-moons than exo-plants in the universe.
Essentially, 2x, 3x, 5x, maybe 10x, the number of habitable worlds out there in the universe, our current estimate, like the Drake equation. So this is one way to increase the confidence and increase the value of that parameter. And just know where to look. I mean, we would like to know where should we listen for technosignatures, where should we be looking for biosignatures. And not only that, but what role does the moon have in terms of its influence on the planet? We talked about these directly imaged telescopes earlier, these missions that want to take a photo to quote Carl Sagan, the pale blue dot of our planet, but the pale blue dot of an exo-planet. And that's the dream to one day capture that. But as impressive as the resolution is that we are planning and conspiring to design for the future generation telescopes to achieve that, even those telescopes will not have the capability of resolving the Earth and the moon within that. It will be a pale blue dot pixel, but the moon's grayness will be intermixed with that pixel. And so this is a big problem because one of the ways that we are claiming to look for life in the universe is a chemical disequilibrium. So you see two molecules that just shouldn't be there, they normally react with each other, or even one molecule that's just too reactive to be hanging around the atmosphere by itself. So if you had oxygen and methane hanging out together, those would normally react fairly easily. And so if you detected those two molecules

in your pale blue dot spectra, you're like, okay, we have evidence for life. Something's metabolizing on this planet. However, the challenge is what if that moon was Titan? Titan has a methane-rich atmosphere. And what if the pale blue dot was in fact a plant devoid of life, but it had oxygen because of water undergoing this phatolicist reaction splitting into oxygen, hydrogen separately. So then you have all of the hallmarks of what we would claim to be life, but all along you were tricked. It was just a moon that was deceiving you. And so we are never going to, we're never going to, I would claim, really understand the, or complete this quest of looking for life by signatures in the universe, unless we have a deep knowledge of the prevalence and role that moons have. They may even affect the habitability of the planets themselves. Of course, our rain moon is freakishly large. By mass ratio, it's the largest moon in the solar system. It's a 1% mass moon. If you look at Jupiter's moons, they're like 10 to the power minus four, much smaller. And so our own moon seems to stabilize the obliquity of our planet. It gives rise to tides, especially early on when the moon was closer, those tides would have covered entire continents. And those rock pools that would have been scattered across the entire plateau may have been the origin of life on our planet. The moon-forming impact may have stripped a significant fraction of lithosphere off the Earth, which without it, plate tectonics may not have been possible. We'd heard a stagnant lid because there was just too much lithosphere stuck on the top of the planet. And so there are speculative reasons, but intriguing reasons as to why a large moon may be not just important, but central to the question of having the conditions necessary for life. So moons can be habitable in their own right, but they can also play a significant influence on the habitability of the planets they orbit. And further, they will all surely interfere with our attempts to detect life remotely from afar.
So taking a tangent upon a tangent, you've written about binary planets. What's, and that they're surprisingly common, or they might be surprisingly common. What's the difference between a large moon and binary planets? What are binary planets? What's interesting to say here about giant rocks flying to space and orbiting each other? The thing that's interesting about binary objects is that they're very common in the universe. Binary stars are everywhere. In fact, the majority of stars seem to live in binary systems. When we look at the outer edges of the solar system, we see binary Kuiper belt objects all the time, asteroids basically bound to one other. Pluto-Sharon is kind of an example of that. It's a 10% mass ratio system. It almost is, by many definitions, a binary planet, but now it's a dwarf planet. So I don't know what to call that now. But we know that the universe likes to make things in pairs.
So you're saying our sun is an incel. So most things are dating, they're in relationships, and ours is alone. It's not a complete freak of the universe to be alone, but it's more common for sun-like stars. If you count up all the sun-like stars in the universe, about half of the sun-like star systems are in binary or trinary systems, and neither half are single. But because those binaries are two or three stars, then cumulatively, maybe like a third of all sun-like stars are single. I'm trying hard to not anthropomorphize the relationship.
Yeah, I've met those folks also. So is there something interesting to learn about the habitability the how that affects the probability of habitable worlds when they couple up like that in those different ways? Well, it depends where you're talking about the stars of the planet. Certainly, if stars couple up, that has a big influence on the habitability. Of course, this is very famous from Star Wars. Tatooine in Star Wars is a binary star system, and you have Luke Skywalker looking

at the sunset and seeing two stars come down. And for years, we thought that was purely a product of George Lucas' incredibly creative mind. And we didn't think that planets would exist around binary star systems. It seems like too tumultuous an environment for a quiescent planetary disc, circumstellar disc to form planets from. And yet, one of the astounding discoveries from Kepler was that these appear to be quite common. In fact, as far as we can tell, they're just as common around binary stars as single stars. The only caveat to that is that you don't get planets close into binary stars. They have like a clearance region on the inside where maybe they form there, but they don't last. They are dynamically unstable in that zone.
But once you get out to about the distance that the Earth orbits the Sun or even a little bit closer in, you start to find planets emerging. And so that's the right distance for liquid water, so a distance for potentially life on those planets. And so there may very well be plenty of habitable planets around the binary stars. Binary planets is a little bit different. Binary planets, I don't think we have any serious connection of planet binarity to habitability.
Certainly when we investigated it, that wasn't our drive, that this is somehow the solution to life in the universe or anything. It was really just like all good science questions, a curiosity driven question. Was the dynamic legit orbiting each other as they orbit the star?
So the formation mechanism proposed here, because it is very difficult to form two protoplanets close to each other like this. They were generally merged within the disk and so that's why you normally get single planets. But you could have something like Jupiter and Saturn form at separate distances. They could dynamically be scattered in towards one another and basically not quite collide but have a very close on encounter. Now, because tidal forces increase dramatically as the distance decreases between two objects, the tides can actually dissipate the kinetic energy and bring them bound into one another. So that seemed when we, you know, when you first hear that, you think, well, that seems fairly contrived that you'd have the conditions just right to get these tides to cause a capture. But numerical simulations have shown that about 10% of planet-planet encounters are shown to produce something like binary planets, which is a startling prediction. And so that seems at odds with naively the exoplanet catalog for which we know of so far no binary planets. And we propose one of the resolutions to this might be that the binary planets are just incredibly difficult to detect, which is also counterintuitive. Because remember how they form is through this tidal mechanism. And so they form extremely close to each other. So the distance that Io is away from Jupiter, just a few planetary radii, they're almost touching one another. And they're just tidally locked facing each other for eternity. And so in that configuration, as it transits across the star, it kind of looks like you can't really resolve this two planets. It just looks like one planet to you that's going across the star. The temporal resolution of the data is rarely good enough to distinguish that. And so you'd see one transit. But in fact, it's two planets very close together, which are transiting at once. And so, yeah, we wrote a paper just recently where we developed some techniques to try and get around this problem and hopefully provide a tool where we could finally look for these plants, the problem of detection.
Yes, that was our focus was how do you how do you get around this this merging problem. So whether they're out there or not, we don't know, we're planning to do a search for them.
But it remains an open question. And I think just one of those fun astrophysics curiosity questions where the binary planets exist in the universe, because then you have binary

earths, you can have binary Neptune, all sorts of wild stuff that would float to the sci-fi imagination. I wonder what the physics on a binary planet feels like. It might be trivial. I have to think about that. I wonder if there's some interesting dynamics, like you feel multiple or would gravity feel different at different parts of the surface of the sphere when there's another large sphere, that's interesting. Yeah, I would think that the force would be fairly similar because the shape of the object would deform to a flat geopotential, essentially a uniform geopotential, but it would lead to a distorted shape for the two objects. I think they become ellipsoids facing one another. So it would be pretty wild when you know, people like flat earth or spherical earth, you fly from space and see a football-shaped earth as your own planet. Finally, there's proof. And I wonder how difficult it would be to travel from one to the other, because you have to overcome the one. No, it might be kind of easy. Yeah, I mean, they're so close to each other, that helps. And I think the most critical factor would be how massive is the planet. That's always, I mean, one of the challenges with escaping planets, there was a fun paper one of my colleagues wrote that suggested that super-earth planets may be inescapable. If you're a civilization that were born on a super-earth, the surface gravity is so high that the chemical potential energy of hydrogen or methane, whatever fuel you're using, simply is at odds with the gravity of the planet itself. And so you would, you know, our current rockets, I'm not sure of the fraction, but maybe like 90% of the rocket is fuel or something by mass, these things would have to be like the size of the geese or pyramids of fuel with just a tiny tip on the top in order just to escape that planetary atmosphere. And so it has been argued that if you live on a super-earth, you may be forced to live there forever. There may be no escape unless you invent a space elevator or something. But then how do you even build the infrastructure and space to do something like that in the absence of a successful rocket program?
And so the more and more we look at our earth and think about the sorts of problems we're facing, the more you see things about the earth which make it ideally suited in so many regards. It's almost spooky, right, that we don't only live on a planet which has the right conditions for life, for intelligent life, for sustained fossil fuel industry just happens to be in the ground. We have plenty of fossil fuels to get our industrial revolution going. But also the chemical energy contained within those fossil fuels and hydrogen and other fuels is sufficient that we have the ability to escape our planetary atmosphere and planetary gravity to have a space program. And we also happen to have a celestial body which is just within reach, the Moon, which doesn't also necessarily have to be true. Were the Moon not there, what effect would that have had on our aspirations of a space program in the 1960s? Would there have ever been a space race to Mars or to Venus? It's a much harder, certainly for a human program that seems almost impossible with 1960s technology to imagine. It's almost as if somebody constructed a set of challenging obstacles before us, challenging problems to solve. They're challenging, but they're doable and there's a sequence of them. Gravity is very difficult to overcome, but we have given the size of earth, it's not so bad that we can still actually construct proportional systems that can escape it. And the same with climate change, perhaps. Climate change is the next major problem facing our civilization, but we know it is technically surmountable. It does seem sometimes like there has been a series of challenges laid out to progress towards a mature civilization that can one day perhaps

expand to the stars. I'm a little more concerned about nuclear weapons, AI and natural or artificial pandemics, but yes, climate change. Plenty of milestones that we need to cross. And we can argue about the severity of each of them, but there is no doubt that we live in a world that has serious challenges that are pushing our intellects and our will to the limit of whether we're really ready to progress to the next stage of our development.
So thank you for taking the tangent and there'll be a million more, but can we step back to Kepler 1625B? What is it? And you've talked about this kind of journey, this effort to discover exo-moons, so moons out there, or small, cool objects out there. Where does that effort stand and what is Kepler 1625B? Yeah, I've been searching for maximums for most of my professional career
and I think a lot of my colleagues think I'm kind of crazy to still be doing it. After five years of not finding anything, I think most people would probably try doing something else. I even had people say that to me. They said professors, and I remember a cocktail party took me to the side, an MIT professor, and he said, you know, you should just look for hot Jupiters. They're everywhere. It's really, you can write papers, they're so easy to find.
And I was like, yeah, but hot Jupiters, they're not interesting to me. I want to do something that I feel intellectually pushes me to the edge. And it's maybe a contribution that not no one else could do, but maybe it's not certainly the thing that anybody could do. I don't want to just be the first to something for the sake of being first. I want to do something that feels like a meaningful intellectual contribution to our society. And so, you know, this XMN problem has been haunting me for years to try and solve this. Now, as I said, we looked for years and years using Kepler. And the closest we ever got was just a hint for this one star Kepler-1625 has a Jupiter-like planet in orbit of it. And that Jupiter-like planet is on a 287-day period.
So it's almost the same distance as the Earth around the Sun, but for a Jupiter.
So that was already unusual. I don't think people realize that Jupiter-like planets are quite rare in the universe. Certainly, mini-net tunes and net tunes are extremely common. But Jupiters, only about 10% of Sun-like stars have Jupiters around them, as far as we can tell.
When you say Jupiter, which aspect of Jupiter?
In terms of its mass and its semi-draxia. So anything beyond about half an AU, so half the distance of the Earth and the Sun, and something of order of a tenth of a Jupiter mass, that's the mass of Saturn, up to, say, 10 Jupiter masses, which is basically where you start to get to brown dwarfs, those types of objects appear to be somewhat unusual. Most solar systems do not have Jupiters, which is really interesting because Jupiter, again, like the Moon, seems to have been a pivotal character in the story of the development of our solar system, perhaps especially having a large influence of the development of the light-heavy bombardment and the rate of asteroid impacts that we receive and things like this.
Anyway, to come back to 1625, this Jupiter-like planet had a hint of something in the data.
And what I mean by that is when we looked at the transit, we got the familiar decrease in light that we always see when a plant tries to infront of the star. But we saw something extra.
Just on the edges, we saw some extra dips around the outside. It was right at the hairy edge of detectability. We didn't believe it because I think one of the challenges of looking for something for 10 years is that you become your own greatest skeptic. And no matter what you're shown, you're always thinking, it's like falling in love so many times and it's not

working out. You convince yourself it's never going to happen, not for me. This just isn't going to happen. And so I saw that and I didn't really believe it because I didn't dare let myself believe it. But being a good scientist, we knew we had an obligation to publish it, to talk about the result and to follow it up and to try and resolve what was going on. So we asked for Hubble Space Telescope Time, which was awarded in that case. So we were one of those lucky 20 that got telescope time. And we stared at it for about 40 hours continuously. And to provide some context, the dip that we saw in the Kepler data corresponded to a Neptune-sized
moon around a Jupiter-sized planet, which was another reason why I was skeptical. We didn't have that in the solar system. That seems so strange. And then when we got the Hubble data, it seemed to confirm exactly that. There was two really striking pieces of evidence in the data that suggested this moon was there. Another was a fairly clear second dip in light, pretty clearly resolved by Hubble. It was about a five-sigma detection. And on top of that, we could see the planet didn't transit when it should have done. It actually transited earlier than we expected it to by about 20 minutes or so. And so that's a hallmark of a gravitational interaction between the planet and the moon. We actually expected that. You can also expect that if the moon transits after the planet, then the planet should come in earlier than expected because the center of mass lives between the two of them, kind of like on a balancing arm between them. And so we saw that as well. So the phase signature matched up. The mass of the moon was measured to be Neptune mass. And the size of the moon was measured to be Neptune radius. And so everything just really lined up. And we spent months and months trying to kill it. This is my strategy for anything interesting. We just try to throw the kitchen sink at it and say, we must be tricked by something. And so we tried looking at the centroid motion of the telescope. But the different wavelength channels have been observed, the pixel level information. And no matter what we did, we just couldn't get rid of it. And so we submit it to science. And I think at the time, science, which is one of the top journals said to us, would you mind calling your paper Discovery of an ExoMoon? And I had to push back and we said, no, we're not calling it that. I don't even despite everything we've done, we're not calling it a discovery. We're calling it evidence for an ExoMoon. Because for me, I'd want to see this repeat two times, three times, four times before I really would bet my house that this is the real deal. And maybe, and I do worry, as I said, that perhaps that's my own skepticism, self skepticism going too far. But I think it was the right decision. And since that paper came out, there has been continuous interest in this object. Another team independently analyzed that star and recovered actually pretty much exactly the same results as us, the same dip, the same, the same wobble of the planet. And a third team looked at it and they actually got something different. They saw the dip was diminished compared to what we saw. They saw a little hint of a dip, but not as pronounced as what we saw. And they saw the wobble as well. So there's been a little bit of tension about analyzing the reduction of the Hubble data. And so the only way my mind to resolve this is just to look again. We actually did propose to Hubble straight after that. And we said, look, if our model is right, if the moon is there, it came in late last time, it translated after the planet. Because of the orbit, we can calculate that it should transit before the planet next time. If it's not there, if it doesn't transit before, and even if we see a dip afterwards,

we know that's not our moon. It's obviously some instrumental effect for the data.
We had a causal prediction as to where the moon should be. And so I was really excited about that, but we didn't get the telescope time. And unfortunately, if you go further into the future, we no longer have the predictive capability because it's like predicting the weather. You might be able to predict the weather next week to some level of accuracy, but predicting the weather next year becomes incredibly hard. The uncertainties just grow and compound as you go forward into the future more and more. How are we able to know where the moon would be positioned? So you're able to tell the orbiting geometry and frequency?
Yeah. So basically from the wobbles of the planet itself,
that tells us the orbital motion of the moon. It's the reflex motion of the moon on the planet.
But isn't it just an estimate to where... I'm concerned about you making a strong prediction here because if you don't get the moon where the moon leads on the next time around,
if you did get in a couple of times, couldn't that mean something else if you didn't see that?
Because you said it would be an instrumental... I feel the strong urge to disprove you,
which is a really good imperative. It's a good way to do science, but this is such a noisy signal, right? Or blurry signal, maybe. A low-resolution signal, maybe.
Yeah. I mean, it's a five-sigma signal. That's at the slightly uncomfortable edge. I mean,
it's often said that for any detection of a first new phenomena, you really want a 20-25 sigma detection. Then there's just no doubt that what you're seeing is real. This was at that edge. I mean, I guess it's comparable to the Higgs boson, but the Higgs boson was slightly different because there was so much theoretical impetus as to expect a signal at that precise location.
A Neptune-sized moon was not predicted by anyone. There was no papers you can find that expect Neptune-sized moons around Jupiter-sized planets. I think we were inherently skeptical about its reality for that reason, but this is science in action. When we fit the wobbles, we fit the dips, and we have this 3G geometric model for the motion of the orbit, and projecting that forward, we found that about 80% of our projections led to the moon to be before. It's not 100%.
There was maybe 20% of the cases it was over here, but to me, that was a hard enough projection that we felt confident that we could refute the exit, which was what I really wanted to say.
I wanted to refutable the basis of science, a falsifiable hypothesis. How can you make progress in science if you don't have a falsifiable testable hypothesis? That was the beauty of this particular case. There's a numerical simulation with a moon that fits the data that we observed, and then you can now make predictions based on that simulation.
That's so cool. It's fun. These are like little solar systems that we can simulate on the computer and imagine their motions, but we are pushing things to the very limits of what's possible, and that's double-edged sword. It's both incredibly exciting intellectually, but you're always risking, to some degree, the pushing too far.
So I'd like to ask you about the recent paper you co-authored, an exo-moon survey of 70 cool giant exoplanets and the new candidate coupler 1708 Bi.
I'd say there's three or four candidates at this point, of which we have published two of them, and to me, two are quite compelling and deserve a follow-up observations.
And so to get a confirmed detection, at least in our case, we would need to see it repeat, for sure. One of the problems with some of the other methods that have been proposed is that you don't get that repeatability. So, for instance, an example of a technique that would lack that

would be gravitational microlensing. So it is possible with a new telescope coming up in the future called the Roman space telescope, which is basically a repurpose by satellite that's the size of the Hubble mirror getting up into space. It will stare at millions of stars simultaneously, and it will look to see, instead of whether any of those stars get dimmer for a short amount of time, which would be a transit, it'll look for the opposite, it'll look to see if anything can get brighter. And that brightness increase is caused by another planetary system passing in front and then gravitationally lensing light around it to cause a brightening. And so this is a method of discovering entire solar system, but only for a glimpse. You just get a short glimpse of it passing like a ship sailing through the night, just that one photo of it.
Now, the problem with that is that it's very difficult. The physics of gravitational lensing are not surprisingly quite complicated. And so there's many, many possible solutions. So you might have a solution, which is this could be a red dwarf star star with a Jupiter-like planet around it. That's one solution. But another solution is that it's a free-floating planet, a rogue planet like Jupiter with an Earth-like moon around it.
And those two solutions are almost indistinguishable. Now, ideally, we would be able to repeat the observation, we'd be able to go back and see, well, if the moon really is there, then we could predict its mass, it's predicted its motion and expect it to be maybe over here next time or something. With microlensing, it's a one snapshot event. And so for me, it's intriguing as a way of revealing something about the exo-moon population. But I always come back to transits because it's the only method we really have that's absolutely repeatable, that we'll be able to come back and prove everyone, prove to everyone that, look, on the 17th of October, the moon will be over here and the moon will look like this and we can actually capture that image. And that's what we see with, of course, many exoplanets. So we want to get to that same point of full confidence,
full confirmation, the slam dunk detection of these exo-moons. But yeah, it's been a hell of a journey to try and push the field into that direction. And is there some resistance to the transit method? Not to the transit, I just say to exo-moons. So the transit method is by far the most popular method for looking for exo-planets. But yeah, as I've alluded to, exo-moons is kind of a niche topic within the discipline of exoplanets. And that's largely because there are people I think are waiting for those slam dunks. And it was like the, if you go back to the first exoplanet discovery that was made in 1995 by Michel Mayor and Didier Kellos, I think it's true at the time that they were seen as mavericks, that the idea of looking for planets around stars was considered fringe science. And I'm sure many colleagues told them, why don't
you do something more safe like study eclipsing stars? To binary star systems, we know those exist. So why are you wasting your time looking for planets? You're going to get this alien moniker or something and you'll be seen as a fringe maverick scientist. And so I think it was quite difficult for those early planet hunters to get legitimacy and be taken seriously. And so very few people risked their careers to do it, except for those that were either emboldened to try or had maybe the career, maybe like tenure or something. So they didn't have to necessarily worry about the implications of failure. And so once that happened, once they made the first discoveries overnight, everyone and their dog was getting into exoplanets. And all of a sudden, the whole astronomy community shifted and huge numbers of people that were once upon a time

studying eclipsing binaries changed to becoming exoplanet scientists. And so that was the first wave of exoplanet scientists. We're now in a kind of a second wave or even third wave where people like me to some degree kind of grew up with the idea of exoplanets as being normal. I was 11 years old, I guess, when the first exoplanet was discovered. And so to me it was a fairly normal idea to grow up with. And so we've been trained in exoplanets from the very beginning. And so that brings a different perspective to those who have maybe transitioned from a different career path. And so I suspect with exo-moons and probably technosignatures, astrobiology, many of the topics which are seen at the fringes of what's possible, they will all open up into becoming mainstream one day. But there's a lot of people who are just waiting, waiting for that assuredness that there is a secure career net ahead of them before they commit. Yeah, it does seem to me that exo-moons open wider or open for the first time the door to aliens. So more seriously academically studying, all right, let's look at like alien worlds. So I think it's still pretty fringe to talk about alien life, even not like on Mars and the moons and so on. You're kind of like, you'll be nice. But imagine the first time to discover a living organism that's going to change, then everybody will look like an idiot for not focusing everything on this. Because the possibility of the things, it's possible it might be super boring. It might be very boring bacteria. But even the existence of life elsewhere. I mean, that changes everything. That means life is everywhere. Yeah. If you knew now that in five years, 10 years, the first life would be discovered elsewhere, you knew that in advance, it would surely affect the way you approach your entire career. As a, especially someone junior in astronomy, you would surely be like, well, this is clearly going to be the direction I have to dedicate my classes and my training and my education towards that direction. All the new textbooks, all the written. And I think there's a lot of value to hedging, like allocating some of the time to that possibility. Because the kind of discovery will, the kind of discoveries we might get in the next few decades, it feels like we're in the verge of a lot of getting a lot of really good data and having better and better tools that can process that data. So there's just going to be a continuous increase of the kind of discoveries that will open. But a slam dunk, that's hard to come by. Yeah, I think a lot of us are anticipating, I mean, we're already seeing it to some degree with Venus and the Phosphine incident. But we've seen it before with Bill Clinton, it's in the White House lawn, announcing life from Mars. And there are inevitably going to be spurious claims or at least claims which are ambiguous to some degree. There will be for sure a high profile journal like Nature or Science that will one day publish a paper saying biosignature discovered or something like that on Travis One or some other planet. And then there will be years of back and forth in the literature. And that might seem frustrating, but that's how science works. That's the mechanism of science at play of people scrutinizing the results to intense skepticism. And it's like a crucible. You burn away all the relevant says until whatever is left is the truth. And so you're left with this product, which is that, okay, we either believe or don't believe that biosignatures are there. So there's inevitably going to be a lot of controversy and debate and argument about it. We just have to anticipate that. And so I think you have to basically have a thick skin to some degree academically to dive into that world. And you're seeing that with Phosphine. It's been uncomfortable to watch from the outside the kind of dialogue that some of the scientists have been having with each other about that because... They get a little aggressive. Yeah. You can understand

why because... Jealousy? I don't know. It's me saying that you. It's me talking. I'm sure there's some envy and jealousy involved on the behalf of those who are not part of the original discovery. But there's also, in any case, just leave the particular people involved in Venus alone. In any case of making a claim of that magnitude, especially life, because life is pretty much one of the biggest discoveries of all time, you can imagine scientifically, you can see, and I'm so conscious of this in myself when I get close to, as I said, even the much smaller goal of setting an exo-moon, the ego creep in. And so, as a scientist, we have to be so guarded against our own egos, you see the lights in your eyes of a Nobel Prize or the fame and fortune and being remembered in the history books. And we all grew up in our training learning about Newton and Einstein, these giants of the field, Feynman and Maxwell. And you get the idea of these individual contributions which get immortalized for all time. And that's seductive. It's why many of us with the skill set to go into maybe banking instead decided, actually, there's something about the idea of being immortalized and contributing towards society in a permanent way that is more attractive than the financial reward of applying my skills elsewhere. So, to some degree, that ego can be a benefit because it brings in skillful people into our field who might otherwise be tempted by money elsewhere. But on the other hand, the closer you get towards when you start flirting with that Nobel Prize in your eyes or you think you're on the verge of seeing something, you can lose objectivity. A very famous example, this is a Barnard star. There was a planet claimed there by Peter van der Kamp, I think it was in 1968, 69. And at the time, it would have been the first ever exoplanet ever claimed. And he felt assured that this planet was there. He was actually using the wobbling star method, but using the positions of the stars to see them to claim this exoplanet. It turned out that this planet was not there. A subsequent analysis by both dynamicists and theorists and those looking at the instrumental data established fairly unanimously that there was no way this planet was really there. But Peter van der Kamp insisted it was there, despite overwhelming evidence that was accruing against him. And even to the day he died, which was, I think in the early 90s, he was still insisting this planet was there, even when we were starting to make the first genuine exoplanet discoveries. And even at that point, I think Hubble had even looked at that star and had totally ruled out any possibility of what he was talking about. And so that's a problem. How do you get to a point as a scientist where you just can't accept anything that comes otherwise? Because it starts out with the dream of fame and then it ends in a stubborn refusal to ever back down.
Of course, the flip side of that is sometimes you need that to have the strength to carry a belief against the entire scientific community that resists your beliefs. And so it's a double-edged sword. That can't happen. But I guess the distinction here is evidence. So in this case, that the evidence was so overwhelming, it wasn't really a matter of interpretation.
And you would observe this star with the same star, but with maybe 10, even 100 times greater precision for much longer periods of time. And there was just no doubt at this point, this planet was a mirage. And so that's why you have to be very careful. I always say, don't ever name my wife or my daughter. Name this planet after me that you discover. And I can't ever name a planet after you because I won't be objective anymore. How could I ever turn around to you and say that planet wasn't real that I named after you?
So you're somebody that talks about and it's clear in your eyes and in your way of being that you love the process of discovery, that joy, the magic of just

seeing something, a new observation, a new idea. But I guess the point is when you have that great feeling is to then switch on the skepticism to start testing what does this actually mean? Is this real? What are the possible different interpretations that could make this a lot less grand than I first imagined? So both have the wander and the skepticism on one brain.
Yeah, I think generally the more I want something to be true, the more I inherently doubt it. And I think that just comes from, I grew up with a religious family and was just sort of indoctrinated to some degree like many children are that, okay, there's just normal that there's a God and this is the way the world is. God created the earth. And then as I became more well read and illiterate of what was happening in the world scientifically, I started to doubt. And it really just struck me that the hardest thing to let go of when you do decide not to be religious anymore. And it's not really like a light bulb moment, but it just kind of happens over 11 to 13, I think for me it was happening. But it's that sadness of letting go of this beautiful dream, which you had in your mind of eternal life for behaving yourself on earth, you would have this beautiful heaven that you could go to and live forever. And that's very attractive. And for me personally, that was one of the things that pulled me against it. It's like it's too good to be true. And it's very convenient that this could be so. And I have no evidence directly in terms of scientific sense to support this hypothesis. And it just became really difficult to reconcile my growth as a scientist. And I know some people find that reconciliation, I have not. Maybe I will one day. But as a general guiding principle, which I think I obtained from that experience, was that I have to be extremely guarded about what I want to be true, because it's going to sway me to say things which are not true, if I'm not careful. And that's not what we're trying to do as scientists.
So you felt from a religious perspective that there was a little bit of a gravitational field in terms of your opinions, like it was affecting how you could be as a scientist.
Like as a scientific thinker, obviously we're young.
Yeah, I think that's true, that whenever there's something you want to be true, it's the ultimate seduction intellectually. And I worry about this a lot with UFOs, and it's true already with things like Venus, Phosphine, and searching for astrobiological signals. We have to guard against this all the way through from however we're looking for life, however we're looking for whatever this big question is. There is a part of us, I think I would love there to be life in the universe. I hope there is life in the universe, but I've somewhat been on record several times as being fairly firm about trying to remain consciously agnostic about that question. I don't want to make up my mind about what the answer is before I've collected evidence to inform that decision. That's how science should work. If I already know what the answer is, then what am I doing? That's not a scientific experiment anymore. You've already decided, so what are you trying to learn? What's the point of doing the experiment if you already know what the answer is? There's no point.
It's so complicated because if I'm being honest with myself, when I imagine the universe, so first thing I imagine about our world is that we humans, and me certainly, as one particular human, know very... My first assumption is I know almost nothing about how anything works. So first of all, that actually applies for things that humans do know, like quantum mechanics and all the things that there's different expertise that I just have not dedicated to. So even that's starting point. But if we take all of

knowledge as human civilization, we know almost nothing. That's kind of an assumption I have because it seems like we keep discovering mysteries and it seems like history, human history is defined by moments when we said, okay, we pretty much figured it all out, and then you realize a century later, when you said that, you didn't figure out anything. Okay, so that's like a starting point. The second thing I have is I feel like the entirety of the universe is just filled with alien civilizations. Statistically, the important thing that enables that belief for me is that they don't have to be human-like. They can be anything. And it's just the fact that life exists and just seeing the way life is on earth, that it just finds a way. It finds a way in so many different complicated environments. It finds a way. Whatever that force is, that same force has to find a way elsewhere also. But then if I'm also being honest, I don't know how many hours in a day I spend seriously considering the possibility that we're alone. I don't know when my heart is in mind or filled with wonder, I think about all the different life that's out there. But to really imagine that we're alone, like really imagine all the vastness that's out there, we're alone, not even bacteria. I would say you don't have to believe that we are alone, but you have to admit it's a possibility of our ignorance of the universe so far.
You can have a belief about something in the absence of evidence.
Carl Sagan famously described that as the definition of faith. If you believe something when there's no evidence, you have faith that there's life in the universe. But you can't demonstrate, you can't prove it mathematically, you can't show me evidence of that.
But is there some, so mathematically math is a funny thing. Is there, I mean, the way physicists think, like intuition, so basic reasoning, is there some value to that?
Well, I'd say there's certainly, you can certainly make a very good argument, I think you've kind of already made one, just the vastness of the universe is the default argument people often turn to, that surely there should be others out there as hard to imagine.
They're of order of 10 to the 22 stars in our observable universe. And so really the question comes down to what is the probability of one of those 10 to the 22 planets, let's say, Earth like planets, if they all have Earth like planets, going on to form life spontaneously. That's the process of a by genesis, the spontaneous emergence of life.
Also the word spontaneous is a funny one.
Okay, maybe we won't use spontaneous, but not being, so to say, ceded by some of the civilization or something like this, it naturally emerges.
Because even the word spontaneous makes it seem less likely.
Yeah.
Like there's just this chemistry and extremely random process.
Right, it could be a very gradual process over millions of years of growing complexity in chemical networks.
Maybe there's a force in the universe that pushes it towards interesting complexity, pockets of complexity, that ultimately creates something like life, which we can't possibly define yet. And sometimes it manifests itself into something that looks like humans, but it could be a totally different kind of computational information processing system that we're too dumb to even visualize.
Yeah, I mean, certainly, I mean, it's kind of weird that complexity develops at all, right?

Because it seems like the opposite to our physical intuition, if you're turning in
physics of entropy, that complexity is hard to spontaneously, or I shouldn't say spontaneously,
but hard to emerge in general.
And so that's an interesting problem.
I think there's been, certainly from an evolutionary perspective, you do see growing complexity.
And there's a nice argument, I think it's by Gold, who shows that if you have a certain
amount of complexity, it can either become less complex or more complex through random
mutation. And the less complex things are stripping away something,
something that was necessary potentially to their survival. And so in general, that's,
that's going to be not particularly useful in its survival. And so it's going to be detrimental
to strip away a significant amount of its useful traits. Whereas if you add something,
the most typical thing that you add is probably not useful at all. It's probably just doesn't
really affect its survival negatively, but it neither does it provide any significant benefit.
But sometimes on rare occasions, of course, it will be of benefit. And so if you're,
I have a certain level of complexity, it's hard to go back in complexity, but it's fairly easy to
go forward with enough bites at the cherry, you will eventually build up in complexity. And that
tends to be why we see complexity growing in, certainly in an evolutionary sense,
but also perhaps it's operating in chemical networks that led to the emergence of life.
I guess the real problem I have with the numbers game, just to come back to that,
is that we are talking about a certain probability of that occurring. It may be to go from the
primordial
soup, however you want to call it, the ingredients that the earth started with, the organic molecules,
the probability of going from that initial condition to something that was capable of
Darwinian natural selection that maybe we could define as life. The probability that is maybe
1%, 1% of the time that happens, in which case you're right, the universe will be
absolutely teeming with life, but it could also be 10 to the power of minus 10, in which case
it's one per galaxy, or 10 to the power of minus 100, in which case the vast majority of universes
even do not have life within it. Or 90%. Or 90%. You said 1%, you said 1%, but it could be 90%
if the conditions, the chemical conditions of a planet are correct, or a moon are correct.
I admit that. It could be any of those numbers. And the challenges we just have no
rigorous reason to expect why 90% is any, because we're talking about a probability
of a probability, is 90% more a priori likely than 10 to the power of minus 20?
Well, the thing is, we do have an observation, and of one, of earth. And it's difficult to
know what to do with that, what kind of intuition you build on top of that, because on earth,
it seems like life finds a way in all kinds of conditions, in all kinds of crazy conditions.
Good. And it's able to build up from the basic chemistry. You could say, okay,
maybe it takes a little bit of time to develop some complicated technology like mitochondria,
I don't know, photosynthesis, fine, but it seems to figure it out and do it extremely well.
Yeah, but I would say you're describing a different process. I mean, maybe I'm at fault
for separating these two processes, but to me, you're describing basically natural selection
evolution at that point. Whereas I'm really describing a biogenesis, which is, to me,
a separate distinct process. Do you limit it to human scientists? Yes. But why would it be a
separate process? Why? Why is the birth of life a separate process from the process of life?

I mean, we're uncomfortable with the big bang. We're uncomfortable with the first thing, I think. Like, where does this come from? Right. So I would say, I just twist that question around and say, you're saying why is it a different process? And I would say, why shouldn't it be a different process, which isn't really a good defense, except to say that we have knowledge of how natural selection evolution works. We think we understand that process. We have almost no information about the earliest stages of how life emerged on our planet. It may be that you're right and it is a part of a continuum. It may be that it is also a distinct, improbable set of circumstances that led to the emergence of life. As a scientist, I'm just trying to be open-minded to both possibilities. If I assert that life must be everywhere, to me, you run the risk of experiment as bias. If you think you know what the answer is, if you look at an earth-like planet and you are preconditioned to think there's a 90% chance of life on this planet, it's going to, at some level, affect your interpretation of that data. Whereas if I, however critical you might be of the agnosticism that I impose upon myself, remain open to both possibilities, then I trust in myself to make a fair assessment as to the reality of that evidence for life.
Yeah, but I wonder sort of scientifically, and that's really beautiful to hear and inspiring to hear, I wonder scientifically how many firsts we truly know of, and then we don't eventually explain as actually a step number one million in a long process. I think that's a really interesting thing if there's truly firsts in this universe. For us, whatever happened at the Big Bang is the kind of first, the origin of stuff. But it just, again, it seems like history shows that we'll figure out that it's actually a continuation of something. But then physicists say that time is emergent and that our causality in times is a very human kind of construct that it's very possible that all of this, so there could be really firsts of a thing to which we attach a name.
So whatever we call life, maybe there is an origin of it.
Yeah, and I would also say I'm open to it being part of a continuation, but the continuation maybe is more broader, and it's a continuation of chemical systems and chemical networks. And what we call this one particular type of chemistry and this behavior of chemistry life. But it is just one manifestation of all the trillions of possible permutations in which chemical reactions can occur. And we assert specialness to it because that's what we are. And so this is also true of intelligence. You could extend the same thing and say, you know, we're looking for intelligent life in the universe. And then you sort of, where do you define intelligence? Where's that continuum of something that's really like us? Are we alone? There may be a continuum of chemical systems, a continuum of intelligences out there.
And we have to be careful of our own arrogance of assuming specialness about what we are, that we are some distinct category of phenomena. Whereas the universe doesn't really care about what category we are, it's just doing what it's doing and doing everything in infinite diversity and infinite combinations, essentially what it's doing. And so we are taking this one slice and saying, no, this has to be treated separately. And I'm open to the idea that it could be a truly separate phenomena, but it may just be like a snowflake, every snowflake's different. It may be just be that this one particular iteration is another variant of the vast continuum. And maybe the algorithm of natural selection itself is an invention of Earth. I kind of also tend to suspect that this, whatever the algorithm is, it kind of operates at all levels throughout the universe. But maybe this is a very kind of peculiar thing that where there's a bunch of

chemical systems that compete against each other somehow for survival under limited resources. And that's a very Earth-like thing. We have a nice balance of there's a large number of resources enough to have a bunch of different kinds of systems competing, but not so many that they get lazy. And maybe that's why bacteria were very lazy for a long time. Maybe they didn't have much competition. Quite possibly. I mean, I try to, as fun as it is to get into the speculation about the definitions of life and what life does and this gross network of possibilities, honestly, for me, the strongest argument for remaining agnostic is to avoid that bias and assessing data. And we've seen it. I mean, first of all, I talked about my channel and maybe last year or two years ago, who's a very famous astronomer who in the 19th century was claiming the evidence of canals on Mars. And from his perspective, and even at the time culturally, it was widely accepted that Mars would, of course, have life. I mean, I think it seems silly to us, but it was kind of similar arguments to what we're using now about exoplanets that, well, of course, there must be life in the universe. How could it just be here? And so it seemed obvious to people that when you looked at Mars with its polar caps, even if its atmosphere had seasons, it seemed obvious to them that that too would be a place where life not only was present,
but had emerged to a civilization which actually was fairly comparable in technology to our own, because it was building canal systems. Of course, a canal system seems a bizarre technosignature to us, but it was a product of their time. To them, that was the cutting edge in technology. It should be a warning shot actually a little bit for us that if we think solar panels or building star links or whatever, space mining is like an inevitable technosignature, that may be laughably antiquated compared to what other civilizations far more advanced than it's maybe doing. And so anyway, Percival Lowell, he was, I think, was a product of his time that he thought life was there. Inevitably, he even wrote about it extensively. And so when he saw these lines, these linear on the surface of Mars, to him, it was just obvious they were canals. And he was, that was experimental bias playing out. He was told for one that he had basically the greatest eyesight out of any of his peers. An ophthalmologist had told him that in Boston that his eyesight was absolutely spectacular. So he just was convinced everything he saw was real. And secondly, he was convinced there was life there. And so to him, it just added up. And then that kind of wasted decades of research of treating the idea of Mars being inhabited by this canal civilization. But on the other hand, it's maybe not a waste because it is a lesson in history of how we should be always on guard against our own preconceptions and biases about what whether life is out there and furthermore, what types of things life might do if it is there.
If I were running this simulation, which you also talk about because you make the case against it, but if I were running the simulation, I would definitely put you in a room with an alien and just to see you mentally freak out for hours at a time. You for sure would have thought you would be convinced that you've lost your mind. I mean, no, not that, but I mean, and like if we discover life, we discovered interesting new physical phenomena, I think the right approach is definitely to be extremely skeptical and be very, very careful about things you want to be true. I'm not like some extreme denialist of evidence. If there was compelling evidence for life on another planet, I would be the first one to be celebrating that and be shaking hands with the alien on the White House lawn, whatever. I grew up with Star Trek and that was my fantasy was to be Captain Kirk and fly across the stars, meaning of the civilization.

So there's nothing more I'd want to be true, as I've said, but we just have to guard against it when we're assessing data. But I have to say I'm very skeptical that we will ever have that Star Trek moment, even if there are other civilizations out there, they're never going to be at a point which is in technological lockstep with us, similar level of development. Even intellectually, the idea that they could have a conversation with us, even through a translator, I mean, we can't communicate with Humback Whales, we can't communicate with dolphins in a meaningful way. We can sort of bark orders at them, but we can't have abstract conversations with them about things. And so the idea that we will ever have that fulfilling conversation I'm deeply skeptical of, and I think a lot of us are drawn to that, it is maybe a replacement for God to some degree, that that father figure civilization that might step in, teach us the air of our ways and bestow wisdom upon our civilization. But they could equally be a giant fungus that has doesn't even understand the idea of social socialization, because it's the only entity on its planet. It just swells over the entire surface. And it doesn't, it's incredibly intelligent, because maybe each node communicates with each other to create essentially a giant neural net. But it has no sense of what communication even is. And so alien life is out there, surely going to be extremely diverse. I'm pretty skeptical that we'll ever get that that fantasy moment I always had as a kid of having a dialogue within the civilization. So dialogue, yes, what about noticing them? What about noticing signals? Do you hope? So one thing we've been talking about is getting signatures, biosignatures, technical signatures about other planets, maybe for extremely lucky in our lifetime to be able to meet life forms, get evidence of living or dead life forms on Mars or the moons of Jupiter and Saturn. What about getting signals from outer space, interstellar signals? What kind of, what would those signals potentially look like? That's a hard question to answer, because we are essentially engaging in xenopsychology to some degree. What are the activities of another civilization? But a lot of that is in that word, xenopsychology, I apologize to interrupt. Maybe I'm just fabricating that word really, but they're trying to guess at the machinations and motivations of another intelligent being that was completely evolutionary divorced from us. So it's like, like you said, exo moons, it's exo psychology, extra solar psychology. Yeah, alien psychology is another way of maybe making it more grounded. But we can't really guess at their motivations too well, but we can look at the sorts of behaviors we engage in and at least look for them. We're always guilty that when we look for biosignatures, we're really looking for, and even when we look for planets, we're looking for templates of Earth. When we look for biosignatures, we're looking for templates of Earth based life. When we look for technosignatures, we tend to be looking for templates of our own
behaviors or extrapolations of our behaviors. So there's a very long list of technosignatures that people have suggested we could look for. The earliest ones were, of course, radio beacons. There was sort of Project Osmo that Frank Drake was involved in, trying to look for radio signatures, which could either be just like blurting out high power radio signal saying, hey, we're here, or could even have encoded within them galactic encyclopedias for us to unlock, which has always been the allure of the radio technique. But there could also be unintentional signatures. For example, you can have something like the satellite system that

we've produced around the Earth, the artificial satellite system, Starlink type systems, we mentioned, you could detect the glint of light across those satellites as they orbit around the planet. You could set a geostationary satellite belt which would block out some light as the planet transferred across the star. You could detect solar panels potentially spectrally on the surface of the planet. Heat island effects, New York is hotter than New York State by a couple of degrees because of the heat island effect of the city. And so you could thermally map different planets and detect these. So there's a large array of things that we do that we can go out and hypothesize we could look for. And then on the furthest end of the scale, you have things which go far beyond our capabilities, such as warp drive signatures, which have been proposed, you get these bright flashes of light or even gravitational wave detections from LIGO could be detected. You could have Dyson spheres, the idea of covering basically
a star is completely covered by some kind of structure which collects all the light from the star to power the civilization. And that would be pretty easily detectable to some degree because you're transferring all of the visible light thermodynamically, it has to be reemitted to come out as infrared light. So you'd have an incredibly bright infrared star, yet one that was visibly not present at all. And so that would be pretty intriguing signatures to look for. Well, is there efforts to look for something like that for Dyson spheres out there, or would there be the strong infrared signal? There has been. Yeah, there has been. And there's been, I think in the literature, there was one with the IRAS satellite, which is an infrared satellite. They targeted, I think, a ward of 100,000 stars, nearby stars and found no convincing examples of what looked like a Dyson sphere star. And then Jason Wright and his team extended this,
I think, using Ys, which is another infrared satellite, to look around galaxies. So could an entire galaxy have been converted into Dyson spheres or a significant fraction of the galaxy, which is basically the Kardashev type three, right? This is when you've basically mastered the entire galactic pool of resources. And again, out of 100,000 nearby galaxies, there appears to be no compelling examples of what looks like a Dyson galaxy, if you want to call it that. So that by no means proves that they don't exist or don't happen, but it seems like it's an unusual behavior for a civilization to get to that stage of development and start harvesting the entire stellar output. Unusually, yes. And I mean, LIGO is super interesting with gravitational waves. If that kind of experiment could start seeing some weirdness, some weird signals, some that compare to the power of cosmic phenomena.
Yeah. Yeah. I mean, it's a whole new window to the universe, not just in terms of astrophysics, but potentially for technosciences as well. I have to say with the warp drives, I am skeptical that warp drives are possible because you have kind of fundamental problem in relativity. You can either really have relativity, faster than light travel or causality. You can only choose two of those three things. You really can't have all three in a coherent universe. If you have all three, you basically end up with the possibility of these kind of temporal paradoxes and time loops in grandfather paradoxes. Well, can't there be pockets of causality, something like that? Like where there's like pockets of consistent causality.
You could design it in that way. You could be, if you had a warp drive or a time machine, essentially, you could be very conscious and careful of the way you use it so as to not

to cause paradoxes or just do it in a local area or something. But the real fundamental problem is you always have the ability to do it. And so in a vast cosmic universe, if time machines are all over the place, there's too much risk of someone doing it, right? Somebody having the option of essentially breaking the universe with it. So there's a fundamental problem. Hawking has this chronology protection conjecture where he said that essentially, this just can't be allowed because it breaks all our laws of physics if time travel is possible.
Current laws of physics, yes.
Correct, yeah. And so we need to rip up relativity. I mean, that's the point,
is the current laws of physics, so you'd have to rip up our current law of relativity to make sense of how FTL could live in that universe because you can't have relativity, FTL and causality sit nicely and play nicely together. But we currently don't have quantum mechanics and relativity playing nice together anyway, so it's not like everything is all a nice little fact. It's certainly not the full picture. There must be more to go. So it's already ripped up, so it might as well rip it up a little more. And in the process, I actually try to connect the two things because maybe in the unification of the standard model and general relativity may be there lies some kind of new wisdom about warp drives. So by the way, warp drives is somehow messing with the fabric of the universe to be able to travel faster than the speed of light.
Yeah, you're basically bending spacetime. You could also do it with a wormhole or tack. Some of the hypothetical FTL systems doesn't have to necessarily be the Alcubare drive, the warp drive. It could be any faster than my system. As long as it travels super evenly, it will violate causality. And presumably they'll be observable with LIGO.
Potentially. Yeah, potentially. It depends on, I think, the properties of whatever the spacecraft is. I mean, one problem with warp drives is there's all sorts of problems with warp drives. Like the start of this and one problem with the warp drives.
There's just this one minor problem that we have to get around. But when it arrives at its destination, it basically collects this vast, basically it has like an event horizon almost at the front of it. And so it collects all this radiation at the front as it goes.
And when it arrives, all that radiation gets dumped on its destination and basically completely exterminate the planet that arrives at. That radiation is also incident within the shell itself. There's Hawking radiation occurring within the shell, which is pretty dangerous.
And then it also raises all sorts of exacerbations of the Fermi Paradox, of course, as well. So you might be able to explain why we don't see a galactic empire. I mean, even here it's hard.
You might be able to explain why we don't see a galactic empire if everybody's limited to Voyager 2 rocket speeds of like 20 kilometers per second or something. But it's a lot harder to explain why we don't see the stars populated by galactic empires.
Galactic empires, when warp drive is eminently possible, because it makes expansion so much more trivial that it makes our life harder. There's some wonderful simulation work being done out of Rochester where they actually simulate all the stars in the galaxy or a fraction of them.
And they spawn a civilization on one of them. And they let it spread out at sublight speeds.
And actually the very mixing of the stars themselves, because the stars are not static, they're in orbit of the galactic center. And they have crossing paths with each other.
If you just have a range of even like five light years, and your speed is of order of a few percent, the speed of light is the maximum you can muster, you can populate the entire galaxy within

something
like 100,000 to about a million years or so. So another a fraction of the lifetime of the galaxy itself. And so this raises some fairly serious problems because if any of the stars are not static, because if any civilization, the entire history of the galaxy decided to do that, then either we shouldn't be here, or we happen to live in this kind of rare pocket where they chose not to populate to. And so this is sometimes called facte, heart's facte, as the facte is that a civilization is not here now. An alien civilization is not in present occupation of the earth. And that's difficult to resolve with the apparent ease at which even a small extrapolation of our own technology could potentially populate a galaxy in far faster than galactic history. So to me, by the way, the firm paradox is truly a paradox for me. But I suspect that if alien visit earth, I suspect if they do, if they are everywhere, I think they're already here and we're too dumb to see it. But leaving that aside, I think we should be able to, in that case, have very strong, obvious signals when we look up at the stars, at the emanation of energy required. We would see some weirdness where these are these kinds of stars and these are these kinds of stars they're being messed with, leveraging the nuclear fusion of stars to do something useful. The fact that we don't really see that, maybe you can correct me, wouldn't we be able to, if there is alien civilizations running galaxies, wouldn't we see weirdnesses from an astronomy perspective with the way the stars are behaving? Yeah, I mean, it depends exactly what they're doing. But I mean, the Dyson sphere example is one that we would discuss where a survey of 100,000 nearby galaxies find that they are not, have all been transformed into Dyson sphere collectors. You could also imagine them doing things like we read a paper this recently of starlifting, where you can extend the life of your star by scooping mass off the star. So you'd be doing stellar engineering, essentially. Space, if you're doing a huge amount of asteroid mining, you would have a spectral signature because you're basically filling the solar system with dust. By doing that, there'd be debris from that activity. And so there are some limits on this. Certainly, we don't see bright flashes, which would be, one of these consequences of the warp drives, as I said, is as they decelerate, they produce these bright flashes of light. We don't seem to see evidence of those kind of things. We don't see anything obvious around the nearby stars or the stars that we've surveyed in detail beyond that, that indicate any kind of artificial civilization. The closest maybe we had was Boyajian star, there was a lot of interest in. There was a star that was just very peculiarly dipping in and out its brightness. And it was hypothesized for a time that that may indeed be some kind of Dyson-like structure, so maybe a Dyson sphere that's half built. And so as it comes in and out, it's blocking out huge swaths of the star. It was very difficult to explain it really with any kind of planet model at the time. But an easier hypothesis that was proposed was it could just be a large number of comets or dust or something, or maybe a planet that had broken apart. And as its fragments orbit around, it blocks out starlight. And it turned out with subsequent observations of that star, which especially the amateur astronomy community made a big contribution to as well, that the dips were chromatic, which was a real important clue that that probably wasn't a solid structure then that was going around it. It was more likely to be dust, dust is chromatic. But chromatic, I mean, it looks different in different colors. So it blocks out more red light than blue light. If it was a solid structure, I shouldn't do that. It shouldn't be, it should be opaque,

right? A solid metal structure or something. So that was one of the clear indications and the behavior of in the way the light changed or the dips changed across wavelength was fully consistent with the expectations of what small particulates would do.
And so that's very hard. I mean, the real problem with alien hunting, the technical term, this is the one problem. One problem with the warp drive and the one problem with alien hunting. Yes. But actually, I'd say there's three big problems for me with any search for life, which includes UFOs, or the way to fossils and Mars, is that aliens have three unique properties as a hypothesis. One is they have essentially unbounded explanatory capability. So there's almost no phenomena I can show you that you couldn't explain with aliens to some degree. You could say, well, the aliens just have some super high tech way of creating that illusion. The second one would be unbounded avoidance capacity. So I might see a UFO tomorrow, and then the next day, and then the next day, and then predict I should see it on Thursday at the end of the week. But then I don't see it, but I could always get out of that and say, well, that's just because they chose not to come here. You know, they have this, they can always avoid future observations fairly easily.
If you survey an exoplanet for biosignatures and you don't see oxygen, you don't see methane, that doesn't mean there's no one living there. They could always be either tricking their atmosphere, engineering it, we actually wrote a paper about that, how you can use lasers to hide your biosignatures
as advanced civilization. Or you could just be living underground or underwater or something where there's no biosignatures. So you can never really disprove there's life on another planet or on another star. It has infinite avoidance. And then finally, the third one is that we have incomplete physical understanding of the universe. So if I see a new phenomena, which Boyajin Star was an example of that, we saw this new phenomena of these strange dips we'd never seen before. It was hypothesized immediately, this could be aliens, it's like a god of the gaps, but it turned out to be incomplete physical understanding. And so that happens all the time in the first pulsar that was discovered. Same story. Jocelyn Bell kind of somewhat tongue in cheek called it little green man one, because it looked a lot like the radio signature that was expected from a civilization. But of course, it turned out to be a completely new type of star that we had never seen before, which was a neutron star with these two jets coming out the top of it. And so that's a challenge. Those three things are really, really difficult in terms of experimental design for a scientist to work around something that can explain anything, can avoid anything. So it's almost unfalsifiable. And could always just be to some degree, as you said, we have this very limited knowledge of the infinite possibilities of physical law, and we're probably only scratching the surface. Each time, and we've seen it so often in history, we may just be detecting some new phenomena. Well, that last one, I think I'm a little more okay with making mistakes on. Yeah, because it's exciting still.
So you might exaggerate the importance of the discovery, but the whole point is to try to find stuff in this world that's weird, and try to characterize that weirdness.
Sure, you can throw a little green man as a label on it. But eventually, it's as mysterious and as beautiful, as interesting as little green man. We tend to think that there's some kind of threshold, but there's all kinds of weird organisms on this earth that operate very differently than humans that are super interesting. The human mind is super interesting. Weirdness

and complexity is as interesting in any of its forms as what we might think from Hollywood, what aliens are. So that's okay. Looking for weirdness is on Mars.
That's one of the best sales pitches to do technical signature work, is that we always have that as our fallback, that we're going to look for alien signatures. If we fail, we're going to discover some awesome new physics along the way. And so even any kind of signature that we detect is always going to be interesting. And so that compels us to have not only the question of looking for life in the universe, but it gives us a strong scientific grounding as to why this sort of research should be funded and should be executed because it always pushes the frontiers of knowledge. I wonder if we'll be able to discover and be open enough to a broad definition of aliens, where we see some kind of technical signature, basically like a Turing test, like this thing is intelligent. Like it's processing information in a very interesting way. But you can say that about chemistry, you can say that about physics, maybe not physics, chemistry. Like interesting complex chemistry, you could say that this is processing, this is storing information, this is propagating information over time.
It's a gray area between a living organism that we would call an alien. And I think that's super interesting. It's able to carry some kind of intelligence.
Yeah, information is a really useful way to frame what we're looking for, though, because then you're divorced from making assumptions about even a civilization necessarily or anything like that. So any kind of information-rich signature, indeed, you can take things like the light curve from Boyajin star and ask what is the minimum number of free parameters or the minimum information content that must be encoded within this light curve.
The hope is that maybe a good example would be from a radio signature, you detect something that has a thousand megabytes of parameters essentially contained within it. That's pretty clearly at that point not the product of a natural process, at least any natural process that we could possibly imagine with our current understanding of the universe. Even if we can't decode, which actually I'm skeptical would be able to ever decode it in our lifetimes, it would probably take decades to fully ever figure out what they're trying to tell us. But if there was a message there, we could at least know that there is high information content and there is complexity and that this is an attempt at communication information transfer and leave it to our subsequent generations to figure out what exactly it is they're trying to say.
What, again, a wild question and thank you for entertaining them, I really, really appreciate that. But what kind of signal in our lifetime, what kind of thing do you think might happen could possibly happen where the scientific community would be convinced that there's alien civilizations out there? What, as you already said, maybe a strong infrared signature for something like a Dyson sphere? Yeah, that's possible. That's also at some degree a little bit ambiguous. That's the challenge to interrupt is where your brain would be like you as a scientist would be like, I know it's ambiguous, but this is really weird. Yeah, I think if you had something, I can imagine something like a prime number sequence or a mathematical sequence like the Fibonacci series, something being... Mathematically provable that this is not a physical phenomenon. Right. I mean, yeah, prime numbers is a pretty good case because there's no natural phenomena that produces prime number sequences. It seems to be a purely an abstract mathematical
concept as far as I'm aware. And so if we detected a series of radio blips that were following that

sequence, it would be pretty clear to me or it could even be in a car say you can suggested that pi could be encoded and that or you might use the hydrogen line, but multiplied by pi like some very specific frequency of the universe like a hydrogen line, but multiply it by a abstract mathematical constant that would imply strongly that there was someone behind the scenes operating
that. Sorry, stored in which phenomenon though. In that case, I think of a radio wave, but the information, I mean, we kind of toyed with this idea in a video I did about hypothetical civilization on my channel. But one kind of fun way, I do want to bring this conversation towards time a little bit and thinking about not just looking for life and intelligence around us right now, but looking into the past and even to the future to some degree or communicating with the future. And so we had this fun experiment of imagining a civilization that was born at the beginning of the history of the galaxy and being the first and what it would be like for them and they were desperately searching for evidence of life, but couldn't find it. And so they decided to try and leave something behind for future civilizations to discover, to tell them about themselves. But of course, a radio thing is not going to work there because it has have a power source and that's a piece of machinery, it's going to eventually break down, it's going to be hard to maintain that for billions of years timescale. And so you wanted something that was kind of passive
that doesn't require an energy source, but can somehow transmit information, which is hard to think about something that satisfies those criteria. But there was a proposal by one of my colleagues, Luke Arnold, which inspired a lot of us in tetanus signatures. And he suggested that you could build artificial transitors. So you could build sheets of material that transit in front of the star, maybe one thin sheet passes across first, then two, then three, then five and seven. So you could follow the prime number sequence of these. And so there'd be a clear indication that someone had manufactured those, but they didn't require any energy source because they're just sheets of material in all of the star. They would eventually degrade from micrometeorites, maybe they always become destabilized, but they should have lifetimes far exceeding the lifetime of any battery or mechanical electronic system that we could, at least without analogy, conceive of building. And so you could imagine an extending that and how could you encode not just a prime number sequence, but maybe in the spatial pattern of this very complex light curve we see, you could
encode more and more information through 2D shapes and the way those are quotations happen. And maybe
you could even encode messages and in-depth information from that. You could even imagine it being like a lower layer of information, which is just the prime number sequence. But then you look closely and you see the smaller divots embedded within those that have a deeper layer of information to extract. And so to me, something like that would be pretty compelling that there was somebody who had managed, unless it's just a very impressive hoax, that would be a pretty compelling evidence for this civilization. And actually the methods of astronomy right now are kind of marching towards being able to better and better detect a signal like that.
Yeah. I mean, to some degree, it's just building bigger aperture in space,
the bigger the telescope, the finer ability to detect those minute signals.
Do you think the current sort of the scientific community, another weird question,

but just the observations that are happening now, do you think they're ready for a prime number sequence in the sort of, if we're using the current method, the transit timing variation method? Like, do you think you're ready? Do you have the tools to detect the prime number sequence? Yeah, for sure. I mean, there's 200,000 stars that Kepler monitored and it monitored them all the time. It took a photo of each one of them every 30 minutes, measured their brightness, and it did that for four and a half years. And so you have already, and Tess is doing it right now, another mission. And so you have already an existing catalog and people are genuinely scouring through each of those light curves with automated machine learning techniques. We even developed some in our own team that can look for weird behavior. We wrote a code called the weird detector, for instance, that of course, you know, it was just the most generic thing possible. Don't assume anything about the signal shape. Just look for anything that repeats. The signal shape can be anything and we kind of learn the template of the signal from the data itself. And then we, it's like a template matching filter to see if that repeats many, many times in the data. And so we actually applied that and found a bunch of interesting stuff, but we didn't see anything that was the prime number sequence, at least in the Kepler data. That's 200,000 stars, which sounds like a lot, but compared to 200 billion stars in the Milky Way, it's really just scratching the surface. So one, because there could be something much more generalizable than the prime number sequence, it's ultimately the question of a signal that's very difficult to compress in the general sense of what compressed means. So maybe as we get better
and better machine learning methods that automatically figure out, analyze the data to understand how to compress it, just you'll be able to discover data for some reason is not compressible. But then, you know, compression really is a bottomless pit because like, that's really what intelligence is, is being able to compress information.

Yeah. And to some degree, the more you, I would imagine, I don't work in compression algorithms, but I would imagine the more you compress your signal, the, the more assumptions that kind of go on behalf of the decoder, the more skilled they really have to be, you know, some of the the prime number sequences completely unencoded information, essentially. But if you look at the Aracibo message, they were fairly careful with their pixelation of the simple image they sent to try and make it as interpretable as possible to be that even a dumb alien would be able to figure out what we're trying to show them here, because there's all sorts of conventions and rules that are built in that we, we tend to presume when we design our messages. And so, if you're messages, assuming they know how to do an MP3 decoder, particularly the compression algorithm, I'm sure they could eventually reverse engineer it and figure it out, but you're, you're making it harder for them to get to that point. So maybe I always think, you know, you probably would have a two tier system, right? You probably have some lower tier key system. And then maybe beneath that, you'd have a deeper compressed layer of more in-depth information.

What about maybe observing physical actual physical objects? So first, let me go to your tweet as a source of inspiration. You tweeted that it's interesting to ponder that if or clouds are ever mined by the systems of alien civilizations, mining equipment from billions of years ago could be in our or cloud, since the or clouds are, they, they, they extend really, really, really, really far outside the, the, the actual star that, so, you know, mining equipment, just

like basic boring mining equipment out there. I don't know if there's something interesting to say about or clouds themselves that they're interesting to you and about possible non-shiny light emitting mining equipment from alien civilizations. Yeah. I mean, that's what, I mean, that's kind of the beauty of the field of techno signatures and looking for life is you can find inspiration and intellectual joy in just the smallest little thing that starts a whole thread of building upon it and wondering about the implications. And so in this case, I was just really struck by, we couldn't mention this a little bit earlier, the idea that stars are not static. We tend to think of the galaxy as having stars in a certain location from the center of the galaxy and they kind of live there. But in truth, the stars are not only orbiting around the center of the galaxy, but those orbits are themselves changing over time, they're processing. And so in fact, the orbits look more like a spirograph if you've ever done those as a kid, they kind of whirl around and trace that all sorts of strange patterns. And so the stars intersect with one another. And so the current closest star to us is Proxima Centauri, which is about 4.2 light years away, but it will not always be the closest star. And over millions of years, it will be supplanted by other stars. In fact, stars will come even closer than Proxima within just a couple of light years. And that's been happening, not just we can project that will happen over the next few million years, but that's been happening presumably throughout the entire history of the galaxy for billions of years. And so if you went back in time, it would have been all sorts of different nearest stars, different stages of the Earth's history.
And those stars are so close that their alt clouds do intermix with one another. So the alt cloud can extend out to even a light year or two around the Earth. There's some debate about exactly where it ends. It probably doesn't really have a definitive end, but kind of more just kind of peters out more and more and more as you go further away.
By the way, for people who don't know an alt cloud, I don't know what the technical definition is, but a bunch of rocks that kind of know objects that orbit the star. And they can extend really really far because of ground. So these are objects that probably are mostly icy rich.
They were probably formed fairly similar distances to Jupiter and Saturn, but were scattered out through the interactions of those giant planets. We see a circular disk of objects around us, which kind of looks like the asteroid belt, but just further away called the Kuiper Belt.
And then further beyond that, you get the alt cloud. And the alt cloud is not on a disk, it's just a sphere. It kind of surrounds us in all directions. So these are objects that were scattered out through three dimensionally in all different directions. And so those objects are potentially resources for us, especially if you were planning to do an interstellar mission one day, you might want to mine the water that's embedded within those and use that as either oxygen or fuel for your rocket. And so it's quite possible. There's also some rare earth metals and things like that as well. But it's quite possible that a civilization might use alt cloud objects as a jumping off point. Or in the Kuiper Belt, you have things like Planet 9 evens.
There might even be objects beyond in the alt cloud, which are actually planet-like that we just cannot detect. These objects are very, very faint. So that's why they're so hard to see.
I mean, even Planet 9, it's hypothesized to exist, but we've not been able to confirm its existence because it's at something like a thousand a year away from us, a thousand times the distance of the earth from the sun. And so even though it's probably larger than the earth, the amount of light it reflects from the sun, the sun just looks like a star at that point so far away from it,

that it barely reflects anything back. It's extremely difficult to detect.
So there's all sorts of wonders that may be lurking out in the outer solar system.
And so this leads you to wonder, in the alt cloud, that alt cloud must have intermixed with other alt clouds in the past. And so what fraction of the alt cloud is truly belongs to us, belongs to what was scattered from Jupiter and Saturn. What fraction of it could in fact be interstellar visitors? And of course, we've got excited about this recently because of Oumuamua, this interstellar asteroid, which seemed to be at the time the first evidence of an interstellar object. But when you think about the alt cloud intermixing, it may be that a large fraction of comets, comets are seeded from the alt cloud that eventually come in.
And some of those comets may indeed have been interstellar in the first place that we just didn't know about through this process. There even is an example, I can't remember the name, there's an example of a comet that has a very peculiar spectral signature that has been hypothesized to have actually been an interstellar visitor, but one that was essentially sourced through this alt cloud mixing. And so this is kind of intriguing. It also, you know, the outer solar system is just such a, it's like the bottom of the ocean. We know so little about what's on the bottom of our own planet's ocean. And we know next to nothing about what's on the outskirts of our own solar system. It's all darkness. Yeah. So like, that's one of the things is to understand the phenomena, we need light. And we need to see how light interacts with it or what light emanates from it. But most of our universe is darkness. So it's, there could be a lot of interesting stuff. I mean, this is where your interest is with the cool world and the interesting stuff lurks in the darkness, right? Basically, all of us, you know, 400 years of astronomy, our only window into the universe has been light. And that has only changed quite recently with the discovery of gravitational waves. That's now a new window. And hopefully, well, to some degree, I guess, solar neutrinos, we've been detecting for a while, but they come from the sunlight interstellar space. But we may be able to soon detect neutrino messages has even been hypothesized as a way of communicating civilizations as well, or just do neutrino telescopes to the universe. And so there's a growing interest in what we'd call multi messenger astronomy now.
So not just messages from light, but messages from these other physical packets of information that are coming our way. But when it comes to the outer solar system, light really is our only window. There's two, there's two ways of doing that. One is you detect the light from the all cloud object itself, which, as I just said, is very, very difficult.
There's another trick, which we do in the Kuiper Belt, especially. And that's called an occultation. And so sometimes those objects will just pass in front of a distant star, just coincidentally, these are very, very brief moments, they last for less than a second.
And so you have to have a very fast camera to detect them, which conventionally, astronomers don't usually build fast cameras. Most of the phenomena we observe occurs on hours, minutes, days even. But now we're developing cameras which can take thousands of images per second, and yet do it at the astronomical fidelity that we need for this kind of precise measurement.
And so you can see these very fast dips, you even get these kind of diffraction patterns that come around, which are really cool to look at. And that's, I kind of love it because it's almost like passive radar. You have these pinpricks of light. Imagine that you live in a giant black sphere, but there's these little pinholes that have been poked. And through those pinholes, almost laser light is shining through. And inside this black sphere, there are unknown

things wandering around, drifting around that we are trying to discover. And sometimes they will pass in front of those little pencil thin laser beams, block something out. And so we can tell that it's there. And it's not an active radar, because we didn't actually, you know, beam anything out and get a reflection off, which is what the sun does, the sun's light comes off and it comes back. That's more like an active radar system. There's more like a passive radar system where we are just listening very intently. And so I'm kind of so fascinated by that, the idea that we could map out the rich architecture of the outer solar system, just by doing something that we could have done potentially for a long time, okay, which is just listening in the right way, just tuning our instrumentation to the correct way of not listening, but viewing the universe to catch those objects. Yeah, I mean, it's really fascinating. It seems almost obvious that your efforts, when projected out in over like 100 to 200 years, will have a really good map through even methods like basically transit timing, high resolution transit timing, but basically the planetary and the planet satellite movements of all the different star systems out there.
Yeah, and it could revolutionize the way we think about the solar system. I mean, that revolution has happened several times in the past when we discovered Vesta in the 19th century.
That was, I think, the seventh planet for a while or the eighth planet when it was first discovered. And then we discovered Ceres and there was a bunch of asteroid objects, Janus.
And so for a while, the textbooks had, there was something like 13 planets in the solar system.
And then that was just a new capability that was emerging to detect those small objects.
And then we ripped that up and said, no, no, we're going to change the definition of a planet.
And then the same thing happened when we started looking the outer skirts of the solar system.
Again, we found Ares, we found Sedna, these objects which resembled Pluto and more and more of them
we found, Makemake. And eventually, we again had to rethink the way we've contextualized what a planet is and what the nature of the outer solar system is. So regardless as to what you think about the debate about whether Pluto should be devoted or not, which I know often folks love strong feelings, it is an incredible achievement that we were able to transform our view of the solar system in a matter of years just by basically charged coupled devices, the things that's in cameras, though the invention of that device allowed us to detect objects which were much further away, much fainter and revealed all of this stuff that was there all along. And so that's the beauty of astronomy. There's just so much to discover and even in our own backyard.
Do you ever think about this? Do you imagine what are the things
that will completely change astronomy over the next 100 years? Like if you transport yourself forward 100 years, what are the things that will blow your mind when you look at what? Would it be just a very high resolution mapping of things like holy crap? Like one surprising thing might be holy crap, there's like earth-like moons everywhere. Another one could be just totally different devices for sensing. Yeah, I think usually astronomy moves forward dramatically and science in general, when you have a new technological capability come online for the first time. And we kind of just gave examples of that there with the solar system. So what kind of new capabilities might emerge in the next 100 years? The capability I would love to see is not just, I mean, in the next 10, 20 years, we're hoping to take these pale blue dot images we spoke about. So that requires building something like JWST but on even larger scale

and optimize for direct imaging and have to have either coronagraph or a star shade or something to block out the starlight and reveal those pale blue dots. So in the next sort of decades, I think that's the achievement that we can look forward to in our lifetimes is to see photos of other earths. Going beyond that, maybe in our lifetimes towards the end of our lifetimes, perhaps I'd love it if we, I think it's technically possible as Breakthrough Starshot giving us a lot of encouragement with to maybe send a small probe to the nearest stars and start actually taking high resolution images of these objects. There's only so much you can do from far away if you want to have, and we can see it in the solar system. I mean, there's only so much you can learn about Europa by pointing Hubble Space Telescope at it. But if you really want to understand that moon, you're going to have to send something to orbit it to hopefully land on it and drill down to the surface. And so the idea of even taking a flyby and doing a snapshot photo that gets beamed back, that could be, doesn't even have to be more than 100 pixels by 100 pixels, that even that would be a completely game changing capability to be able to truly image these objects. And maybe at home in our own solar system, we can certainly get to a point where we produce crewed maps of exoplanets. One of the ultimate limit of what a telescope could do is governed by its size. And so the largest telescope you could probably ever build would be one that was the size of the Sun. There's a clever trick for doing this without physically building a telescope that's the size of the Sun, and that's to use the Sun as a gravitational lens. This was proposed, I think, by Van Eschleman in 1979, but it builds upon Einstein's theory of generativity, of course, that there is a warping of light, a bending of light from the Sun's gravitational field. And so a distant starlight, it's like a magnifying glass. Anything that bends light is basically can be used as a telescope. It's going to bend light to a point. Now, it turns out the Sun's gravity is not strong enough to create a particularly great telescope here, because the focus point is really out in the Kuiper Belt. It's at 550 astronomical units away from the Earth. So 550 times further away from the Sun than we are, and that's beyond any of our spacecraft I've ever gone. So you have to send a spacecraft to that distance, which would take 30, 40 years, even optimistically improving our chemical propulsion system significantly. You'd have to bound it into that orbit, but then you could use the entire Sun as your telescope. And with that kind of capability, you could image planets to kilometer scale resolution
from afar. And that really makes you wonder. I mean, if we can conceive, maybe we can't engineer it,
but if we can conceive of such a device, what might other civilizations be currently observing about our own planet? And perhaps that is why nobody is visiting us, because there is so much you can do from afar, that to them, that's enough. Maybe they can get to the point where they can set our radio leakage, they can trip to our terrestrial television signals, they can map out our surfaces, they can tell we have cities, they can even do infrared mapping of the heat island effects and all this kind of stuff, they can tell the chemical composition of our planet. And so that might be enough. Maybe they don't need to come down to the surface and study anthropology and see what our civilization is like. But there's certainly a huge amount you can do, which is significantly cheaper to some degree than flying there, just by exploiting cleverly the physics of the universe itself. So your intuition is, that's very well made be true, that observation might be way easier than travel. From our perspective, from an alien

perspective, we could get very high resolution imaging before we could ever get there.
It depends on what information you want. If you want to know the chemical composition and you want to know kilometers of scale maps of the planet, then you could do that from afar with some version of these kind of gravitational lenses. If you want to do better than that, if you want to image a newspaper selling the porch of somebody's house, you're going to have to fly there. There's no way that unless you had a tusk at the size of such a star or something, you just simply cannot collect enough light to do that from many light years away. So there is certainly reasons why visiting will always have its place, depending on what kind of information you want. We've proposed in my team, actually, that the Sun is the ultimate pinnacle of telescope design, but flying to a thousand AU is a real pain in the butt because it's just going to take so long. And so a more practical way of achieving this might be to use the Earth. Now, the Earth doesn't have anywhere near enough gravity to create a substantial gravitational lens, but it has an atmosphere, and that atmosphere refracts light, it bends light. So whenever you see a sunset, just as the Sun is setting below the horizon, it's actually already beneath the horizon. It's just the light is bending through the atmosphere. It's actually already about half a degree down beneath. And what you're seeing is that curvature of the light path. And your brain interprets, of course, if you're following a straight line, because your brain always thinks that. And so you can use that bending. Whenever you have bending,
you have a telescope. And so we've proposed in my team that you could use this refraction to similarly create an Earth-sized telescope called the telescope.
The telescope. You have a great video on this.
And do you have a paper on the telescope? I do. Yeah, great. Sometimes get confused this because they've heard of an Earth-sized telescope because they may have heard of the Event Horizon
telescope, which took an image of, well, it's taking an image right now of the center of our black hole. And it's very impressive. And it previously did Messier 87, a nearby supermassive black hole. And so those images were interferometric. So they were small telescopes scattered across the Earth. And they combined the light paths together interferometrically to create effectively an Earth-sized angular resolution. Telescopes always have two properties. There's the angular resolution, which is how small of a thing you can see on the surface. And then there's the magnification. How much brighter does that object get versus just your eye or some small object? Now, what the Event Horizon telescope did, it traded off amplification or magnification for the angular resolution. That's what it wanted. It wanted that high angular resolution, but doesn't really have much photon collecting power because each telescope individually is very small. The telescope is different because it is literally collecting light with a light bucket, which is essentially the size of the Earth. And so that gives you both benefits, potentially. Not only the high angular resolution that a large aperture promises you, but also actually physically collects all those photons so you can detect light from very, very far away, throw it out to edges of the universe. And so we propose this as a possible future technological way of achieving these extreme goals, ambitious goals we have in astronomy.
But it's a very difficult system to test because you essentially have to fly out to these focus points and these focus points lie beyond the moon. So you have to have someone who is willing to fly

beyond the moon and hitchhike an experimental telescope onto it and do that cheaply. If it was something doing low Earth orbit, it'd be easy. You could just attach a CubeSat to the next Falcon 9 rocket or something and test it out. It'd probably only cost you a few tens of thousands dollars, maybe hundreds of thousands of dollars. But there's basically no one who flies out that far, except for bespoke missions such as like a mission that's going to Mars or something that would pass
through that kind of space. And they typically don't have a lot of leeway and excess payload that they're willing to strap on for radical experiments. So that's been the problem with it. In theory, it should work beautifully, but it's a very difficult idea to experimentally test.
Can you elaborate where the focal point is that far away?
So you get about half a degree bend from the Earth's atmosphere when you're looking at the Sun at the horizon. And you get that two times over if you're outside of the planet's atmosphere because the star is half a bend to you still in the horizon, then half a degree back out the other way. So you get about a one degree bend. You take the rays of the Earth, which is about 7,000 kilometers, and do your arc tan function. You'll end up with a distance that's about, it's actually the inner focal point, it's about two thirds the distance of the Earth-Moon system. The problem with that inner focal point is not useful because that light ray path had to basically scrape the surface of the Earth. So it passes through the clouds, it passes through all the thick atmosphere, it gets a lot of extinction along the way. If you go higher up in altitude, you get less extinction. In fact, you can even go above the clouds. And so that's even better because the clouds obviously are going to be a pain in the neck for doing anything optical. But the problem with that is that the atmosphere, because it gets thinner at higher altitude, it bends light less. And so that pushes the focal point out. So the most useful focal point is actually about three or four times the distance of the Earth-Moon separation. And so that's what we call one of the Lagrange points, essentially. And so there was a stable orbit. It's kind of the outermost stable orbit you could have around the Earth. So the atmosphere does bad things to the signal. Yeah, it's absorbing light. Is that possible to reconstruct, to remove the noise, whatever it is? So it's just strength. It's not nothing else. It's possible to reconstruct. I mean, to some degree, we do this as a technology called adaptive optics that can correct for what's called wavefront errors that happen through the Earth's atmosphere. The Earth's atmosphere is turbulent. It is not a single plane of air of the same density. There's all kind of wiggles and currents in the air. And so that each little layer is bending light in slightly different ways. And so the light actually kind of follows a wiggly path on its way down. What that means is that two light rays, which are traveling at slightly different spatial separations from each other, will arrive at the detector at different times. Because one maybe goes on more or less a straight path, and the one wiggles down a bit more before it arrives. And so you have an incoherent light source. And when you're trying to image reconstruction, you always want an incoherent light source. So the way they correct for this is that if this path had to travel a little bit faster, the straight one goes faster and the wiggly one takes longer, the mirror is deformable. And so you actually bend the mirror on the straight one down a little bit to make it an equivalent light path distance. So the mirror itself has all these little actuators. It's actually made up of like thousands of little elements. Almost looks like a liquid mirror, because they can manipulate it in kind of real time. And so they scan the atmosphere with a laser beam to tell what the

deformations are in the atmosphere, and then make the corrections to the mirror to account for it.
That's amazing.
So you could, you could do something like this for the telescope, but it would be
it's cheaper and easier to go above the atmosphere and just fly out.
I think so. It would be very, it's a very, that's a very challenging thing to do. And normally when you do adaptive optics, as it's called, you're looking straight up. So you're very close to straight up. If you look at the horizon, we basically never do astronomical observations on the horizon, because you're looking through more atmosphere. If you go straight up, you're looking at the thinnest portion of atmosphere possible. But as you go closer and closer towards the horizon, you're increasing what we call the air mass, the amount of air you have to travel through.
So here it's kind of the worst case because you're going through the entire atmosphere in and out again with a telescope. So you'd need a very impressive adaptive optic system to correct for that. So yeah, I would say it's probably simpler, at least for proof of principle, just to test it with having some satellite that was at a much wider orbit.
Now, speaking of traveling out into deep space, you already mentioned this a little bit.
You made a beautiful video called the journey to the end of the universe.
And sort of at the start of that, you're talking about office and tarry. So what would it take for humans or for human-like creatures to travel out to office and tarry?
There's a few different ways of doing it, I suppose. One is, it depends on how fast your ship is, that's always going to be the determining factor. If we devised some interstellar propulsion system that could travel a fraction of the speed of light, then we could do it in our lifetimes, which is, I think, what people normally dream of when they think about interstellar propulsion and travel, that you could literally step onto the spacecraft, maybe a few years later you step off an Alpha Centauri B, you walk around the surface and come back and visit your family. There would be, of course, a lot of relativistic time dilation as a result of that trip. You would have aged a lot less than people back on Earth by traveling close to the speed of light for some fraction of time. The challenge of this, of course, is that we have no such propulsion system that can achieve this. But do you think it's possible? You have a paper called The Halo Drive, fuel-free relativistic propulsion of large masses via recycled boomerang photons.
Do you think, first of all, what is that? And second of all,
how difficult are alternate propulsion systems?
Yeah. Before I took in The Halo Drive, there was an idea, because I think The Halo Drive is not going to solve this problem. I'll talk about The Halo Drive in a moment, but The Halo Drive is useful for a civilization, which is a bit more advanced than it has spread across the stars, and it's looking for a cheap highway system to get across the galaxy. For that first step, because just to context that, The Halo Drive requires a black hole, so that's why you're not going to be able to do this on the Earth right now. But there are lots of black holes in the Milky Way, so that's the good news. So we'll come to that in a moment. But if you're trying to travel to Alpha Centauri without a black hole, then there are some ideas out there. There was a Project Daedalus and Project Icarus that were two products that the British Interplanetary Society conjured up on sort of a 20, 30-year timescale, and they asked themselves if we took existing and speculatively but realistic attempts at future technology that are emerging

over the next few decades. How far could we push into that travel system? And they settled on fusion drives in that. So if we had the ability to essentially either detonate, you can always imagine that kind of nuclear fission or nuclear fusion bombs going off behind the spacecraft and propelling it that way, or having some kind of successful nuclear fusion reaction, which obviously we haven't really demonstrated yet as a propulsion system, then you could achieve something
like 10% the speed of light in those systems. But these are huge spacecrafts. And I think you need a huge spacecraft if you're going to take people along. The conversation recently has actually switched, and that idea seems a little bit antiquated now. And most of us have given up an idea of people physically, biologically, stepping on board the spacecraft. And maybe we'll be sending something that's more like a micro probe that maybe just weighs a gram or two. And that's much easier to accelerate. You could push that with a laser system to very high speed, get it to maybe 20% the speed of light. It has to survive the journey, probably a large fraction of them won't survive the journey, but they're cheap enough that you could maybe manufacture millions of them. And some of them do arrive and able to send back an image or maybe even if you wanted to have a person there, we might have some way of doing like a telepresence or some kind of delayed telepresence or some kind of reconstruction of the planet which is sent back so you can digitally interact with that environment in a way which is not real time, but representative of what that planet would be like to be on the surface. So we might be more like digital visitors to these planets, certainly far easier practically to do that than physically forcing this wet chunk of meat to fly years across space to do that. And so that's maybe something we can imagine down the road. The halo drive, as I said, is thinking even further ahead. And if you did want to launch large masses, large masses could even be planet sized things. In the case of the halo drive, you can use black holes. So this is kind of a trick of physics. I often think of the universe as like a big computer game. And you're trying to find cheat codes, hacks, exploits that the universe didn't intend for you to use. But once you find them, you can address all sorts of interesting capabilities that you didn't previously have. And the halo drive does that with black holes. So if you have two black holes, which are very common situation, a binary black hole, and they're inspiring towards each other, LIGO is detected, I think dozens of these things, maybe in over 100 at this point. And these things as they merge together, the pre-merger phase, they're orbiting each other very, very fast, even close to the speed of light. And so Freeman Dyson, before he passed away, I think in the 70s, he had this provocative paper called gravitational machines. And he suggested that you could use neutron stars as a interstellar propulsion system. And neutron stars are sort of the lower mass version of a binary black hole system, essentially. In this case, he suggested just doing gravitational slingshot, just fly your spacecraft into this very compact and relativistic binary system. And you do need neutron stars because if there were two stars, they'd be physically touching each other. So the neutron stars are so small, like 10 kilometers across, they can get really close to each other and have these very, very fast orbits with respect to each other. You shoot your spacecraft through, right through the middle light, flying through the eye of a needle, and you do a slingshot around one of them. And you do it around the one that's coming sort of towards you. So one of them be coming away, one of them be coming towards you at any one point. And then you could basically steal some of the kinetic energy in the slingshot. In principle, you can sell up to twice the speed.

You can take your speed, and it becomes your speed plus twice the speed of the black of the neutron star in this case. And that would be your new speed after the slingshot. This seems great because it's just free energy, basically. You're not doing any, you know, you're not generally to have a nuclear power reactor or anything to generate this, you're just stealing it. And indeed, you can get to relativistic speeds this way. So I loved that paper, but I had a criticism. And the criticism was that this is like trying to fly your ship into a blender, right? This is two neutron stars, which have huge tidal forces. And they're whipping around each other once every second or even less than a second. And you're trying to fly your spaceship and do this maneuver that is pretty precarious. And so it just didn't seem practical to me to do this. I loved it. And so I took that idea, and this is how science is, it's iterative. It's you take a previous great man's idea, and you just sort of maybe slightly tweak and improve it. That's how I see the Hello Drive. And I just suggested why not replace those out for black holes, which is certainly very common. And rather than flying your ship into that, that hellhole of a blender system, you just stand back and you fire a laser beam. Now, because black holes have such intense gravitational fields, they can bend light into complete 180s, they can actually become mirrors. So, you know, the sun bends light by maybe a fraction of a degree through gravitational lensing, but a compact object like a black hole can do a full 180. In fact, if you obviously, if you went too close, if you put the laser beam too close, the black hole will just fall into it and never come back out. So you just kind of push it out, push it out, push it out until you get to a point where it's just skirting the event horizon. And then that laser beam skirts around and it comes back. Now, the laser beam wants to do a grav, I mean, it is doing a gravitational slingshot. But laser, I mean, light photons can't speed up unlike, unlike the spaceship case. So instead of speeding up, the way they steal energy is they, they increase their frequency. So they become higher energy photon packets, essentially, they get blue shifted. So that you send maybe a red laser beam that comes back blue, it's got more energy in it. And because photons carry momentum, which is somewhat unintuitive in everyday experience, but they do, that's how solar sails work, they carry momentum, they push things. You can even use them as laser tweezers and things to pick things up. Because they push, it comes back with more momentum than it left. So you get an acceleration force from this. And again, you're just seeing energy from the black hole to do that. So you can get up to the same speed. It's basically the same idea as Freeman Dyson, but doing it from a safer distance. And there should be a order of, you know, a million or so or 10 million black holes in the Milky Way galaxy. Some of them would be even as close as sort of 10 to 20 light years when you do the occurrence rate statistics of how close you might expect feasibly one to be. They're, of course, difficult to detect because they're black. So they're inherently hard to see. But statistically, there should be plenty out there in the Milky Way. And so these objects would be natural waypoint stations. You could use them to both accelerate away and to break and slow down. And on top of all this, you know, there's, we've been talking about astronomy and cosmology. There's been a lot of exciting breakthroughs in detection and exploration of black holes. So the boomerang, boomeranging photons that you're talking about, there's been a lot of work on photon rings and just all the fun stuff going on outside the black holes. So all the garbage outside is actually might be the thing that holds a key to understanding what's going on inside. And there's the Hawking radiation. There's all kinds of fascinating stuff. Like,

I mean, there's trippy stuff about black holes that I can't even, most people don't understand. I mean, the holographic principle with the plate and the information being stored potentially outside of the black hole, I don't even, I can't even comprehend how you can project a three-dimensional object onto a 2D and somehow store information where it doesn't destroy it. And if it does destroy it, challenging all the physics, all of this is very interesting, especially for kind of more practical applications of how the black hole can be used for propulsion. Yeah. I mean, it may be that black holes are used in all sorts of ways by advanced civilizations. I think, again, it's been a popular idea in science fiction or science fiction tropes that Sagittarius A star, the supermassive black hole in the center of our galaxy could be the best place to look for intelligent life in the universe because it is a giant engine in a way. You know, a unique capability for black holes is you can basically throw matter into it and you can get these jets that come out of the accretion disks and the jets that fly out. And so you can more or less use them to convert matter into energy v equals mc squared. And there's
pretty much nothing else except for, you know, annihilation with its own antiparticle as a way of doing that. So they have some unique properties. You could perhaps power a civilization by just throwing garbage into a black hole, right? Just throwing asteroids in and power your civilization with as much energy as you really would ever plausibly need. And you could also use them to accelerate the way across the universe. And you can even imagine using small artificial black holes as thermal generators, right? So the Hawking radiation from them kind of exponentially increases as they get smaller and smaller in size. And so a very small black hole one that you can almost imagine like holding in your hand would be a fairly significant heat source. And so that raises all sorts of prospects about how you might use that in an engineering context to power your civilization as well. You have a video on becoming a Kardashev type one civilization. What's our hope for doing that? Or a few orders of magnitude away from that? Yeah, it is surprising. I think people tend to think that we're close to this scale that the Kardashev type one is defined as a civilization which is using as much energy as is essentially incident upon the planet from the star. So that's the order, I think, for the earth of something like 10 to the 5terros or 10 to the 7terros is a gigantic amount of energy. And we're using a tiny, tiny, tiny fraction of that right now. So if you became a Kardashev type one civilization, which is seen not necessarily as a goal into itself, I think people think, well, why are we aspiring to become this energy hungry civilization? Surely our energy needs might improve our efficiency or something as time goes on. But ultimately, the more energy you have access to, the greater your capabilities will be. I mean, if you want to lift Mount Everest into space, there is just a calculable amount of potential energy change that that's going to take in order to accomplish that. And the more energy you have access to as a civilization, then clearly the easier that energy achievement is going to be. So it depends on what your aspirations are as a civilization. It might not be something we want to ever do. But we should make clear that lifting heavy things isn't the only thing, it's just doing work. So it could be computation. It could be more and more and more and more sophisticated and larger and larger and larger computation, which is it does seem where we're headed with a very fast increase in the scale and the quality of our computation outside the human brain, artificial computation. I mean, computation is a great example of, I mean, already I think some like 10% of US power electricity use is going towards the supercomputing

centers. So there's a vast amount of current energy needs, which are already going towards computing surely only increase over time. If we start ever doing anything like mind uploading or creating simulated realities, that cost will surely become a dominant source of our energy requirements at that point, if civilization completely moves over to this kind of post-humanism stage. And so it's not unreasonable that our energy needs would continue to grow. Certainly historically, they always have at about 2% per year. And so if that continues, there is going to be a certain point where you're running up against the amount of energy which you can harvest, because you're using even if you cover the entire plant and solar panels, there's no more energy to be had. And so this is a, you know, there's a few ways of achieving this. I sort of talked about in the video how there were several renewable energy sources that we're excited about, like geothermal wind power waves, but pretty much all of those don't really scratch the surface or don't really scratch the itch of getting to a Kardashev type one civilization. They're meaningful now, I would never tell anybody don't do wind power now, because it's it's it's clearly used for our current stage of civilization. But it's not, it's going to be a pretty negligible fraction of our energy requirements if we got to that stage of development. And so there has to be a breakthrough in either our ability to harvest solar energy, which would require maybe something like a space array of solar panels of beaming the energy back down, or some developments and innovations in nuclear fusion that would allow us to essentially reproduce the same process of what's producing the solar photons, but here on Earth. But even that comes with some consequences. If you're generating the energy here on Earth, and you're doing work on it on Earth, then that work is going to produce waste heat. And that waste heat is going to increase the ambient temperature of the planet. And so whether even if this isn't really a greenhouse effect that you're increasing the temperature of the planet, this is just the amount of computers that are churning the hand to a computer, you can feel the warmth coming off them. If you do that much work of literally, you know, the entire instant energy of the planet is doing that work. The planet is going to warm up significantly
as a result of that. And so, you know, that clearly indicates that this is not a sustainable path, that civilizations as they approach Kardashev type one are going to have to leave planet Earth, which is really the point of that video to show that it's a Kardashev type one civilization, even though it's defined as instant energy upon a planet, that is not a species that is going to still be living on their planet, at least in isolation, they will have to be harvesting energy from afar, they will have to be you doing work on that energy outside of their planet, because otherwise you're going to dramatically change the environment in which you live.
Well, yeah, so the more energy you create, the more energy you use, the higher the imperative to expand out into the universe, but also not just the imperative, but the capabilities. And you've kind of, as a side on your lab page mentioned that you're sometimes interested in astroengineering. So what kind of space architectures do you think we can build to house humans or interesting things outside of Earth?
Yeah, I mean, there's a lot of fun ideas here. One of the classic ideas is an Oenil cylinder or a Stanford torus. These are like two rotating structures that were devised in space. They're basically using the centrifugal force as artificial gravity. And so these are structures which tend to be many kilometers across that you're building in space, but could potentially habitat millions of people in orbit of the Earth. Of course, you could imagine pulling them, if the expanse does

a pretty good job, I think of exploring the idea of human exploration of the solar system and having many objects, many of the small near Earth objects and asteroids inhabited by mining colonies. One of the ideas we've played around with our group is this technology called a quasite. A quasite is an extension. Again, we always tend to extend previous ideas. Ideas build upon ideas. An extension idea called a statite. A statite was an idea proposed, I think, by Ron forward in the 1970s. 1970s seemed to have all sorts of wacky ideas. I don't know what was going on then. We had the Stanford torus, the Oenil cylinder, statites, the gravitational lens. People were really having fun dreaming about space in the 70s. The statite is basically a solar sail, but it's such an efficient solar sail that the outward force of radiation pressure equals the inward force of gravity from the sun. It doesn't need to orbit. The sun is pulling us right now through force of gravity, but we are not getting closer towards the sun, even though we are falling towards the sun because we're in orbit, which means our translational speed is just enough to keep us at the same altitude, essentially, from the sun. You're in orbit, and that's how you maintain distance. A statite doesn't need to do that. It could be basically completely static in inertial space, but it's just balancing the two forces of radiation pressure and inward gravitational pressure. Aquazite is the in-between of those two states. It has some significant outward pressure, but not enough to resist fully falling into the star. It compensates for that by having some translational motion. It's in-between an orbit and a statite. What that allows you to do is maintain artificial orbits. Normally, if you want to calculate your orbital speed of something that's, say, half an AU, you'd use Kepler's third law and go through that, and you'd say, okay, if it's half an AU, I can calculate the period by p squared is proportional to a cubed and go through that. For an aquazite, you can basically have any speed you want. It's just a matter of how much of the gravitational force you're balancing out. You effectively enter an orbit where you're making the mass of the star be less massive than it really is. It's as if you're orbiting a 0.1 solar mass star or a 0.2 solar mass star, whatever you want. That means that mercury orbits with a pretty fast orbital speed around the sun because it's closer to the sun than we are, but we could put something in Mercury's orbit that would have a slower speed and so it would co-track with the Earth. We would always be aligned with them at all times. This could be useful if you wanted to have either a chain of colonies or something that were able to easily communicate and move between one another, between these different bases. You'd probably use something like this to maintain that easy transferability, or you could even use it as a space where the monitoring system which we'll actually propose in the paper. We know that major events like the Carrington event that happen can knock out all of our electromagnetic systems quite easily. A major solar flare could do that, a geomagnetic storm, but if we had the ability to detect those higher elevated activity cycles in advance, the problem is they travel obviously pretty fast and so it's hard to get ahead of them, but you could have a station which is basically sampling solar flares very close to the surface of the Earth and as soon as it detects anything suspicious, magnetically, it could then send that information straight back at the speed of light to your Earth and give you maybe a half an hour warning or something bad was coming. You should shut off all your systems or get in your Faraday cage now and protect yourself. These quads are kind of a cool trick of, again, hacking the laws of physics. It's like another one of these exploits that the universe seems to allow us to do to potentially manifest these artificial systems that would otherwise be difficult to produce. So leveraging natural phenomena. Yeah. That's always the key.

My mind is to work with nature. That's how I see astroengineering rather than against it. You're not trying to force it to do something. That's why you always think solar energy is so powerful because in the battle against nuclear fusion, nuclear fusion, you're really fighting a battle where you're trying to confine plasma into this extremely tight space. The sun does this for free. It has gravitation. That's in essence what a solar panel does. It is a nuclear fusion reactor fueled energy system, but it's just using gravitation for the confinement and having a huge standoff distance for its energy collection. There are tricks like that. It's a very naive, simple trick in that case where we can rather than having to reinvent the wheel, we can use the space infrastructure if you like, the astrophysical infrastructure that's already there to our benefit. Yeah. I think in the long arc of human history, probably natural phenomena is the right solution. That's the simple, that's the elegant solution because all the power is already there. That's why a distance sphere in the long, you don't know what a distance sphere would look like, but some kind of thing that leverages the power, the energy that's already in the sun is better than creating artificial and nuclear fusion reaction. Then again, that brings us to the topic of AI. How much of this, if we're traveling out there, interested out of travel or doing some of the interesting things we'll be talking about, how much of those ships would be occupied by AI systems, do you think?
What would be the living organisms occupying those ships?
Yeah. It's depressing to think about AI in the search for life because
I've been thinking about this a lot over the last few weeks with playing around with chat GPT-3 like many of us and being astonished with its capabilities. You see that our society is undergoing a change that seems significant in terms of the development of artificial talent. We've been promised this revolution, this singularity for a long time, but it really seems to be stepping up its pace of development at this point. That's interesting because as someone who looks fairly in life out there in the universe, it implies that our current stage of development is highly transitional. You go back for the last four and a half billion years, the planet was dumb essentially. If you go back a few thousand years, there was a civilization, but it wasn't really producing any technosignatures. Then over the last maybe 100 years, there's been something that might be detectable from afar. We're approaching this cusp where we might imagine it. We're thinking of maybe years and decades with AI development, typically when we talk about this, but as an astronomer, I have to think about much longer timescales of centuries, millennia, millions of years. If this wave continues over that time scale, which is still the blink of an eye on a cosmic time scale, that implies that everything will be AI essentially out there if this is a common behavior. That's intriguing because it implies that we are special in terms of our moment in time as a civilization, which normally is something we're averse to as astronomers. We normally like this mediocrity principle. We're not special. We're a typical part of the universe. Sometimes we have the cosmological principle, but in a temporal sense, we may be in a unique location. Perhaps that is part of the solution to the Fermi paradox, in fact, that if it is true that planets tend to go through basically three phases, dumb life for the vast majority, a brief period of biological intelligence, and then an extended period of artificial intelligence that they'd transition to, then we would be at a unique and special moment in galactic history that would be of particular interest for any anthropologists out there in the galaxy. This would be the time that you would want

to study a civilization very carefully. You wouldn't want to interfere with it. You would just want to see how it plays out, similar to the ancestor simulations that sometimes talk about the simulation argument, that you are able to observe perhaps your own origins and study how the transformation happens. That has for me recently been throwing the Fermi paradox a bit on its head, and this idea of the Zoo hypothesis that we may be monitored, which has for a long time been seen as a fringe idea even amongst the SETI community, but if we live in this truly transitional period, it adds a lot of impetus to that idea, I think. Even AI itself, by its very nature, would be observing us. There used to be this concept of human computation, which is actually exactly what's feeding the current language models, which is leveraging all the busy stuff we're doing to do the hard work of learning. The language models are trained on human interaction and human language on the internet. AI feeds on the output of brain power from humans.
It would be observing and observing, and it gets stronger as it observes, so it actually gets extremely good at observing humans. One of the interesting philosophical questions that starts percolating is, what is the interesting thing that makes us human? We tend to think of it, and you say there's three phases. What's the thing that's hard to come by in phase three?
Is it something like scarcity, which is limited resources? Is it something like consciousness?
Is that the thing that emerged the evolutionary process in biological systems that are happening under constrained resources? This thing that feels like something to experience the world, which we think of as consciousness, is that really difficult to replicate in artificial systems? Is that the thing that makes us fundamentally human, or is it just the side effect that we attribute way too much importance to? Do you have a sense?
If you look on into the future, and AI systems are the ones that are traveling out there, to office and Tori and beyond, do you think they have to carry the flame of consciousness with them?
No, not necessarily. They may do, but it may not be necessarily... I guess we're talking about the difference here between sort of an AGI, artificial general intelligence or consciousness, which are distinct ideas, and you can certainly have one without the other. So I could imagine...
Yeah, I would disagree with this certainly in that statement.
Okay. I think it's very possible in order to have intelligence, you have to have consciousness.
Okay. Well, I mean, to a certain degree,
GBT-3 has a level of intelligence already. It's not general intelligence, but it displays properties of intelligence with no consciousness.
Again, I would disagree.
Okay. Well, I don't know.
Because you said, it's very nice, you said it displays properties of intelligence.
In the same way it displays properties of intelligence, I would say it's starting to display properties of consciousness. It certainly could fool you that it's conscious.
Correct. Yeah. So there's, I guess, like a chewing test problem. If it's displaying all those properties, if it cracks like a parrot, it looks like a parrot, or cracks like a duck, things like... Isn't it basically a duck at that point?
So yeah, I can see that argument. It probably, I mean, certainly, I tried to think about it from the observer's point of view as an astronomer. What am I looking for?
Whether that intelligence is conscious or not has little bearing, I think, as to what I should be looking for when I'm trying to detect evidence of them.

It would maybe affect their behavior in ways that I can't predict. But that's, again,
getting into the game of what I would call xenopsychology of trying to make projections
about the motivations of an alien species is incredibly difficult.
And similarly, for any kind of artificial intelligence, it's unfathomable what its
intentions may be. I mean, I would sort of question whether it would even be interested
in traveling between the stars at all. If its primary goal is computation,
computation for the sake of computation, then it's probably going to have a different
way of... It's going to be engineering its solar system and the nearby material around it
for a different goal if it's just simply trying to increase computer substrate across the universe.
And that, of course, if that is its principal intention to just essentially convert dumb
matter into smart matter as it goes, then I think that would come into conflict with our
observations of the universe, because the Earth shouldn't be here if that were true.
The Earth should have been transformed into computer substrate by this point. There has been
plenty of time in the history of the galaxy for that to have happened. So I'm skeptical that we
can... I'm skeptical in the part that that's a behavior that AI or any civilization really
engages in, but I also find it difficult to find a way out of it to explain why that would never
happen in the entire history of the galaxy amongst potentially if life is common, millions,
maybe even billions of instant instantiations of AI could have occurred across the galaxy.
And so that seems to be a knock against the idea that there is life else or intelligent
life elsewhere in the galaxy. The fact that that hasn't occurred in our history is maybe
the only solid data point we really have about the activities of other civilizations.
Of course, the scary one could be that we just at this stage intelligent alien civilizations just start
destroying themselves. It becomes too powerful. Everything's just too many weapons, too many
nuclear weapons, too many nuclear weapons style systems that just from mistake to aggression to
like the probability of self-destruction is too high relative to the challenge of avoiding the
technological
challenges of avoiding self-destruction. You mean that the AI destroys itself or we destroy ourselves
prior to the advent of AI?
As we get smarter and smarter AI, either AI destroys us or other, there could be just a million, like
AI is correlated, the development of AI is correlated with all this other technological innovation,
genetic engineering, like all kinds of engineering at the nano scale,
mass manufacture of things that could destroy us or cracking physics enough to have very powerful
weapons, nuclear weapons, all of it. Just too much physics enables way too many things that can
destroy us before it enables the propulsion systems that allow us to fly far enough away before we
destroy ourselves.
So maybe that's what happens to the other alien civilizations. Is that your resolution? Because I
mean, I think us in the technosignature community and the astronomy community aren't thinking
about this problem seriously enough, in my opinion. We should be thinking about what AI is doing to
our society and the implications of what we're looking for.
And so I think part of this thinking has to involve people like yourself who are more intimate with the
machine learning and artificial intelligence world. How do you reconcile, in your mind, you said
earlier that you think you can't imagine a galaxy where life and intelligence is not all over the place?
And if artificial intelligence is a natural progression for civilizations, how do you reconcile that with

the absence of any information around us? So any clues or hints of artificial behavior, artificially engineered stars, or colonization, computer substrate, transform planets, anything like that?
It's extremely difficult for me. The Fermi paradox broadly defined is extremely difficult for me. And the terrifying thing is, one thing I suspect is that we keep destroying ourselves. The probability of self-destruction with advanced technology is just extremely high.
That's why we're not seeing it. But then again, my intuition about why we haven't blown ourselves up with nuclear weapons, it's very surprising to me from a scientific perspective.
Given all the cruelty I've seen in the world, given the power that nuclear weapons place in the hands of a very small number of individuals, it's very surprising to me we've had to destroy ourselves. And it seems to be a very low probability situation we have happening here.
And then the other explanation is the zoo, is the observation that we're just being observed. That's the only other thing. It's so difficult for me. Of course, all of science, everything is very humbling. It would be very humbling for me to learn that we're alone in the universe.
It would change. Maybe I do want that to be true because you want us to be special. That's why I'm resisting that thought maybe. There's no way we're that special. That's where my resistance comes from.
I would just say, the specialness is implicitly in that statement, there's kind of an assumption that we are something positive. We're a gift to this planet or something, and that makes it special. But it may be that intelligence is more like rats or cockroaches.
We're an infestation of this planet. We're not some benevolent property that the planet would ideally like to have if you can even say such a thing. But we may be not only a generally a negative force for a planet's biosphere and its own survivability, which I think you can make a strong argument about. But we may also be a very persistent infestation that may even in interesting thoughts, in the wake of a nuclear war, would there be an absolute eradication of every human being, which would be a fairly extreme event?
Or would the kind of a consciousness, as you might call it, the flame of consciousness, continue with some small pockets that would maybe in 10,000 years, 100,000 years, we see civilization reemerge and play out the same thing over again?
Yeah, certainly, but nuclear weapons aren't powerful enough yet. But to sort of push back on the infestation, sure, but the word special doesn't have to be positive. I just mean...
I think it tends to imply, but I take your point. Yeah, but maybe just maybe extremely rare might be. And that to me, it's very strange for me to be cosmically unique. It's just very strange. I mean, the only thing of this level of complexity in the galaxy just seems very strange to me.
Yeah, I do think it depends on this classification. Again, it's kind of buried within there as a subtext, but there is a classification that we're doing here that what we are is a distinct category of life, let's say, in this case.
When we talk about intelligence, we are something that can be separated. But of course, we see intelligence across the animal kingdom in dolphins, humback whales, octopuses, crows, ravens.
And so it's quite possible that these are all manifestations of the same thing. And we are not a particularly distinct class except for the fact we make technology.
That's really the only difference with our intelligence. And we classify that separately, but from a biological perspective to some degree, it's really just all part of a continuum.
And so that's why when we talk about unique, you are putting yourself in a box which is distinct and

saying, this is the only example of things that fall into this box.
But the walls of that box may themselves be a construct of our own arrogance that we are something distinct.
But I was also speaking broadly for us, meaning all life on Earth.
But then it's possible that there's all kinds of living ecosystems and on other planets and other moons that just don't have interest in technological development.
And maybe technological development is the parasitic thing that destroys the organism broadly. And then maybe that's actually one of the fundamental realities, whatever broad way to categorize technological development, that's just the parasitic thing that just destroys itself.
We're floating around this idea of the great filter a little bit here. So we're really asking, where is this? Does it lie ahead of us? Nuclear war? Maybe imminent? That would be a filter that's ahead of us.
Or could it be behind us? And it's the advent of technology that is genuinely a rare occurrence in the universe. And that explains the Fermi Paradox.
And so that's something that obviously people have debated and argued about in SETI for decades and decades. But it remains a persistent...
People argue whether it should be really called a paradox or not. But it remains a consistent apparent contradiction that you can make a very cogent argument as to why you expect life and intelligence to be common in the universe.
And yet, everything we know about the universe is fully compatible with just us being here. And that's a haunting thought. But I have no preference or desire for that to be true.
I'm not trying to impose that view on anyone. But I do ask that we remain open-minded until evidence has been collected either way.
The thing is, it's one of, if not the, probably I would argue is the most important question facing human civilization or the most interesting.
I think scientifically speaking, what question is more important than... somehow there could be other ways to sneak up to it, but it gets to the essence of what we are, what these living organisms are.
It's somehow seeing another kind helps us understand.
It speaks to the human condition, helps us understand what it is to be human to some degree.
I have tried to remain very agnostic about the idea of life and intelligence. One thing I try to be more optimistic about, and I've been thinking a lot with as searches for life in the universe, is life in the past.
I think it's actually not that hard to imagine we are the only civilization in the galaxy right now.
Living.
Yeah, that's currently extant. But there may be very many extinct civilizations.
If each civilization has a typical lifetime comparable to, let's say AI is the demise of our own, that's only a few hundred years of technological development, or maybe 10,000 years if you go back to the Neolithic Revolution, the dawn of agriculture, hardly anything in cosmic time span.
That's nothing, that's the blink of an eye. And so it's not surprising at all that we would happen not to coexist with anyone else.
But that doesn't mean nobody else was ever here.
And if other civilizations come to that same conclusion and realization, maybe they scour the galaxy around them to find any evidence for intelligence, then they have two options.

They can either give up on communication and just say, well, it's never going to happen.
We just may as well just worry about what's happening here on our own planet.
Or they could attempt communication, but communication through time.
And that's almost the most selfless act of communication, because there's no hope of getting anything back.
It's a philanthropic gift almost to that other civilization that maybe might just be nothing more than a monument, which the pyramids essentially are, a monument of their existence, that these are the things they achieved, these are the things they believed in, their language, their culture.
Or it could be maybe something more than that, it could be lessons from what they learned in their own history.
And so I've been thinking a lot recently about how would we send a message to other civilizations in the future?
Because that act of thinking seriously about the engineering of how you're designed it would inform us about what we should be looking for.
And also perhaps be our best chance, quite frankly, of ever making contact.
It might not be the contact we dream of, but it's still contact.
There would still be a record of our existence as pitiful as it might be compared to a two-way communication.
And I love the humility behind that project, the universal project.
It humbles you to the vast temporal landscape of the universe, just realizing our day-to-day lives, all of us will be forgotten.
It's nice to think about something that sends a signal out to other.
It was almost like a humility of acceptance as well, of knowing that you have a terminal disease, but your impact on the earth doesn't have to end with your death.
And it could go on beyond with what you leave behind for others to discover with maybe the books you write or what you leave in the literature.
Do you think launching the Roadster vehicle out in space?
Yeah, the Roadster.
I'm not sure what someone would make of that if they found that.
Yeah, that's true.
I mean, there have been quasi attempts at it beyond the Roadster.
I mean, there's like plaques on, there's the pioneer plaques, there's the Voyager 2 golden record.
It's pretty unlikely anybody's going to discover those because they're just adrift in space
and they will eventually mechanically die and not produce any signal for anyone to spot.
So you'd have to be extremely lucky to come across them.
I've often said to my colleagues that I think the best place is the moon.
The moon, unlike the earth, has no significant weathering.
How long will the Apollo descent stages, which are still still on the lunar surface, last for?
The only real effect is micrometorites, which are slowly like dust smashing against them pretty much.
But that's going to take millions, potentially billions of years to erode that down.
And so we have an opportunity, and that's on the surface.
If you put something just a few meters beneath the surface, it would have even greater protection.

And so it raises the prospect of that if we wanted to send something, a significant amount of information,
to a future galactic spanning civilization that maybe cracks the interstellar propulsion problem,
the moon's going to be there for five billion years.
That's a long time for somebody to come by and detect maybe a strange pattern that we draw on the sand,
for them to, you know, big arrow, big cross, like, look under here,
and we could have a tomb of knowledge of some record of our civilization.
And so I think it's, when you think like that, well, that implies to us,
well, okay, the galaxy's 13 billion years old, the moon is already four billion years old,
there may be places familiar to us, nearby to us,
that we should be seriously considering as places we should look for life,
and intelligent life, or evidence of relics that they might leave behind for us.
So that thinking like that will help us find such relics,
and it's like a beneficial cycle that happens.
Yes, exactly.
That enables the science of study better, like of searching for bios and tech signatures and so on.
And it's inspiring.
I mean, it's also inspiring in that we want to leave a legacy behind as an entire civilization,
not just in the symbols, but broadly speaking, that's lasting somehow.
Yeah, and I'm part of a team that's trying to repeat the golden record experiment.
We're trying to create like an open source version of the golden record
that future spacecraft are able to download and basically put a little hard drive
that they can carry around with them and get these distributed hopefully across the solar system eventually.
So it's going to be called the H-Hackers Guide to the Galaxy, right?
Yeah, it could be. That's a good name for it.
We've been toying a little bit with the name,
but I think probably just be golden record at this point,
or god record version two or something.
But I think another benefit that I see of this activity
is that it forces us as a species to ask those questions
about what it is that we want another civilization to know about us.
The golden record was kind of funny because it had photos on it
and it had photos of people eating, for instance,
but it had no photos of people defecating.
And so I thought that was kind of funny because if I was an alien,
or if I was studying an alien, if I saw images of an alien,
I'm not trying to be like a pervert or anything,
but I would want to see the full biology.
I want to understand the biology of that alien.
And so we always censor what we show.
We should show the whole actual natural process

and then also say we humans tend to censor these things.
We tend to not like to walk around naked.
We tend to not to talk about some of the natural biological phenomena
and talk a lot about others
and actually just be very...
like the way you would be to a therapist or something,
very transparent about the way we actually operate this world.
And Sagan had that with the golden record.
I think he originally...
there's a male and a female figure to pitch on the golden record
and the woman had a genitalia originally drawn
and there was a lot of pushback from, I think,
a lot of Christian groups who were not happy
about the idea of throwing this into space.
And so eventually they had to remove that.
And so it would be confusing biologically
if you're trying to study xenobiology of this alien
that apparently has no genitalia or the manders,
but for some reason the woman doesn't.
And that's our own societal and cultural imprint
happening into that information.
That's to be fair.
Just even having two sexes and predators and prey,
just a whole...
that could be just a very unique, earth-like thing.
So that might be confused about why there's like pairs of things.
Like why are you...
Why is there a man and a woman in general?
Like they could be...
I mean, they could be confused about a lot of things in general.
I don't think the...
They don't even know which way to hold the picture.
Exactly.
Or there's a picture.
They might not need...
they might have very different sensory devices
to even interpret this.
If they only have sound,
is there only way of navigating the world?
It's kind of lost to send any kind of...
There's been a lot of conversation about sending video and audio...
and video and pictures.
And that's one of the things I've been a little bit resistant about

in the team that I've been thinking,
well, they might not have eyes.
And so if you lived in under Europa's surface,
having eyes wouldn't be very useful.
If you lived on a very dark planet,
on the tightly locked night side of an exoplanet,
having eyes wouldn't be particularly useful.
So it's kind of a presumption of us to think that video
is a useful form of communication.
Do you hope we become a multi-planetary species?
So we're almost sneaking up to that,
but the efforts of SpaceX, of Elon,
maybe in general, what your thoughts are about those efforts.
So you already mentioned Starship will be very interesting
for astronomy, for science in general,
just getting stuff out into space.
But what about the longer-term goal of actually colonizing
of building civilizations on other surfaces,
on moons, on planets?
It seems like a fairly obvious thing to do for our survival, right?
There's a high risk.
If we are committed to trying to keep this human experiment going,
putting all of our eggs in one basket is always going to be
a risky strategy to pursue.
It's a nice basket though, but yeah.
It is a beautiful basket.
I personally have no interest in living on Mars or the moon.
I would like to visit,
but I would definitely not want to spend the rest of my life
and die on Mars.
It's a hellhole.
Mars is a very, very difficult...
I think the idea that this is going to happen in the next 10, 20 years
seems to be very optimistic.
Not that it's insurmountable,
but the challenges are extreme to survive on a planet like Mars,
which is like a dry, frozen desert with a high radiation environment.
It's a challenge of a type we've never faced before.
I'm sure human ingenuity can tackle it,
but I'm skeptical that we'll have thousands of people living on Mars
in my lifetime, but I would relish that opportunity
to maybe one day visit such a settlement
and do scientific experiments on Mars or experience Mars,

do astronomy from Mars,
and all sorts of cool stuff you could do.
Sometimes you see these dreams of outer solar system exploration
and you can fly through the clouds of Venus
or you could just do these enormous jumps
on these small moons where you can essentially jump as high as a skyscraper
and traverse them.
There's all sorts of wonderful ice skating on Europa.
It might be fun.
I love the idea of us becoming into planetary.
I think it's just a question of time.
Our own destructive tendencies, as you said earlier,
are at odds with our emerging capability to become into planetary.
The question is, will we get out of the nest before we burn it down?
I don't know.
Obviously, I hope that we do,
but I don't have any special insight that there is a problem.
There is somewhat of a gnawing intellectual itch I have
with the so-called doomsday argument,
which I try not to treat too seriously,
but there is some element of it that bothers me.
The doomsday argument basically suggests that you're typically
the mediocrity principle you're not special,
that you're probably going to be born somewhere in the middle
of all human beings who will ever be born.
You're unlikely to be one of the first 1% of human beings
that ever lived and similarly the last 1% of human beings
that ever lived, because you'd be very unique and special
if that were true.
By this logic, you can calculate how many generations
of humans you might expect.
If there's been, let's say, 100 billion human beings
that have ever lived on this planet,
then you could say to 95% confidence,
you divide by 5%,
so 100 billion divided by 0.05 would give you 2 trillion
human beings that would ever live.
You'd expect by this argument.
If, let's say, each planet,
in general, the planet has a 10 billion population,
so that would be 200 generations of humans
we would expect ahead of us.
If each one has an average lifetime of, say, 100 years,

then that would be about 20,000 years.
There's 20,000 years left in the clock.
There's a typical doomsday argument type.
That's how they typically lay it out.
Now, a lot of the criticisms of the doomsday argument
come down to, what are you really counting?
You're counting humans there,
but maybe you should be counting years,
or maybe you should be counting human hours.
Because what you count makes a big difference
to what you get out on the other end.
So this is called the reference class.
And so that's one of the big criticisms
of the doomsday argument.
But I do think it has a compelling point
that it would be surprising if our future is to one day
blossom and become a galactic spanning empire.
Trillions upon trillions of human beings
will one day live across the stars
for essentially as long as the galaxy exists
and the stars burn.
We would live at an incredibly special point in that story.
We would be right at the very, very, very beginning.
It's not impossible, but it's just somewhat improbable.
And so part of that sort of irks against me,
but it also almost feels like a philosophical argument
because you're sort of talking about souls being drawn
from this cosmic pool.
So it's not an argument that I lose sleep about
for our fate of the doomsday,
but it is somewhat intellectually annoying
that there is a slight contradiction there, it feels like,
with the idea of a galactic spanning empire.
Yeah, but of course, there's so many unknowns.
I, for one, would love to visit even space,
but Mars, just imagine standing at Mars
and looking back at Earth.
Yeah, I mean...
It would give you such a fresh perspective
after your entire existence and wanting to be human.
Yeah, and then come back to Earth.
It would give you a heck of a perspective.
Plus, the sunset on Mars is supposed to be nice.

I loved what William Shatner said after his flight.
His words really moved me when he came down.
And I think it really captured the idea
that we shouldn't really be sending engineers,
our scientists into space.
We should be sending out poets
because those are the people when they come down
who can truly make a difference
when they describe their experiences in space.
And I found it very moving reading what he said.
Yeah, when you talk to astronauts,
when they describe what they see,
it's like they discovered a whole new thing
that they can't possibly convert back into words.
Yeah, it's beautiful to see.
Just as a quick before I forget, I have to ask you,
can you summarize your argument against the hypothesis
that we live in a simulation?
Is it similar to our discussion about the Doomsday Clock?
No, it's actually pretty more similar to my agnosticism
about life in the universe.
It's just sort of remaining agnostic about all possibilities.
The simulation argument, sometimes it gets...
It makes this kind of two distinct things
that we need to consider.
One is the probability that we live in so-called base reality,
that we're not living in a simulated reality itself.
And another probability we need to consider is the probability
that that technology is viable or possible
and something we will ultimately choose to one day do.
Those are two distinct things.
They're probably quite similar numbers to each other,
but they are distinct probabilities.
So in my paper, I wrote about this.
I just tried to work through the problem.
I teach astrocystics, I was actually teaching it this morning.
And so it just seemed like a fun case study
of working through a Bayesian calculation for it.
Bayesian calculations work on conditionals.
And so when you hear what kind of inspired this project was
when I heard Musk said it was like a billion-to-one chance
that we don't live in a simulation,
he's right if you add the Bayesian conditional

and the Bayesian conditional is conditioned upon the fact
that we eventually develop that technology and choose to use it.
Or it's chosen to be used by such species,
by such civilizations.
That's the conditional.
And you have to add that in because that conditional
isn't guaranteed.
And so in a Bayesian framework,
you can kind of make that explicit.
You see mathematically explicitly
that's a conditional in your equation.
And the opposite side of the coin is basically
in the trilemma that Boston originally put forward.
It's options one and two.
So option one is that you basically never develop
the ability to do that.
Option two is you never choose to execute that.
So we kind of group those together
as sort of the non-simulation scenario.
Let's call it.
And so you've got non-simulation scenario
and simulation scenario.
And agnosticly, we really have to give, though,
how do you assess the model,
the a priori model probability of those two scenarios?
It's very difficult.
And we can, I think people would probably argue
about how you assign those priors.
In the paper, we just assigned 50-50.
We just said this hasn't been demonstrated yet.
There's no evidence that this is actually technically possible,
but nor is it that it's not technically possible.
So we're just going to assign 50-50 probability
to these two hypotheses.
And then in the hypothesis where you have a simulated reality,
you have a base reality set at the top.
So there is, even in the simulated hypothesis,
there's a probability you still live in base reality.
And then there's a whole myriad of universes beneath that,
which are all simulated.
And so you have a very slim probability
of being in base reality if this is true.
And you have a 100% probability

of living in base reality.
On the other hand, if it's not true
and we never develop that ability
or choose never to use it.
And so then you apply this technique
called Bayesian model averaging,
which is where you propagate the uncertainty
of your two models to get out a final estimate.
And because of that one base reality
that lives in the simulated scenario,
you end up counting this up
and getting that it always has to be less than 50%.
So the probability of living in a simulated reality
versus a base reality has to be slightly less than 50%.
Now, that really comes down to that statement
of giving it 50-50 odds to begin with.
And on the one hand, you might say,
look, David, I'm working artificial intelligence.
I'm very confident that this is going to happen,
just of extrapolating our current trends.
Or on the other hand, a statistician would say,
you're giving way too much weight
to the simulation hypothesis
because it's an intrinsically highly complicated model.
You have a whole hierarchy of realities
within realities, within realities.
It's like the inception-style thing, right?
And so this requires hundreds,
thousands, millions of parameterizations to describe.
And by Occam's razor,
we would always normally penalize
inherently complicated models as being disfavored.
So I think you could argue I'm being too generous
or too kind with that.
But I sort of want to develop
the rigorous mathematical tools to explore it.
And ultimately, it's up to you
to decide what you think that 50-50 odds should be.
But you can use my formula
to plug in whatever you want and get the answer.
And I use 50-50.
But in that first pile,
with the first two parts of the bottom talks about,

it seems like connected to that
is the question we've been talking about,
which is the number of times at bat you get,
which is the number of intelligent civilizations
that are out there that can build such simulations.
It seems like very closely connected,
because if we're the only ones that are here
and they can build such things,
that changes things.
Yeah, yeah.
The simulation hypothesis has all sorts of implications like that.
I've always looked at Sean Cowell points
that are really interesting contradiction, apparently,
with the simulation hypothesis
that I speak about a little bit in the paper.
But he showed that, or pointed out,
that in this hierarchy of realities,
which then develop their own AIs within the realities,
or really ancestor simulations, I should say, rather than AI,
they develop their own capability to simulate realities,
you get this hierarchy.
And so eventually, there'll be a bottom layer,
which I often call the sewer of reality.
It's like the worst layer where it's the most pixelated
that you could possibly do, right?
Because each layer is necessarily going to have less
computational power than the layer above it.
Because not only are you simulating that entire planet,
but also some of that's being used for the computers themselves
that those are simulated.
And so that base reality, also in the debate,
the sewer of reality,
is a reality where they are simply unable
to produce ancestor simulations
because the fidelity of the simulation is not sufficient.
And so from that point of view,
it might not be obvious that the universe is pixelated,
but you'll be able to manifest that capability.
What if they're constantly simulating...
Because in order to appreciate the limits of the fidelity,
you have to have an observer.
What if they're always simulating a dumber and dumber observer?
What if the sewer has very dumb observers that can't...

Like scientists, they're the dumbest possible scientists.
So it's very pixelated,
but the scientists are too dumb to even see the pixelations.
That's built into the universe,
always has to be a limitation on the cognitive capabilities
of the complex systems that are within it.
Yeah, so that sewer of reality,
they would still presumably be able to have
a very impressive computational capability.
They'd probably be able to simulate galactic formation
or this kind of impressive stuff,
but they would be just short of the ability to,
however you define it,
create a truly sentient, conscious experience in a computer.
That would just be just beyond their capabilities.
And so Carol pointed out that if you add up
all the, you know, you count up how many realities
there should be, probabilistically, if this is true,
over here, the simulation hypothesis or scenario,
then you're most likely to find yourself in the sewer
because there's just far more of them
than there are of any of the higher levels.
And so that sort of sets up a contradiction
because then you live in a reality
which is inherently incapable of ever producing
ancestor simulations.
But the premise of the entire argument
is that ancestor simulations are possible.
So there's a contradiction that's been issued.
There's that old quote,
we're all living in the sewer,
but some of us are looking up at the stars.
This is maybe more true than we think.
To me, so there's, of course, physics
and computational fascinating questions here,
but to me, there's a practical psychological question
which is, you know, how do you create
a virtual reality world that is as compelling
and not necessarily even as realistic,
but almost as realistic,
but as compelling or more compelling than physical reality?
Because something tells me it's not very difficult.
In a full history of human civilization,

that is an interesting kind of simulation to me
because that feels like it's doable in the next 100 years,
creating a world where we're all preferred
to live in the digital world.
And not like a visit,
but like it's like you're seen as insane.
No, like you're required,
it's unsafe to live outside of the virtual world.
And it's interesting to me from an engineering perspective
how to build that,
because I'm somebody that sort of loves video games
and it seems like you can create incredible worlds there
and stay there.
And that's a different question
than creating an ultra high resolution,
high fidelity simulation of physics.
But if that world inside a video game is as consistent
as the physics of our reality,
then you can have your own scientists in that world
that trying to understand that physics world.
They might look different.
And presumably they'd eventually forget,
give it long enough they might forget about their origins
of being once biological and assume this is their only reality.
Especially if you're now born,
well certainly if you're born,
even if you're eight years old or something
when you first started wearing the headset.
Yeah, or you have a memory wipe when you go in.
I mean, it also kind of maybe speaks to this issue
of like neurolink and how do we keep up with AI in our world.
If you want to augment your intelligence,
perhaps one way of competing
and one of your impetuses for going into this digital reality
would be to be competitive intellectually
with artificial intelligence that you could trivially augment
your reality if your brain was itself artificial.
But I mean, one skepticism I've always had about that
is whether it's more of a philosophical question,
but how much is that really you if you do a mind upload?
Is this just a duplicate of your memories
that thinks it's you versus truly a transference
of your conscious stream into that reality?

And I think when you, it's almost like
the teleportation device in Star Trek,
but with teleportation, quantum teleportation,
you can kind of rigorously show that that,
you know, as long as all of the quantum numbers
are exactly duplicated as you transfer over,
it truly is from the universe's perspective
in every way indistinguishable from what was there before.
It really is in principle you and all the sense of being you
versus creating a duplicate clone and uploading memories
to that human body or a computer
that would surely be a discontinuation
of that conscious experience
by virtue of the fact you've multiplied it.
And so I would be hesitant about uploading for that reason.
I would see it mostly as my own killing myself
and having some AI duplicate of me
that persists in this world,
but is not truly my experience.
Typical 20th century human
with an attachment to this particular
singular instantiation of brain and body.
How silly humans used to be.
Used to have rotary phones
and other silly things.
You're an incredible human being.
You're an educator.
You're a researcher.
You have like an amazing YouTube channel.
Looking to young people,
if you were to give them advice,
how can they have a career
that maybe is inspired by yours?
Inspired by wandering curiosity?
A career they can be proud of
or a life they can be proud of?
What advice would you give?
I certainly think in terms of a career in science,
one thing that I may be discovered late
but has been incredibly influential on me
in terms of my own happiness and my own productivity
has been this synergy of doing two passions at once.
One passion in science communication

and another passion in research
and not surrendering either one.
And I think that tends to be seen as something
that's an either or.
You have to completely dedicate yourself to one thing
to gain mastery in it.
That's a conventional way of thinking about
both science and other disciplines.
And I have found that both have been elevated
by practicing in each.
And I think that's true in all assets of life.
I mean, if you want to become the best researcher
you possibly can,
you're pushing your intellect
and a sense of your body to a high level.
And so to me, I've always wanted to couple that
with training of my body, training of my mind
in other ways besides from just what I'm doing
when I'm in the lecture room or when I'm in my office
calculating something.
Focusing on your own development
through whatever it is, meditation.
For me, it's often running, working out
and pursuing multiple passions
provides this almost synergistic bliss
of all of them together.
So often I've had some of the best research ideas
from making a YouTube video
and trying to communicate an idea
or interacting with my audience
who've had a question that sparked a whole trail of thought
that led down this wonderful intellectual rabbit hole
or maybe to a new intellectual discovery
can go either way sometimes with those things.
And so thinking broadly, diversely
and always looking after yourself
in this highly competitive
and often extremely stressful world that we live in
is the best advice I can offer anybody
and just try, if you can, it's very easy
but if you can follow your passions
you'll always be happy.
Trying to sell out for the quick cash out

for the quick book out
can be tempting in the short term.
Looking for exo-means was never easy
but I made a career not out of discovering exo-means
but out of learning how to communicate
the difficult problem
and discovering all sorts of things along the way.
We shot for the sky and we discovered
all this stuff along the way.
We discovered dozens of new planets
using all sorts of new techniques.
We pushed this instrumentation to new places
and I've had an extremely productive research career
in this world.
I've had all sorts of ideas working on technosignatures.
It's, you know, thinking innovatively
pushes you into all sorts of exciting directions.
So just try to, yeah, it's hard to find that passion
but you can sometimes remember it when you were a kid
what your passions were and what fascinated you as a child.
For me, as soon as I put up a space book
when I was five years old, I was hooked on space
and I almost betrayed my passion at college.
I studied physics which I've always been fascinated by physics as well
but I came back to astronomy because it was my first love
and I was much happier doing research
in astronomy than I was in physics
because it spoke to that wonder I had as a child
that first was the spark of curiosity for me in science.
So society will try to get you to look at hot Jupiters
and the advice is to look for the cool world instead.
What do you think is the meaning of this whole thing?
Have you ever asked yourself why?
It's just a ride.
It's just a ride on a roller coaster
and we have no purpose.
It's an accident in my perspective.
There's no meaning to my life.
There's no objective deity
who is overwatching what I'm doing
and I have some fate or destiny.
It's all just riding on a roller coaster
and trying to have a good time

and contribute to other people's enjoyment of the ride.
Yeah, try to make it a happy accident.
Yeah, I see no fundamental providence
in my life or in the nature of the universe
and you just see this universe is this beautiful cosmic accident
of galaxies smashing together, stars forging here and there
and planets occasionally spawning maybe life across the universe.
And we are just one of those instantiations
and we should just enjoy this very brief episode that we have
and I think trying to look at it much deeper than that
is not very soul satisfying.
I just think enjoy what you've got and appreciate it.
It does seem noticing that beauty helps make the ride pretty fun.
Yeah, absolutely.
David, you're an incredible person.
I haven't covered most of the things I wanted to talk to you about.
This was an incredible conversation.
I'm glad you exist.
I'm glad you're doing everything you're doing and I'm a huge fan.
Thank you so much for talking today. This was amazing.
Thank you so much, Lex. It's real honor. Thank you.
Thanks for listening to this conversation with David Kipping.
To support this podcast, please check out our sponsors in the description.
And now let me leave you with some words from Carl Sagan.
Perhaps the aliens are here but are hiding because of some Lex Galactica,
some ethic of non-interference with emerging civilizations.
We can imagine them curious and dispassionate observing us
as we would watch a bacterial culture in a dish
to determine whether this year, again, we managed to avoid self-destruction.
Thank you for listening and hope to see you next time.