|  |  |
| --- | --- |
| Automated Voice: | This meeting is being recorded. |
| Tiffany: | All right. Hi, everyone. Thanks for coming today. It's my pleasure today to introduce our next exoguide, Vikki Meadows. Just reading off her bio here, Vikki is a professor of astronomy at the University of Washington and director of the UW astrobiology program. She is the principal investigator for the NASA virtual planetary laboratory research team which she'll be talking about today which uses interdisciplinary exo-planet models to understand how to search for life beyond the solar system. Previously, she worked at JPL with an agency with [inaudible] two science team and as a Venus Scientist and at the Spitzer Science Center CAL Tech as a solar system scientist. |
|  | Vikki has served on several NASA and National Academies committees including ones that I actually served under her as Vikki was chair for the exoastrosolar science panel for the Astro 2020 Decadal. And developing strategies for the fields of exoplanet astrobiology and solar system science. She earned her PhD in physics from the University of Sydney. So with that, Vikki, I think you can take it away. Go ahead and share your screen. |
| Victoria Meadow...: | Okay, I will try to. I don't use Webex but let's see if I can use this one. All right, is that working? |
| Tiffany: | Yep. |
| Victoria Meadow...: | Okay, so you can see. So if I go to presenter view, that's good? |
| Tiffany: | Mm-hmm (affirmative) |
| Victoria Meadow...: | Okay? You can see my pictures? |
| Tiffany: | I think, yeah. And just as a note to folks, it's just a little small. There is a zoom bar on the left side. Probably your screen is probably massive, Vikki, so it probably looks just a little smaller on our screen. |
| Victoria Meadow...: | Yeah, okay. All right. |
| Tiffany: | If you zoom in for everybody, it should be fine though. Just a note. |
| Victoria Meadow...: | Okay. Is that to me or just? |
| Tiffany: | Oh, no. It's to everybody on the call. Yeah. |
| Victoria Meadow...: | Okay, cool. Yeah, again, I'm just not really good with Webex. Zoom, yes, but Webex, no. |
|  | So, hello. I'm excited to be here and talking to all of you. I think you so much to Tiffany and the other organizers for the invitation to do that. So today I'm going to talk about the Virtual Planetary Laboratory which is my research group. This is going to be a slightly different talk from the ones that I usually do in that I am going to not only talk about our science but also talk a little bit along the way about our philosophy and what our key themes are and maybe little tidbits on how to organize stuff and some take away messages. So I'll be talking about collaborative science, what it can do, and what's important to get working for collaborative science. I hope I will address what my advisors here have asked for me to do. |
|  | So the Virtual Planetary Laboratory, it's a research group for advancing the search for extraterrestrial life with what I call a massively interdisciplinary collaboration. By massively interdisciplinary, I mean it's not just molecular biologists talking to cell biologists. It is evolutionary molecular biologists talking to stellar astronomists. So it's again a very wide diversity of disciplines involved and a very broad gap between the science for when people are actually talking and interacting with each other. |
|  | So if you want to run a large, collaborative group that is interdisciplinary, I would say that the very first thing that you need to do is come up with an overarching guiding question. That question really has to focus and cover pretty much all of the research that you want to do in your group. So the VPL's question is how do we recognize whether an extrasolar planet can or does support life. So within that sentence, the recognize is talking about getting data and being able to interpret it, then the can support life would be is it habitable, and does support life is can we see signs of life biosignatures in that atmosphere. So that is VPL's question. That's what we've worked on, basically, for the last 20 years. That's what we've been heading for. |
|  | So I'm just going to go over some of the main themes and terms and you're all exoplanet scientists so you probably know a lot of this stuff but I'll just go over it for completeness. So the search for life, at least on exoplanets, is the search for liquid water. We believe that underpins pretty much the types of environments that we want to try and search for life in. In this case, it's the search for surface liquid water. Water actually running on the surface of the planet. |
|  | Many things affect whether a planet has liquid water. This is one of the central themes of the Virtual Planetary Laboratory, is the idea that if you have a planet with liquid water, it's not just a chance occurrence. It's come about because of a bunch of different interactions with different components of that planetary system. One of those being, of course, the intrinsic properties of the planet itself. How it formed, its composition, and evolution. That evolution has been driven by an interaction with planetary systems whether via orbital interaction with other planets or the delivery of volatiles early on in small bodies, but also, of course, one of the most principal and important interactions is with the star. The star's evolution over time and the star's intrinsic properties will very much drive whether or not this planet is able to maintain liquid water on its surface. |
|  | So those are the three basic areas in which you will find the interactions that will produce potentially liquid water on the surface. But if we break this down into the constituent bits and pieces, we see that the question of exoplanet habitability is really quite a complicated one that really spreads out to a lot of different fields and a lot of different areas within exoplanet science. Sorry about this. So, I would imagine that a lot of your science, all of your science probably, can be found somewhere on this particular diagram. |
|  | So key questions that we ask about habitability, what we're trying to assess to recognize if something is habitable are does it have an atmosphere, what is the nature of it's atmosphere... So sorry about this. Whether or not it has an ocean and whether or not there are in fact signs of life. This is the hierarchy of questions that we would ask ourselves about when trying to ascertain if something is habitable. |
|  | So other overarching questions when we're talking about detecting signs of life are trying to ask, okay, what are the things we might expect to see? What does life produce? When we focus in on those biosignatures, the things that life produces that might impact the environment, we still have to ask ourselves, well, if there isn't any life there, could we still be fooled by processes that are intrinsic to the planet or its environment or its interaction with other things that have really nothing to do with life. |
|  | Another key question in biosignature science at the moment is how do we interpret all of this with what will be spectacularly limited data in trying to figure out whether or now we actually do have a sign of life. A really big part of where the field is going right now is in how do we quantify our uncertainties or our certainty. Can we look at a particular system, can we say this system is more or less likely to have life in its planetary system and how do we actually go about quantifying that and potentially conveying that to the public with the other sciences? |
|  | So this slide and all the questions came out of a workshop that we put together. Hopefully this will calm down. Back in 2016 and we published a series of papers. Many of these were in fact led by Virtual Planetary Laboratory scientists looking at all these different aspects of what we should do for biosignature detection. |
|  | So I think one of the major themes that really has driven the VPL research is this idea of exoplanet and solar system synergy. For us, we came at the exoplanet modeling side from the solar system side. So our founding team members were members of the solar system modeling community and we understand that to model exoplanets credibly, to have robust sensibility underneath what we do, because we model terrestrial planets, right? It's extremely important for us to validate our models against measurements of planets in our own solar system. And so the solar system and exoplanet science is complimentary because solar system planets allow us to measure that grand truth of what's actually going on on the planet whether we sense [inaudible] like we did yesterday or we look at information we get from orbiters from remote sensing. We can, with these robotic spacecrafts, get good spacial and temporal resolution on planetary processes that might be common elsewhere. So there's a wealth of knowledge within the solar system on typical planetary processes that we can potentially apply to other planets. |
|  | In turn, though, exoplanet science provides a really large statistical sample of planets that can be clues for different trends and sets our solar system in a broader context. And so these two areas are complimentary and VPL has been very much, I think at the forefront. We started this about 20 years ago of really pushing this idea that don't, as I say to my students when they come up with a theory for something for an exoplanets, I say, "Look right, look left." You know? "Look to Venus and Mars. Is there anything that you've just said that is potentially contradicted by something that we already know about what's in our system?" So we try to keep ourselves humble by making sure that we compare our theories with things that are in fact found in our solar system. |
|  | Another key theme of course, probably one of our biggest ones, is interdisciplinarity. That is driven by a lot of things. That complexity of planetary habitability diagram I shared where planets are hard diagrammed. Just realization of something I said really early one. It takes a village to model a planet. To be able to understand all of these interacting components and the interaction with the planetary system and the star, you really do need a bunch of people with a lot of different expertise to help with that. |
|  | Also this idea of a probabilistic assessment for life. The fact that it's one thing to detect a biosignature but it's another thing to be able to interpret it. To be able to say conclusively whether that thing is due to life or in fact is due to the planet. It requires people who understand the planet and who understand the history of the planet. So that's all important things to us. I think, this is one I'm always waving my sign about, is biosignatures must always have to be interpreted in the context of their environment. So when we see something that we think or hope is a biosignature, we really need to hold ourselves accountable by looking at the environment that this thing is in and trying very hard to see if there is any other way that we can explain this particular biosignature. If I have enough time, I'll go over a very specific and high profile example of that which is the phosphine on Venus story that has been prominent over the last four months or so. |
|  | So because of all these reasons, we basically concluded that we need massively interdisciplinary science to search for extraterrestrial habitability and life. That's really the best way to go. So that was a big driver in setting up the VPL in the first place, was bringing this community of people together to work on these questions. |
|  | The other thing we're very aware of, and this is in part because of where our funding is coming from, is that it's one thing to go up and model stuff and say, "Oh, look. This is really cool. This interacts with that," or whatever, but ultimately we want to be good scientists and make sure that we come up with testable hypotheses that can be challenged by actual data at some point. And when the VPL was first founded, that was about 20 years ago, we though, how naïve we were, that we would get the terrestrial planet finder within about six years of when we were first funded. So we were really very much pushing toward the TPS type observation. Since then, of course, that has fallen away and perhaps been reincarnated as some other missions which I'll talk about in a second, but we've always tried to keep this focused on whatever our modeling is, that we're actually going to tie that ultimately to observations that we hope to get. |
|  | So JWST and ground based telescopes are coming in the next five years and they will allow us to get a picture of planetary atmospheres using transmission and reflective of light and for terrestrial exoplanets so we're very, very excited about that happening. Again, that drives our research into the things that we do to couple with data in the short-term. And then, potentially, in the longer-term, we have these four missions that are currently under consideration and that's part of that National Academy Panel that Tiffany and I were both on. |
|  | We don't actually look at the missions. We were part of what's called a science panel so we were set to discuss and try to outline what we thought was the most important science questions going forward in the area of exoplanet solar systems and science and astrobiology, but that science report then drives the main panels that looks at the four different mission concepts under consideration for a large flagship mission for astronomy and tries to select these. The exciting thing is that that report, it's coming out hopefully in the next two to five months. So we will have better guidance from our colleagues on which mission they think should be considered first to be implemented. And there's no point in asking Tiffany or I what's going on there because actually we don't know. We don't know anything about the deliberations in the upper panel. So we're also waiting excitedly to see what they decided is the most important mission to be selected. Which I think... Yep. They didn't tell us anything. |
|  | So three of these missions will have direct capability to actually observe extrasolar planets. Which is pretty exciting. Lynx here is an x-ray observatory. It will get us information on the stars and the star's behavior which also is, we said the star is very important for the planetary environment as well. So all of these missions will impact exoplanet science in some way but these two missions, HabEx and LUVOIR, are large space based telescopes that are operating in the UV visible near-infrared. They will have both direct imaging and transmission capabilities for terrestrial exoplanets. And then, of course, we have the Origins Space Telescope which will have transmission capability for terrestrial planets. So we're looking forward to those. |
|  | And then, of course... It's a very busy slide. Sorry about that. There's also ground based high resolution spectroscopy coming up with ELTs which will also be incredibly exciting. Using a combination of things, potentially combining adaptive optics and direct imaging capability for nulling the star with high resolution spectroscopy to filter out the light, the absorption coming from the Earth's atmosphere. By coupling those techniques, we may in fact be able to get down to observe, again, terrestrial planet atmospheres from the ground with telescopes that are coming online in mid-decade. So 2025, 26, 27. So again in the next five or so years, we're going to get the capability to observe exoplanets from the ground also. |
|  | To that end, we've been finding targets for all of these near-term capabilities and so, by we I mean the entire community. We've found several excellent nearby M Dwarf targets that have planets orbiting around them where we think we might be able to access the atmospheres of these planets. This is, again, a very important part of what we care about is to be able to actually get photons from these targets. |
|  | So most of you probably know these things. GJ1132D, you're getting a nice exo-Venus. We see it's 19 planets. There are an insulation that the earth does. There are habitable zone terrestrial planets with transiting and non-transiting and nearby stars. |
|  | Then the system that is nearest and dearest to my heart is the TRAPPIST-1 system with seven planets. Three which are potentially in the habitable zone. 12 parsecs away are an M8 dwarf that is so tiny that it will produce, hopefully if they are there, strong atmospheric signals from the planets that are in orbit around it. |
|  | So with the ground based telescopes looking at M dwarf systems and with TRAPPIST-1 being served with JWST, then in the near term we are going to have, switch it out there, we're going to have the capability to actually get photons from terrestrial planets. VPL, very early on our main theme was planets are hard meaning it is a complicated process. We need to model these planets as rigorously as possible. Our new theme that keeps coming up is protons are coming. So we are very, very excited about that. |
|  | So again in summary, observation of terrestrial exoplanets with JWST and ELT is in the interim in the next five or so years. Then in the longer term, we hope there will be development of a terrestrial exoplanet capable telescope that can do those observations for us. But Tiffany and I don't know that yet, but we are hoping in a few years for something that we think will be very impactful for exoplanet science for the little teeny guys. |
|  | So what VPL does is the theoretical modeling needed to support these upcoming observations and to inform the development of future instruments to study exoplanets for signs of evolution, habitability, and life. |
|  | Just a little, tiny history with stats for the VPL. It was founded in 2001 at the Jet Propulsion Laboratory. We basically wrote the proposal in 2000, it was awarded in 2001, and it was funded as a member of the NASA Astrobiology Institute which was a large funding program for consortia of groups that interacted with each other and were then also supposed to interact with the other teams in the institute as well. |
|  | The interesting thing about the selection of our team was that we went out of a proposal call where Earth Science funding was also included as part of the funding mechanism. This will be another part of my themes for young researchers is the way to win proposals is to figure out what the sponsor wants and then give it to them. Okay? So that's always been my key. I don't try to convince people, necessarily, that your science is fantastic and they should just fund what you're doing. This is a two way street. You really need to find out what the people with the money actually want and need and then do your best to do something that you think would be relevant to what they actually need. |
|  | So this particular case because we knew there was Earth science funding in there and they had called out priorities where they had wanted Earth and Planetary Science being folded into Exoplanet Science. So we presented to them a proposal to do exactly that. So we tried to be as responsive to the call, as they say, is possible. |
|  | I've been the PI of this thing for the whole 20 years. I've just putting that out there subsequently because people have said, "Well, you haven't been PI for that whole time, right?" And I'm like, "No, no. I have. Really. The whole thing." |
|  | We started out with 17 team members. We now have about 74 with 130 people on slack. That's with all the attendants, students, and everything else. It's a pretty large team. We publish about 60-80 papers a year. Again, this is a massively interdisciplinary, very highly collaborative project. So in the discussion session if you want to ask me questions about how do you get people to collaborate across these types of boundaries or tips for collaborative projects, then I will do my best to answer that type of questions as well. |
|  | Okay. So another important thing when writing a proposal, and also this is a training at JPL as well is if you work on a JPL mission or any mission really, you will encounter this concept of the science traceability matrix. The STM. A lot of people really hate the STM concept and other people have learned to live with it. I think I'm probably one of the ones who have learned to live with it. But the STM, I think, is really a good concept and it essentially says, okay, if you're going to structure either a mission or in this case a research group, you should start with a goal so you clearly know what it is you're aiming for and then to meet that goal, you should identify a bunch of objectives that feed into your goal. Then you should either for a mission you would come up with a measurement requirements that meet your objectives and meet your goals or for a research project you will come up with different tasks that result in products and papers and results that meet your objectives and your goals. |
|  | So for VPL, here's the internal structure of it which I don't usually often talk about. But we have this overarching goal. How do we recognize whether an exoplanet can or does support life? Our objective one is to try and use the solar system to inform our understanding of exoplanet evolution, habitability, and biosignatures. Objective two is looking at the early Earth as a series of alternative habitable environments that are nonetheless extremely different to the modern Earth. Objective three is where we bring our interdisciplinary modeling capabilities together and try and work on that planet to hard diagram, to understand multiparameter influences and characterization on terrestrial exoplanet evolution and habitability. |
|  | Objective four, that's where a lot of our biologists concentrate, we look at the impact of life on terrestrial planet environments both now and in the past and look at trying to identify new biosignatures in the context of the environment we might actually find them in. We also do simulation for exoplanet environments that have similar things as well. Then in objective five it wraps it all together by saying we want to define required measurements and optimal retrieval methods for exoplanet characterizations and that's where we couple into the missions. I can just come up with [inaudible]. |
|  | So there's a diagram that shows the four tasks that map to those objectives. So our solar system analog task really runs along the solar system looking to see if there's any experiments that the solar system can provide for us that we can then use to inform our own study of exoplanet processes or even how we might observe an exoplanet using a solar system analog for that type of geometry or that type of observation. |
|  | We look at the earth through time so we have a whole sleuth of geologists and also biologists who look at ancient life and try to understand the ancient environment of early earth so we can simulate what that environment and that life impact on that environment might look like to look at normal biosignatures. We have a habitable planet task which addresses that planet to hard diagram and looks at interactions and model interactions to expand off this basis of how again star and the planetary system and the planet all interact to affect habitability. The living planets, we send out biologists out into the field and to the lab to get information that ultimately feeds into our understanding of biosignatures and habitability. |
|  | Then this rainbow here is the observer task where we pass pretty much everything we learned in the other four tasks through instrument simulation models to noise up the spectra that we've generated from each of these environments and to look at detectability and retrieval considerations for different types of telescopes. That then ties into the telescopes that we're particularly interested in looking for. |
|  | So here we are combining expertise from the solar system, from earlier and modern earth, and from exoplanetary science to model terrestrial exoplanet evolution, environments, and observations. I also have a more detailed version of this so we don't have to go into it. But again, if you're writing your proposal, you want something like this that says, okay, here's the methods and the things I'm going to use, here's the science I think I'm going to get out of this task, and here's how I'm going to tie it to, for example, our ultimate goal which is impact on NASA missions to look at terrestrial planets. Yeah. That's the structure. This is the VPL pretty much in a single diagram and it's something that we used in our proposal. |
|  | Okay. So another thing I wanted to emphasize here is it's not just the goals and the objectives and the tasks. It's also the team. So the way we structured the VPL was to have each team on each task be massively interdisciplinary in its own right. So this is everybody's disciplines down here. And you can see there is a correlation between yellow and purple and tasks E and task A and that's because we have a lot of observers. Astronomical observing and spectral retrieval sits in these two tasks. But you can see in B, C, and D, we really have a rainbow of different colors going through all of those tasks and that's where we're bringing in our biogeochemists, our geologists, and also the planetary observers as well into these tasks. Even magnetospherists. |
|  | Okay. So our work is done primarily with planetary computer models and this is the Hyak supercomputer cluster that we do a lot of our work on. But we, because we were funded under the NASA Astrobiology Institute, it's not enough to get away with a single discipline or even method. We've augmented our computer with laboratory admissionings and with field work that basically feeds into the models that we're doing. |
|  | Here we have Professor Roger Buick over here taking drill cores from the Pilbara. Understanding the conditions on early Earth by drilling into an exposed craton which is one of the most ancient pieces of the Earth's crust. Here this beautiful image in the middle with this fantastic bio-pattern microbial mat sitting there. This was an experimental set up that Niki Parenteau at the NASA Ames has where she can actually control the gas mixture within the chamber here and grow these organisms under, for example, Archean type atmospheres. And this panel over the top here with all the LEDs, this is in fact a tunable light source. It allows us to mimic the spectra of F, G, K, and dwarf stars for example. It also has an infrared component and an UV component as well. |
|  | So we can, this one isn't just a virtual planetary laboratory. It's actually a little planet system that we can set up and try to look at how life grows in those environments and also what gasses it puts out when it's forced to run a particular metabolic capabilities that it has under different types of environments. |
|  | Okay, so I'm now going to go briefly through the different tasks and the type of science that we can do with them. Just to give you an overview of the type of science that we do and this will go fairly quickly but again if you want to ask me more information about a particular project later on, we can get into that. |
|  | So task A, using the solar system as an analog for exoplanetary systems and also essentially emphasizing the exoplanet solar systems synergies and what we can do with that. So here we use observations and models of Earth, Venus, and other solar system objects. Again, Venus is an exoplanet alternative too [inaudible]. So processes might be discriminant and relevant to exoplanet biosignatures and biosignature false positives. |
|  | I am just throwing two quick examples up here. Ty Robinson, who's a genius at this, goes around the solar system. He started looking at the Earth as an exoplanet but he also found other data from Cassini looking at stellar occultations through the Titan haze and in fact giving us a simulation of what a hazy exoplanet would look like in a transition spectrum. Because we have more information, we are more able to adjust and improve our models to model hazy type environments against that transmission geometry. |
|  | We also have, this is work that Dr. Yaeger is working on right now. We're working on improved retrieval models and with our radiated transfer code, we found this great Earth occultation data set that was put together by Magellan and Cowen and McGill University which combines a bunch of, again, Earth observations but it is one of the most detailed transmission spectra of the Earth that you'll ever find and we're using it to test our transmission models to see just how good it is at reproducing things at high res to allow us to also simulate high res grand res observations as well. |
|  | We have a bunch of Venus as an exoplanet studies as well to understand the evolution, climate, chemistry, environment and spectra of hot Earth because of course hot Earth will be one of the first things we observe with instrumentation like JWST. So there are a bunch of papers on that over the years. Andrew actually put together a fully, self-consistent exo-Venus model that allowed us to look at TRAPPIST-1 planets as Venuses using, as a core, an actual solar system Venus model. John has worked on retrieving information from Venus and understanding what we can and can't see there. And Mike Wong, at the moment, is working on chemistry of Venus and its catalytic chemistry and trying to understand how that might change when you force it with an M dwarf spectrum. Part of that is looking for false positives, in fact, for oxygen. |
|  | Okay, another task A thing. Does it have an ocean? A good question we might ask ourselves and so how can we, in fact, try and figure out whether a distant planet which we can't [inaudible] has an ocean on it's surface? One of the most direct ways of doing that is to look for this ocean glint. So that's when you see an object that is very close to crescent phase. You may well see specular reflectance from any liquid on it's surface. This is a fantastic image of Titan taken with Cassini VIMS where you can see, it's a mirror for wavelength, you are seeing down through the haze and you are seeing specular reflectance off an ethane, methane lake on Titan. So we can see that phenomenon there. Then on the Earth, you can see this really, that bright spot here at crescent. You are in fact an ocean detective. That is something from the Earth's ocean taken from the LCROSS spacecraft as it looped around the Earth on its way to crash landing on the moon which was its mission. |
|  | So, yeah. So we're able to simulate this model and then translate that to what we might see for an exoplanet and look at the potential detectability of oceans for exoplanets. That project was also picked up by Jake Lustig-Yaeger who made it even better by allowing us to use time resolved measurements of a planet like you might get from the LUVOIR space telescope for example. Time resolves spectroscopy as we integrate on an exo-solar Earth-like planet will take many, many hours to do that but if we integrate, we'll have individual flush observations as a function of time. And so we're able to pull out of those time-resolved spectra essentially a map of what the surface is and break it into two different types of components. |
|  | One component which is actually tracking the ocean here, although we won't know that in real life, but we'll know that there is this component. And then another component. And looking at the phase dependence of the behavior of these two things. So in the blue case where you're looking almost directly down on the planet, it has this particular apparent albedo. The ocean is very dark. It doesn't reflect a lot of radiation. But if you look at the planet at crescent stage, you get that specular reflection from the glint and you can see the actual reflectivity of the planet just leap up as a function of phase whereas the land doesn't do that. It pretty much stays the same no matter what phase you're looking at. So by doing this mapping and the phase dependence and the time dependence, we may be able to generate the ability to actually detect whether or not an ocean is present based on the phase dependent behavior. |
|  | Because we tie to telescopes, Jake went on in his paper to actually calculate the yield for missions like HabEx and LUVOIR and came up with an number that one to 10 oceans might be directly detectable in this way. For direct imaging missions it was a 6-15 meter mirror. So HabEx would miss out in this case because it has a four meter mirror but if we went with one of the LUVOIR versions, we might in fact be able to detect oceans as well. |
|  | I think, yeah. So again, the Venus as an exoplanet, I summarized it on the other slide, but we are looking at things like the ocean loss process and the fact that Venus is an ocean loss planet so it can be used as an example of what happens when a planet loses its ocean so we can apply that to other exo-solar planets. Venus also has an amazingly high rate of CO₂ catalysis given how close it is to the star, but O₂ does not build up in its atmosphere which we think is due to the catalyst. That it is in Venus' atmosphere. Mike Wong is working, post-doc working with me, is working on trying got better understand these catalytic reactions and build them into our exoplanet models so we don't [inaudible] O₂ is going to build up because we don't have the right catalytic cycles that Venus told us about. |
|  | Okay, the Earth through time task B. So that's where our geologists and geochemists work to understand the environment of life on early Earth and also our biologists. What is task B about? Early Earth as a series of habitable planets. Potentially, we have this one habitable planet we know and love over here on the left. That's really not what the Earth has looked like for most of its history. So going back to getting data on those environments, we can learn more about what the prevailing environmental conditions were, when metabolisms rose that dominated the early Earth and therefore might have dominated biosignatures on the Earth, and then how to recognize habitability and life for planets that look like our Earth did early on. |
|  | I won't go through this in detail but this is some of our main projects looking at the origin of methanogenesis. Methane is a very detectable form of gas that could be a biosignature so we want to understand how that's changed over time. The early nitrogen cycle could be very interesting for coming up with some novel biosignatures or at least letting us know about things we know about, like nitrous oxide for example, might have dominated in the Earth's environment. And the nitrogen cycle in the Proterozoic oceans is also part of that. |
|  | What I do want to concentrate on is this recent paper that was done by Rika Anderson and Eva Stüeken who are two graduates from our Astrobiology program here at the University of Washington and they're both friends. Eva is over at St. Andrews. Rika's down here at Carleton College. And we actually dreamt up this project, so a bunch of us were sitting around actually one day having snacks and drinks and I was with John Maris as well, who is a legendary astrobiologist oceanographer, and we were discussing how we might actually figure when biosignatures dominated at different points in the Earth's history. |
|  | We came up with this crazy project which Rika has now influences and it's a paper that one of her post-docs that she's been supervising has led. What they did, and this is really cool, is that Eva who is the biogeochemist geologist. She went into the isotope record for the rock record and figured out when particular isotopic fractionations first arose that indicated life processes and the origination of particular metabolisms. So for example, in nitrogen fixation, there is a certain fractionation you'd expect from isotopes in the rock record at that time. She gathered that data and figured out when metabolisms first arose. |
|  | Then Rika used genomic studies going back through when genes were first believed to have arisen and then when they radiated, which is the biological term for became incorporated in a bunch of different organisms or became one of the dominant metabolisms on the planet. So from origination to dominating the planet. So those two worked together with their colleagues and students to put together this map of how these particular metabolisms arose and then the gasses that come off of these metabolisms when they might have been dominant in our environment. |
|  | So I have another student, Gabby [inaudible], who has started with that. She's working on looking at the environmental impact of what Eva and Rika found throughout. So I really like this project and I think it's really cool. It gets all of our different components. The geologists, the biologists, and the astronomer are now all working on this particular project. |
|  | Similarly, many of you probably know. Giada Arney. She is at the Goddard Space Flight Center. She is deputy project scientist now for the DAVINCI+ mission concept which is under development. But she was very much my Earth through time guru when she was a graduate student with me. She simulated a bunch of different environments and along with papers led by some of my other students as well looking at when we might see different biosignatures in the history of the Earth looking at the rise and fall of different gasses throughout. So we have this picture of how this spectrum might have changed over time. |
|  | I actually really like this one here in the Proterozoic Earth before oxygen has risen. It turns out that this ozone band down here, if you have a UV capable telescope, we are so sensitive to ozone at these wavelengths that even tiny amounts of oxygen can produce enough ozone to be detected. So even though oxygen itself cannot be seen in the spectrum, it would be this tiny blue thing here, you can in fact pick up a pretty strong signal from the ozone so that might be a way of stealth detecting small amounts of oxygen as a biosphere works to generate oxygenic photosynthesis. |
|  | Okay, a habitable planet. In this case again we're doing a lot of modeling. We do planet formation and migration. Looking essentially at initial planetary properties. Trying to understand volatile delivery and what initial compositions we might have to work with because ultimately we want know what's out-gassed from the original planet as well that might form the secondary atmosphere that we are more likely to interact with as astronomers. |
|  | We look at planetary evolution in our models so the diversity of plausible environments, the likelihood that you lose your ocean, what is retained, what happens to the atmosphere as you generate a secondary atmosphere for example. That's a really important question that we like to look at. |
|  | Then for most is evolution and different types of environments we might get. We look at more of the observational focused things. We're looking at planetary environments and their observational discriminants. We're trying to assess if a planet loses an atmosphere or loses an ocean or has its composition involved in some way because of its interactions with its star, then what are the key environmental observational factors and discriminants that might let us know that these things happened to the planet. |
|  | So again, we're focused on this planets are hard diagram. I think this is one of the more interesting sequences we've done in the last five years or so which was looking at stellar evolution impacting atmospheric composition which in turn impacts climate inhabitability and time all put together. So this starts with, and I forgot to put the references and the papers on this one. Oh, no. There's one up there. Okay. But I didn't put Andy's reference on here. |
|  | So this was Rodrigo Luger and Rory Barnes, his advisor, working on looking at the pre-main sequence phase of M dwarfs and how that is super luminous as the M dwarf juts out to a fairly large size but then collapses finally onto the main sequence. As it's being large and super luminous, any planet that forms in what will become the habitable zone is essentially going to be subjected to enormous amounts of radiation early on. So it's in this part of the diagram down here, there is way too much radiation. This line is where you cross into safety. This is the line for the inner edge of the habitable zone. So you can see for TRAPPIST-1E for example, it spent a lot of time in what I call the popcorn zone which is where it would have its atmosphere potentially lost or an ocean boiled off. So a significant change to the conditions on that particular planet until it finally gets to a safe haven on the other side of the habitable zone right here. |
|  | You can see for the Earth, we spent a tiny amount of time in the popcorn zone very early on as the planet is forming, and then after that we're in a situation where we don't experience this very bright super luminous phase that could boil an ocean off initially. |
|  | But if we use this model, we can calculate, say for the TRAPPIST-1 planets, the amount of oceans they might lose, conceivably, over time and then what that would mean for oxygen buildup in their atmosphere. So if you lose an ocean, you vaporize it, you send it up into the atmosphere. You can photolyse the water vapor and you lose the hydrogen space, and you can potentially leave oxygen behind. That oxygen could be sequestered in the surface, drawn down into the mantle, drawn down into a magma ocean, or potentially lost off the top by even more violent ancillary decay processes. So it's not the case that will end up with massive amounts of oxygen but we might end up with far more than we would expect for a biosphere. |
|  | Just to give you an idea, if you lose one ocean, you get 250 bars of oxygen from that. So it turns out the TRAPPIST-1 planets could have lost many, many oceans equivalent of water and the endoplanets in particular, we only gave them 20 oceans and they lost pretty much all of them within the first billion years. |
|  | So that can be an issue, certainly, for these planets. But we're also looking at what I call Renaissance planets which are cases where you lose your initial atmosphere and ocean but you still have enough volatiles within the interior to out gas, potentially, an atmosphere and an ocean overtime, so we are also looking at that process as well. |
|  | Andy took this ocean loss and O₂ build up, look at different types of atmospheres that might be generated from ocean loss and then just calculated, used a couple planet photochemical models to calculate their surface temperatures, which is what you're seeing here. What you're seeing is that things in the habitable zone, E, F, and G, they still are statistically more likely to have a habitable surface temperature denoted by this lead condition here. Even for a bunch of different types of compositions. The habitable zone is definitely statistically a region you would like to look in first no matter what has happened to the planet over time. But then in other cases we actually thought if the planet developed a Venus like atmosphere early on in its evolutionary phase, it didn't matter where it was. Even beyond the habitable zone, we still ended up with uninhabitable surface temperatures from a Venus like environment. |
|  | Lots of fun out there. When we actually get a chance to look at the TRAPPIST-1 systems, we can try and distinguish. Are we looking at a permanent Venus type thing or are we looking at things that are potentially more habitable or can we see the signatures of massive ocean loss in the O₂? |
|  | All right, other things that we have done. This is work by Aomawa Shields and she looked at the stellar spectrum impact on ice-albedo climate feedback. Here on Earth we think ice is a really highly reflective high-albedo thing that cools the climate so we have this concept of runaway aglaciation being the edge of the habitable zone. What Aomawa did is she used 3D GC modeling to look at whether those relationships that we intuitively think are the only relationships for G dwarf planets actually hold when you go through a very different stellar spectrum. |
|  | The key here is that in the visible, ice is very reflective and in the near infrared, ice is very absorptive. It has a very strong absorption feature there. So for N dwarfs, which output most of their radiation in the near infrared, it turns out that ice is something that warms the planet rather than cooling it. So she looked at a bunch of different scenarios of how that would play out. She turned the star up and down to look at how the climate would cope with the changes of insulation and what that meant for whether the planet was in fact completely ice covered, which would be down here, or in fact had no ice at all. |
|  | So she was able to show that N dwarf planets can remain ice free and with small polar caps under far lower insulation. So in a sense, it's much harder to get them into a snowball Earth type of state and then in the second paper, she showed that actually you need very little extra insulation. You can turn the star up just a tiny amount to get a N dwarf planet to melt out of its snowball state whereas it takes a lot more chemical inertia and a lot more radiation even to get a G dwarf planet out of that state. |
|  | It's very interesting. It changed our concept of how climate actually behaves to planets orbiting N dwarfs just through the simple mechanism of the fact that the spectrum of the N dwarfs comes out not in a visible, primarily, and so surface materials react very differently with that kind of spectrum. |
|  | We've also looked at stellar spectra modifying atmospheric composition. This is very important. So the star with the GV spectrum will change the photochemistry of an atmosphere. This thing over here is what we call a spaghetti plot. It looks a bit like a kelp forest with the four ranges here. But this is the mixing ratio of species. So the abundance of molecular species in an atmosphere as a function of the altitude in the atmosphere and what we're seeing here is these different colors, green lines for example or yellow lines, are in fact the abundance of the constituents changing as the spectrum of the host star changes. |
|  | So what this does it that for certain types of N dwarf planets, especially around N4 planets, they tend to preferentially build methane up in the atmosphere based on the spectrum of the star, which is very good at essentially not destroying methane. It cuts down on the catalyst. It's complicated. I can go over it later. But because of the spectrum of the star, methane will tend to build up around these N dwarf planets and so what that means is that this is a simulated transmission spectrum of, for example Earth, around Proxima Centauri which is this mint green color versus Earth around the sun. You can see a very big difference in the strength of the methane bands as a result of that preferential buildup on the photochemical spectrum. The photochemistry driven by the spectra of the star. |
|  | And another work that Evan is working on right now, Evan Davis, we are looking at what that means for our ability to interpret how much methane is actually coming off the surface of the planet. If we don't model the spectrum of the star adequately to understand how efficient it is at destroying methane, then we can't really say based on the abundance of methane in the atmosphere, what the source rate of methane is. If we don't know the destruction rate, it is very hard to find the source rate. It turns out that the source rate of methane, how much methane flux is actually being produced at the surface of the atmosphere, falls into one bin for biological fluxes as we know them and into another bin for geological fluxes. So it's really important to discriminate between geology and biology by understanding the spectrum of the star. |
|  | Okay and a living planet, we have again these really super cool experiments where we combine field and lab experiments with a couple chemical, climate, ecosystem models to try and figure out new biosignatures. Here is Niki's amazing set up with her fake star. Actually, I was really excited about this because it was the first time I had seen a [inaudible], a piece of hardware. We don't do that typically. So here we go. [inaudible], a piece of hardware. And so she's been looking, also working with Giada Arney who is our queen of haze but she also studies Venus... |
|  | That's another thing, by the way. I try to make sure that my students study a planet in the solar system in addition to the exoplanet part. So Venus was Giada's signature planet because she was very interested in haze and the development of haze on planets. So she associates haze in the early Archean as well and Niki and Giada are running these experiments to look at the growth and behavior and survivability rate of organisms generated under an Archean type of haze. |
|  | Then there's ideas of developing new frameworks for biosignature interpretation. I think that's a big thing that VPL has pushed. I'm very proud of it. That is because we, it was really weird. It was like an emergent phenomenon. We simultaneously over the period of 2013-2015, came up with a whole bunch of ways that we could generate oxygen without having an oxygenate biosphere on a planet. But we're also able to realize if I can create this in my models, I can also generate what the environment is doing in the models and determine if there's anything in that environment that gives away the fact that there's other processes working. There's non-life processes working. So I guess this has become a moderately famous diagram but it just shows where we might get oxygen in the atmosphere. Here's an example around the defecated CO₂ rich N dwarf that's quite cold if it has no water vapor in the atmosphere. But in that case we would start to see the breakdown products from carbon dioxide building the atmosphere. You would see carbon monoxide actually there. We would not see the water vapor for example. |
|  | So there is a whole bunch of different scenarios where, it terrified us initially. It was like, oh no. Oxygen is supposed to be this [inaudible] biosignature but here I've just made a false positive for it. But we learned to love it because by determining the false positive and determining how it's discriminated it from an authentic biosphere like this one over here, that meant that we were actually making that biosphere more robust rather than less because every time we can knock off the possibility that it was created by something else, we are really building a very strong case for the fact that the oxygen is coming from life. |
|  | All right. Then our final task, observer, we do a bunch of things there. Small exoplanet detection and assessment for target prioritization. That's led mostly by Eric Agol at the University of Washington. We characterize the host star. That's led by [inaudible] as ASU. And we do spectroscopic simulation, detectability assessment, and retrieval for the things that, as I said, everything else that we've modeled before. All those ocean loss planets. Everything else. We can now generate spectra for those. Run them through noise models and simulate how detectable they are to JWST or and ELT or LUVOIR for example. And we've spent a lot of time also testing observational techniques for JWST. |
|  | This was a very recent paper that, I think, just came out last month. It's by Eric Agol and Caroline Dorn over in Switzerland. They took lots and lots and lots and lots of measurements with Spitzer of TRAPPIST-1. The TRAPPIST-1 planets interacting with each other. The TRAPPIST timing variations from the interactions of the planets with each other to measure their masses to absolutely within precisions. So they basically measured them to within 3% to 5% of the accuracy of the masses which is in fact equivalent to an EPRV precision of 2.5 centimeters per second. Which EPRV cannot get right now yet. Right? So it's two orders of magnitude better than that. |
|  | So if you have one of these massively interacting multi-planet systems and you're to dedicate an enormous amount of telescope time to it, you can in fact get these amazing measurements. So with that high precision math, they're able to show that the planets of the TRAPPIST-1 systems all have a fairly consistent density. Some of these guys might be a little less dense than others, the ones further, actually away from the star but it's not a specifically significant result yet. So here we have Venus, Earth, and Mars down here on this dash line here showing a density of terrestrial planets in our own planetary system and then we have the TRAPPIST-1 planets sitting a little bit above that showing that they are definitely overall less dense than planets in our own solar system. |
|  | So that allowed Caroline to start working on interior models of what might be happening there. What we're looking at now is examples of terrestrial planets but unlike the ones that we see in our own solar system. They are similar size but the density is very different. So the question is, why is that? Is it because they have a smaller iron core? That would pretty much get you that density reduction. Or is it because they have no core? I mean, these are potentially volatile subjects that have formed beyond the snow line and so could potentially could have a lot of water in them. Potentially that can react with iron in the system and get tied into silicon within the core so you could end up... I'm sorry. Within the mantle. You could end up with a core-less, all mantle planet. |
|  | They also looked at what I think is the most intriguing result is that the reason that they are less dense is because they have a much higher volatile fraction and so potentially more water which Caroline modeled as either being on the surface or being suspended in a steam atmosphere. But there is certainly work to be done in looking at it. Also, the water being tied into the interior as well. So that could be pretty cool. This could be a water world type planet. |
|  | So we have worked on trying to figure out how to characterize these worlds to look at whether or not they have an atmosphere. This is work that Jake led. I also have to give a shout-out to Caroline. Actually, she's not cited as reference but I'm pretty sure that paper's published by now. Caroline Morely, who is not part of our team but we are just sharing these observations side by side and that we got very similar answers. So that we're not just making all this up or if we are, at least the models are all being consistent. We believe that we can potentially detect whether or not these planets have atmosphere in as little as two to six transits with JWST. So that will be exciting, especially for people who want to know whether, did the TRAPPIST-1 with its [inaudible] sequence blast off that atmosphere? Are we looking at airless worlds closer to the star and maybe planets with atmospheres further out? This will be one of our, a good test is which we can actually see that. |
|  | We've also modeled things that we might want to try and detect that might give away the fact that this planet has lost an ocean. And these O₂O₂ collisions induced absorption lines are where oxygen molecules smash into each other. They do that far more frequently if the atmosphere has a dense oxygen component. So at about three bars, you start to see fairly strong... Three bars of oxygen, you start to see fairly strong O₂O₂ signals. That's something we could potentially detect with JWST. |
|  | Then down here, Andrew did some pretty interesting work that showed, at least for a clear skied Venus which is the type of Venus we think that TRAPPIST-1B would be. TRAPPIST-1B has retained an atmosphere. It is too hot to form sulfuric acid cloud so it might be a clear sky Venus. Actually, I think this one is a clear sky, oh yeah, this is a 10 bar O₂ atmosphere as well. So again, ocean lost if it doesn't build up the CO₂ over time. We have a fresh ocean loss scenario, we may have again a fairly clear sky oxygen, oxygen atmosphere. And in that case, we're looking at the potential detectability of a high fractionation of HCO to H₂O. So again, when hydrogen is lost from an atmosphere, the heavier D from the H, the deuterium can be left behind. So the fraction of deuterium builds up over time as the hydrogen gets lost to space. And that enhanced HCO ratio could potentially be detected in as few as 10 transits for that one target, the TRAPPIST-1B. |
|  | That would again be not only a good indicator that it lost an ocean but also an indicator that it doesn't have one right now because if it did have an H₂O ocean at this time, then the HCO fraction would be diluted. So if we see an HCO fractionation preserved, it means that an ocean has been lost and there is no ocean present at the moment. |
|  | Then of course, does it have life? So data we see in TRAPPIST-1, so we are looking at terrestrial exoplanets. Looking for biosignatures. There's this paper that's been in prep from me forever. I swear I'm going to try to get it finished in the next month or so. The students who are working on it are like, "Ah. Just get it finished." Okay. So what we did is we simulated a bunch of different types of biosignatures in this paper from oxygen, CO₂, methane. A whole bunch of things that you might expect from terrestrial planets. |
|  | So we looked at the detectability of those with JWST and interestingly, and I think this is a really important point, is that the most detectable things with JWST are CO₂ and methane. It turns out that oxygen is terrible. JWST is very bad at oxygen. So that's not really going to be the way we're going to go with it but CO₂ and methane together are in fact a disequilibrium pair. They are a disequilibrium pair that fascinatingly have been around pretty much for as long as we've had methanogenesis on our planet. So we've been producing very high rates of methane from the surface of the planet that are higher than we would expect in geological fluxes. The carbon dioxide is just there as a marker that, hello, I've got an oxygenated atmosphere even if it's just pure CO₂. |
|  | And so this particular pair has actually literally been around for the entire history of our planet. It's still present now. So even if we can't detect the oxygen, we could still detect the methane plus CO₂ disequilibrium pair. Now CO₂ and methane are fairly common constituents of a terrestrial planetary atmosphere so even if we detect this and it is in fact due to a biosignature, it might be difficult to prove that. So it's a highly detectable pair but it might be a difficult one to interpret. |
|  | Oh yeah, and Jake's working right now on a full retrieval to enhance our sensitivity to this sort of thing. My paper is just the detectability paper. I'm looking at [inaudible] but Jake's going to do a full retrieval and see whether we can use some tricky techniques to get some more sensitivity to this sort of thing. |
|  | Okay, so I'm going to wrap up here by going through, it's a fairly long wrap up though isn't it. I'll go as quickly as I can. Just looking at our impact on exoplanet astrobiology and where I think this massive interdisciplinarity has really been able to push the field forward. So as I said, we need that exoplanet solar system synergies concept again driven by the fact that the funding agency wanted us to do something with Earth and with other planets that we, that was basically it right from the beginning. |
|  | We tried to harness terrestrial planet and exoplanet evolution to not just look at things as they were right now but to try and understand the story of a planet's evolution through time. So the Earth through time. This is Niki by the way. This is Niki here with her setup. She took us on a field trip to Yellowstone which was really great. Niki's the one with that amazing lab with the gas chamber set up and the fake star. Yeah. So we are able to look at the Earth through time to try and understand what that could tell us about potential different types of habitable worlds that we couldn't access any other way except to go back through the geological and biological record. |
|  | We've looked at the terrestrial evolution coupled to stellar evolution to try and understand significant processes like atmosphere and ocean loss over time and what might happen. We have definitely embraced the concept of it takes a village to model a planet and tried to get as many people involved in not only allowing us to measure something but in being able to interpret it. |
|  | We did pioneer a system science to habitability. The realization of this diagram and our coupling very early on of the stellar and planetary and planetary systems processes into how we tried to conceive an exoplanet. So this was really, and again, a massive interdisciplinary experiment in exoplanet science and I think it's been both successful and scalable. So the NExSS research coordination network is essentially an attempt to push many of the themes that VPL has developed into a much, an even larger forum overall. |
|  | I will say, too, that we've had a very strong mission relevance and if you remember, you figure out what the sponsor wants and you give it to them. So if NASA is giving you funding to do something, it probably needs or wants something back. So it's really good when you're going again for funding, especially if you're early career, to really try to figure out what that is and place yourself in a position where programmatically you're going to make a lot of sense. |
|  | So when you do a proposal, there's two way you are selected. One after the other. One is you have to have good enough science to get into a pool of proposals that could be selected. After that, the program manager will come in and choose from those highly ranked science proposals, will choose the ones that best fit the portfolio of what they need out of their program. So it's often possible to win based on programmatic aspects. So it's always a good idea to place yourself. And by programmatic, I mean are you really responding to the call and what they want. The types of science that they are wanting to see done? |
|  | So we've been tying into stimulating things for JWST. The [inaudible] support people writing proposals for JWST. A lot of our team members, whether we like it or not, ended up on science technology and definition or study teams for a bunch of these different mission concepts that were developed. But all joking aside, we were actually thrilled to be able to use our research to help plan these types of missions. |
|  | Then I think one of the most important things that we've done at VPL is to try and train the next generation of astrobiologists and mission scientists. I've just got a handful of bright young people up here. Many of them are ones I featured today. These guys are just, I think for me, I am proudest of the fact that we have trained a bunch of absolutely amazing scientists who are going on to do amazing things. |
|  | So Tiffany, I do have a little thing on Venus science. Do we have enough time to go into that? I think I've talked for an hour so. |
| Speaker 1: | [inaudible] Tiffany had to drop off for another meeting. I think if you're up for it, it might be nice if we could move to the round table discussion- |
| Victoria Meadow...: | Sure. |
| Speaker 1: | ... with the cohort because I think they have mentioned there is a lot of stuff they would like to pick your brain about. |
| Victoria Meadow...: | Okay, so let me just skip over the last bit and I'll finish with things I've learned from running the VPL. So this is my last slide. |
|  | You have to have a vision and a focus question. Proximity doesn't spawn interdisciplinarity. Just getting all these people together and putting them in a building together doesn't work. A common goal does. And that common goal can work virtually. People can be all across the planet but if they still have a common goal in their research and they can come together and discuss that, then that is really interesting. |
|  | There is a pyramid to interdisciplinarity so if you have that central goal at the top and it's an interdisciplinary goal, then even people with a single discipline component, even a geologist taking a measure of the rock record or a biologist measuring something, can still participate in that interdisciplinary by feeding their results up to projects that combine and use those data. |
|  | Collaborations run on trust, communication, and good will. That is super important. Because of that, you really need to pick your team members well. Really. This is key. I have a rule which I won't repeat here, maybe later. But essentially it is really important to have good team members who are willing to work with others and support others and to support early career people as well. |
|  | You need to interact often, especially when you're across many different disciplines. You have to teach each other and have formal and informal ways to interact. I like to encourage a culture based on scientific rigor and cooperation rather than competition. I just find that is a much more powerful way of doing science. It isn't the traditional way and certainly our incentives within science are not built up to support that as much as it is to support the competitive aspect. And I will say that competition can definitely be a good thing but certainly in a collaboration you don't want competition within the collaboration. But you do want to help each other, challenge each other, learn from each other, build a research community. And again, the highlight for me is being able to train my future colleagues. I also try to engage them in the non-research aspects of being a scientist as soon as possible. It's one thing to learn how to do research but you also need to navigate what science is and learn the tips and tricks of doing that. |
|  | Finally, it's been great. We've had a lot of fun and as many people go on to do, just enjoy being paid to search for life beyond the solar system because, wow, what a fantastic thing to do. |
|  | All right. So I will finish there and we can go to the panel. |
| Speaker 1: | Perfect. Thank you so much, Vikki. That was a wonderful talk and there was a lot of commentary in the slack between the organizers and how impressed we were and how seriously you took the request to talk about setting up collaborations. Obviously there is a ton of effort put into this. So thank you very much. |
| Victoria Meadow...: | You are very welcome. |
| Speaker 1: | Okay, so I'm actually going to not sign off because that would kill the meeting, but I'm going to mute my computer and turn off all of my inputs and stop this recording in a moment so that you and the cohort can have your round table discussions. |
| Victoria Meadow...: | Okay. How do I unshare? Hang on. Here we go. |
| Speaker 1: | It should be, yeah, there should be something to stop sharing. I'm going to nix this recording for now. |
|  |  |