Madyson Miller: Okay, so how this is going to work is we're going to sort of both do the interview. So, I'm going to start it off, and then once we get to a point where Zach feels like he's ready to take on - he wants to talk more about the mapping and that kind of stuff. So, when we sort of transition the conversation into that, Zach will take it over also because I may or may not have construction going on in the house next to me, and it can get a little distracting. So whenever that starts, I'll go on mute, and we'll switch it up. So, if we accidentally ask a question over one another, I apologize for that. I'm going to basically do like, a little intro, introducing ourselves. You'll introduce yourselves. We'll say like, the date and time that we're doing this interview, and then we'll just get right into it. But we have to slate the interview first. Awesome. Okay, so I'm going to get started. Are we good? Okay, so morning. Before we get started, I just want to break down exactly what's happening. We just did that. So, I'm just reading my script for no reason. We're going to talk about all the things that we talked about in our prep interview. So coral reefs, your experience, your upbringing, expertise, Hawaii, coral mapping, all of that. If that all sounds good, we'll get started. I'm Madison Miller. I'm the Knauss fellow for NOAA's coral reef conservation program. And also interviewing today is Zachary Mason, who's also from NOAA's Coral Reef Conservation Program. Today is Thursday, September 29, 2022 at around 10:40 a.m. Eastern Standard Time [EST]. Can you please state your name and the location that you're calling from?

VC: Sure. My name is Ved Chirayath, and I'm calling in from around Key Biscayne in Miami at the Rosenstiel School.

MM: Awesome, well, we're super excited to have you, and we'll just start from pretty much the very beginning. Can you tell me when and where you were born and a little bit about your upbringing and sort of family life?

VC: Sure. So, I was born in Tucson, Arizona, in the middle of the desert, and my parents had moved to the United States from India and from France. My mother was born in Nice in the south of France. And then her family moved to India and started a ceramics factory where she met my father in Bombay. And they moved from Bombay to Buffalo, which I'm sure is the title of a great autobiography to come. And then from Buffalo, they managed to find the other weather extreme in the United States and moved to Tucson, Arizona, where I was born. My sister was born in Buffalo, and then when I was about three, we moved to Southern California and then bounced around quite a bit in the Los Angeles area.

MM: Awesome. So, you said you lived in the desert. So how did all of your childhood experiences sort of transition you into this world of science and space in the ocean. Can you tell us a little bit about that?

VC: Sure. So, I think I may have gotten the bug for science, even when I was in Arizona, maybe before I was three. There was a gemological show that would come to the state every year, and we would religiously go there, and they had all of the crystals you could imagine, and the diversity of just these inorganic structures were fascinating to me. And then also, the night sky in Arizona is just stunning, and you really get a sense that you're just looking on the universe's doorstep. So, when we moved to Los Angeles, I grew up with a passion for astronomy and for science. And then I started swimming a lot and getting into various lifeguarding activities and diving in the Los Angeles area. And I got to go on a field trip when I was in middle school. I remember it was incredibly memorable because we did a night dive. I don't know how this was permitted or organized, but it was one of the most amazing night snorkeling trips for middle school students out on Catalina. This was before we knew there was a family of great white sharks that lived in those waters. It was mind blowing. Until that point, I was about eight years old or so when I had gone there, I was completely bent on space and astronomy. I knew I wanted to work at NASA since I was about four, and I'd been going to the JPL open house. This is NASA's Jet Propulsion Laboratory [JPL] in Pasadena, and I was watching the Mars rover coming in and landing live. I got to meet Buzz Aldrin. And then suddenly I was plucked and moved into this night snorkel with all these kids in Catalina who were terrified, but I was just enthralled. I kept swimming away from the group. I remember because you could hear so many things, you could see so many things. Every time you moved your arms around, there would be this bioluminescence that would light up. And if you cleared your snorkel, you could basically shoot these stars into the sky from bioluminescent phytoplankton in the water. And then right around this time, to cap it all off, there was at the time what seemed like a thirty foot - It probably was just a ten foot wide - manta [ray] just swam silently beneath us, like this fighter jet that you could not hear. Some people had a different reaction to it, but I couldn't believe it. As it was swimming, it was trailing these bioluminescent contrails, and I thought, “”oh, my goodness, I've been looking maybe in the wrong direction.” There's so much unknown here that also excites me. It's kind of those two passions that led me into science and to try to understand how the universe is made. What makes life tick? Why is life so unique? I spent a lot of time thinking about life outside of Earth. And ultimately, in high school, I had taken that passion to the next level and just said, you know what? I think that we can find planets by looking for the dip in the amount of light coming from a star if a planet transits that star. So, we have that occur on Earth with lunar eclipses. It is a great example of where the Moon passes in front of the sun, it blocks it out. I mean, that's an extreme example of, yes, there is a planetary body orbiting us, and it’s manifestly spherical. Then the probability of that, though, was sort of up for debate. How often, if you were to look at the night sky at stars, would you happen upon a solar system outside of our own that had the right inclination relative to us, that would allow for, hopefully, a large planet to pass in front of its host star and dip the amount of light? I naively started building my own telescopes, getting into the field, and realizing, okay, this is much more rigorous. I'm going to need help. I worked with, at the time, I had an amazing high school teacher, Mr. Thomas Jet, and he said, we're going to figure out all of the math and science that you need to do this, but if you can't find another planet out there, at least let's get you engaged in the field, right? I found a university professor mentor who was at USC [University of Southern California], and in a completely different field, paleo magnetism. But he indulged my astronomy ambitions, and eventually I realized, you have to become really adept at measuring variable stars to try to find planets using this method. And so eventually, I started just looking at known variable stars that had cyclic variations in their brightness. And then that led to finally being able to develop a little camera that was digital, that I made, that cooled, and that camera finally had the sensitivity at a certain point, to start looking for large planets outside of our solar system. I started just periodically scanning all of the known or unknown - just random areas of the sky that finding, hopefully, a star that would exhibit this dip that was not a variable star. Anyway, long story short, after about two and a half years of doing this alone on a mountaintop, going in between classes and doing all of my work remotely, I was able to detect a new planet about one and a half times the size of Jupiter. And that, in high school, when you can do that, it just suddenly makes the world like it seem realizable. All your dreams you can do if you just apply yourself. And science, I think, is one of the most professionally democratic institutions out there in that anyone can participate, anyone can have a good idea. It's really just can you apply yourself? And then often the most difficult thing is, can you get the resources to support you to do that task? I wish I was born a theorist. It would be a lot cheaper, but I was much more born experimentalist and using new tools. That experience and that research time, it really just lit a passion under me to go out and study more. I really wanted to know at the time everything about the fundamental laws of the universe. And again, seeking for that question of, are we alone? Are there other examples of life out there? Can we learn from those other examples? Because we've only got ours to go from. Our history on Earth is marked by many mass extinction events, so it doesn't bode well statistically unless you have another good example elsewhere. So, let's see from there - let me know if I'm going too far. That period in high school was quite difficult. My parents had divorced, and when I started ending up living alone and then homeless for about three years, from like 10th grade till my senior year in high school. And it was a lot during that time that I also found that science was something that excited me and in focus to me. But it also was this escape. It was in a way to get out of this environment where a lot of kids go through this, especially if they're LGBT [Lesbian, Gay, Bisexual, Transexual] identified. They can often get rejected by their own family or end up homeless, and various other things happen to them. For me, science kind of saved my butt. It was there for me when a lot of other resources weren't. And then also the public school system was there, and the library system was there. And those kind of three resources together, I think, enabled me to realize, okay, I can apply for scholarships. I can compete in - when I did the planet detection, I ended up going to the international science fair and winning and then joining the Science Talent Search, which, coincidentally, and I'm now a judge for. It's kind of come full circle. But it was opportunities like that, being born in the right country, growing up in the right place, and then having those amazing teachers and mentors who identify your talent and then enable you to succeed kind of no matter what, that really set me up to go on to the next level. After high school, I graduated early, and I moved to India to start volunteering for UNICEF [United Nations International Children's Emergency Fund], way up in the northern parts of India in Dharamshalah. And I worked for a nonprofit called the Center for Social Research that worked with women's empowerment and primarily domestic violence issues. For me, it was kind of an opportunity to broaden my horizon beyond physics, to learn a bit about my roots and where my parents came from and all the hardships they had to go through to get to the United States and how different it is. How if you were born in the other place and you have that same set of talents, you may just not have won the birth lottery. You may not get to detect a planet or go on and pursue your scientific dreams. You may often just get killed or worse. So, getting that perspective for me was really important before I launched myself into studying hardcore theoretical physics and cosmology. Because the one thing I worried about going to this field was at the same time my sister, who was kind of the all-star in the family and had gotten a full ride to Harvard right as I had left to high school. And I thought, okay, I detected the planet. Surely that counts, as it was like, no. But she was very focused on this issue, the human condition, and the fact that there's so much untapped potential out there, particularly in developing countries, where people don't need handouts, they just need opportunity is really what it comes down to. And that's kind of what differentiates, I think, how lucky we are in the US. Is that you're born into that opportunity, you're given that citizenship, and that carries so many intangibles, at times, benefits. And one of those is, if you're in science, it means that you have the opportunity to compete in something like the International Science Fair. You have mentors and things. Anyway, I'm getting distracted. So, I was in India for about a year. It was a really transformative experience. And then I decided to, after graduating early from high school, go continue in Russia to pursue my degree in physics and astrophysics. And part of it was I had limited resources. My scholarships, I had won a number of scholarships. They were incredibly generous. But at the same time, contemplating paying for an Ivy League education in the United States is just out of reach for so many people. And so even if you come in with a full ride and everything else, how do you pay for housing? How do you pay for meals? How do you not work three or four jobs? So that to me, and I'd seen how my sister had gone through that, and she was somebody who had lots of scholarships and had gone to Harvard, and it was really difficult for her despite all of those advantages. I decided, okay, my money goes a lot further in Moscow, where if I'm studying something like theoretical physics, all the same universal laws apply, and the system there is really good for math and science. I mean, at least for mathematics, it's top notch. The second reason was, since I was a kid, wanted to become an astronaut in the US based program. And so, for me, I had, during the international science, for one of the sorts of awards they give you, they name an asteroid after you which is very bizarre, but you also get to have lunch with an astronaut. And I kind of shared my plan with him. I had this master plan to become an astronaut since, again, I was about like, four. He kind of laughed, and I said, "look, do astronauts have to learn Russian to participate in activities?" At the time, international Space Station had very close partnerships with Russia. "Here's this idea I have to go to Russia and study. What do you think?" And he says, "Go for it. No one's ever done that before. And you'll learn Russian a lot better than all the other astronauts." I said, "okay, I'm going to do that." And that's what I did. I spent four and a half years, close to five years in Moscow. It was a bit of a crash course in realizing I got admitted because I had taken the exam, but it was in Russian, but it was mostly physics and math questions, so you could kind of understand what they're asking. And so that went well. And then I got there, and I realized, oh, wow, this is not going to be in English. This is all going to be in Russian. And I have to live, breathe, learn Russian. I don't know if you've ever stumbled across Russian. If you were to translate it, it sounds like Shakespearean English. They've kept all of their six cases. It's like comically complicated. Just to say hello is like six consonants in a row, and it's like this long. It's wild. I had taken a crash course at UCLA right before I left, just in Russian. And then I thought, okay, surely the largest European city I'll be able to speak English. That was eye opening, but it was also kind of it drove home that point that people who come to the United States like my parents did, they both had the advantage of growing up in a English speaking countries and households. But it's an incredible culture shock. You're dealing with anew academic system, a new language, you don't have friends, you're different, and you've got to somehow get along and then compete with what I realized were all of the top minds in the former Soviet Federation. You've got the top math and science students going to Moscow State University, which is where I went, and it was intense. I kind of had to take remedial mathematics, and this was coming from having top scores and going to a math and science magnet academy public school in California. It was far behind in terms of the math level of what I experienced there. I quickly had to catch up there, figure out the Russian thing, and then things went very well after like, year two or three. I got to experience proper winters, which I hope to never experience again. But it made me also appreciate how nice the weather is where I grew up in California. So, yes, I had a good experience there. I adopted a subway dog, (Amisha?), who was fantastic and was this wolf like creature that kind of accompanied me everywhere I went. And then, unfortunately, in the last year of my education there, I was about to graduate, I had, unfortunately, a number of neo-Nazi racist attacks that were targeting people from the former Soviet Republic. So, there was a big issue with folks from the

Caucuses and white ethnic Russians, considering them to be taking jobs away from them, even though these were jobs that traditionally they didn't want to do. So janitorial, work, things like that. And there was just this I was surprised to see this level of fascism and neo-Nazism kind of thriving in a country that lost twenty-one million people to fascism. The same war that sent my grandparents out from Belgium, fleeing the Nazis and ending up in France and then finally going to India. That whole thing came full circle. And now there was a swastika painted outside of the dormitory building that I lived in. There were groups that were kind of marauding the streets and then stabbing people that looked like they were from the Caucuses. I had fit that profile because I spoke Russian and I was brown and living in Moscow, and so I was assumed, ironically, not to be. There're many other reasons I could have been targeted. I was American. I was LGBT identified, but all those things kind of disappear. You can't really hide your race. That did not help me. I ended up getting attacked three times. And then the fourth time, there was an attack intended for me that ended up targeting one of my colleagues, and he ended up in a coma, stabbed eighteen times, for three months. And so, at that point, I'd been applying for graduate schools and planning on going to graduate schools back in the United States. But it sort of accelerated my plan. And Stanford University said, "You know what? We want you to come in now as a transfer student because it's not safe for you there." And I thought, "Wow, this is amazing." Stanford was one of my top choices, but how am I going to afford this? And then a few emails later, they finally mentioned, also, it's a full ride, and we're giving you a stipend and everything. So, then I was able to leave. Unfortunately, a few weeks shy of graduating. I ended up completing my degree at Stanford and then kind of pursuing my dreams there. And it was a good experience in Russia. It taught me a lot about what people experience and then what people take for granted in different places. Coming to the US, and to Stanford especially, it felt like, I don't know, I'd entered this wonderland where suddenly you're accepted, you can be 'out'. In Moscow, if you were identified as LGBT, they could just expel you from the university. I was not particularly out around people, but with my friends, I was. And it's sad to see the situation has unfortunately deteriorated even more so than when I left. And now you're seeing all the issues that are going on now. So, I got to Stanford, and I started doing astrophysics theoretical physics again. And at that point, I was still kind of hooked on understanding the fundamental. I've been looking really big at cosmology, and then I started looking at particle physics, and very small. It's amazing how much we know about that whole realm and interactions. This is to the point where people were predicting particles properties before they were discovered. I often like to remind people, can you imagine just going into a room and sitting and then writing some scribbles down inequations and then saying, I predict there exists this particle, I'll call it the Higgs Boson, that has this mass energy, and you should find it if you look for it here. That, to me, was mind blowing. It was like the ultimate evolutionary trick, was we evolved to the point where now we can guess what nature is going to do next. That was tremendously exciting. I did that. I realized quickly, as much as my math was good, I don't think it was good enough to be a theorist. Then I said, you know what? - At the same time, I had met a professor in aeronautics, and he was, I don't know, just very engaging and got me totally hooked on studying aeronautics and astronautics. And so, I shifted gears into his lab, and he also gave me kind of free reign, research-wise. I said, "you know what? I want to do something different. I want to develop an airplane that flies on electric fields like in Star Trek." So, he's laughed. He said, "good luck." But then I found this emerging technology, plasma actuating controlled surfaces. These are little, literally. They're nothing more than copper tape and some capped on tape stuck on a wing, and you run 10,000 volts of AC [alternating current] current through them, and it creates plasma, and you can actually use that to accelerate air. I ended up making the first controlled flight in history of an aircraft that flies on electric fields. That led to this AAIA [American Institute of Aeronautics and Astronautics] award. I was super excited. It was fun to be able to hands on build something again, kind of like I did in high school, but with telescopes. I ended up continuing that, and I said, “I want to go back to merging some of my astronomy passions with this new aeronautics and astronautics background I have.” I started building instruments again and ended up developing a technology called atmospheric lensing that could look through the atmosphere and its blurring effects and try to image objects at higher resolution. I was imaging the Sun, the Venus transit, the Moon, astronauts on the ISS [international space station], doing spacewalks and I was like, this is great. We could image so many things at high resolution without big telescopes if we just applied some of these latest tools. And it was around that time that I got to meet Sylvia Earl who was one of my, kind of, childhood heroes growing up and an oceanographer. Her Deepness, we like to call her. She kind of pulled me aside. I'd been giving these talks at NASA, and I'd gotten hired at NASA nearby Stanford NASA Ames Research Center. And she says, “this is all wonderful, babe, but what has the universe done for us apart from give us planet Earth and the ocean? You should really consider diverting your talents to studying the ocean.” I said, “well, surely, we can image things in the ocean at high resolution. We can image all of these planetary bodies at high resolution in our own solar system.” And she said, “you'd be surprised.” And so that's when I started doing a little bit of research on kind of my childhood other passion of the ocean and realizing, wow, we really know less about it than we do about the backside of Mars. It's wild. We can lose entire jet liners in the ocean, big ones and not find them after a five, ten year concerted effort and search. Whereas there was a probe that recently smashed down on Mars. It was found within about a week of an orbiter passing over and the probe was the size of a golf cart. So, to me, the fact that we have this tremendous capacity in astronomy and aeronautics, astronautics, and yet that hasn't for some reason translated quite into this capacity for studying the only life support system we have. It was kind of concerning to me. And then being in California witnessing wildfires, seeing all of these dramatic climactic events occurring in a very compressed period of time, kind of pushed me into oceanography and Earth science. And I said, “you know what?” It's all well and good. I'm not saying that these fields should not be studied. Astronomy and particle physics should go on because they're still making fundamental discoveries that have impacts to our daily lives. But the reality is that we're living in an age where just this week NASA demonstrated the first successful asteroid redirection of an asteroid that's quite far away. Not a threat to us but just to test the planetary defense mechanism we have in place in case there is a planet killer level asteroid coming towards us, that we don't want to repeat the dinosaur level extinction event. But to me, it's ironic that at once we can deflect what is potentially a life ending event in orbit a hypothetical one. And yet here we are, and now, living in Florida, I'm witnessing firsthand category four or five hurricanes walloping us. And it's a much more direct, immediate threat that I think deserves our attention now. I kind of wonder what is the point of redirecting the next planet killing asteroid if we're not around to do it right? It'll happen. We'll see it. Maybe all future life will be wiped out. But we're here now, and these are the problems we're dealing with. And we're dealing with them because we accidentally created a climate crisis. We accidentally introduced a global climatic event. Just imagine what we could do with a bit of intention, if we took that same intentionality we have at planetary defense for asteroids and applied it to protecting the only life support system we have. As much as we like to think we could go and live on the Moon or Mars, we can’t. It really relies on Earth as a resupply for everything. If that one example of life is destroyed or it goes extinct, in that case, us. What a shame, we were so close. I agree with Sylvia Earl. I want to encourage more people to consider oceanography as that next frontier because it is. It's as exciting and as otherworldly and unknown as space. We really do know more about many of the objects in our solar system beyond our own planet. And that's, to me, an unacceptable reality for 2022. Around that time, I joined NASA officially as a civil servant in the Earth Science Division. I just dedicated my life to helping fix this problem, helping understand and mapping our oceans, which are the main planetary driver of our Earth. They really control everything. And, I mean, there's no subtle way of putting it. Without the ocean, there is no human life. We likely evolved from the ocean. If you're looking for life in other solar systems, you're probably looking for ocean worlds that have that correct biogeochemistry that can permit life as we know it. It may not be the case that is how life gets started. But at least on Earth it looks awfully like we all came from a deep sea hydrothermal sea vent. And that's where we got our start since that sort of realization. Also, the realization that my technology at the time worked much better looking through water than it did through the atmosphere. I liked being in coral reefs and around all these amazing sea creatures and not so much on a cold mountaintop taking astronomical observations. I said, "that's it. I'm going to this all the way and I'm going to take all of the tools I've learned in astrophysics, astronomy, in aeronautics, astronomics and apply it to oceanography." It's been a wild ride, and I would never look back. Since then, I founded and directed a new lab at NASA Silicon Valley. The Laboratory for Advanced Sensing. I did that for ten years. I invented a technology called fluid lensing and FluidCam which are now the world's highest resolution instruments and technologies for looking through ocean waves. So now we can map down to about forty-five foot depth in 3D [three dimensional] sub centimeter scale features, coral reefs. It's eye opening. It's like getting to explore Pandora. Every time we do a field mission somewhere I fly drones, helicopters, aircraft, and with my instrument, and then they can peel back that ocean surface and reveal what's underneath. That was my first main invention. That was my PhD at Stanford. I defended it. I mapped a number of coral reefs in the American Samoa. I did a cool project in Western Australia with Stromatolites, which are Earth's earliest life form. And we're all related to yes - it's been, it's been phenomenal. Now that technology has been every year, you know, we're doing maybe six to twelve airborne mapping missions around the world trying to just fix that problem of how much of the ocean is not mapped and how much are we mapping? And then use that to understand how to conserve and protect what I think are some of the most special and interesting creatures our planet has ever produced, which are coral reefs. And we really depend on them for many reasons. Most immediate to me is now those coral reefs protect me and my home from hurricanes and storm surge and all of these climate events. So, it's this nice symbiotic relationship we have where I try to protect them, and they protect me. And then after that Invented a technology called MiDAR [Multispectral Imaging, Detection, and Active Reflectance]. And that was one of NASA's inventions of the year in 2019, and the motivation behind MiDAR was to push further into the ocean depth. So fluid lensing and FluidCam can see the photic zone of the ocean which goes down maximum about one-hundred meters. And then beyond that the ocean is dark. It's just like space. And I know how to do imaging in space. So, the key to do that is you either have to have a very powerful radio telescope and radar system. You actually illuminate the object, or you develop a really large telescope and a sensitive one and you use that to gather every bit of light you can. And MiDAR is kind of the merger of those two things. It combines an active source of light so a laser source and a light emitting diode source with a very sensitive telescope. And together they can see in different wavelengths just like the James Webb Space Telescope can see the early universe and the infrared. Now with MiDAR, we're trying to see the entire ocean in the ultraviolet and the blue bands. And there's some very interesting features that marine life has evolved and exhibit in those wave lengths that you just cannot see with the naked eye. So hopefully next year we'll be publishing some of the first ultraviolet maps of coral reefs. Which hopefully will blow everyone's mind and make them realize we're living on that avatar Pandora planet where it's teeming with life. But it's not just life. It's like interesting life. You couldn't have asked for a better situation. There're so many other planetary bodies in our solar system that we've spent a lot more money on exploring. And to be frank, they're dusty old rocks, and they're so far, they're not teeming with interesting life. They may have fossilized life. Most likely they will not. But here's an example where we can send an instrument, like MiDAR down on an underwater robot, and it observes the creature like the dumbo octopus that to me, just looks like it could be plucked straight out of science fiction. It is a truly otherworldly unique creature that we did not know about until someone decided to send a little probe down to the seafloor. Since then, I moved from NASA just last year to the University of Miami, and I was appointed the Vetlesen Professor of Earth Sciences. And that came with an endowment and a helicopter and basically a ton of resources to let me continue doing a lot of my NASA work. I've been very fortunate in that I'm still proposing new projects to NASA and they're supporting them to help further understand our ocean floor. And it's interesting, we just put out a special feature in oceanography called Oceans Across the Solar System. Oceans are kind of getting are renewed interest from the space agencies as we're learning that many of the moons of Jupiter and Saturn are actually ocean worlds. They have an ocean underneath their ice crusts, and they're now perhaps the most tantalizing target for sending spacecraft to explore for life beyond our home planet. And wouldn't that be cool if in our lifetime we can use technologies we developed to understand and protect life on Earth, to then send them off into these other worlds around in our cosmic backyard and find not just dusty rocks, but, like, vibrant ocean worlds with ice sheets and potentially complex multicellular life. That, to me, is incredibly exciting and has kind of lit a new passion under my butt to just say, I've got to work fast because there's a lot to do, there's a lot to invent. There's a lot of technologies to develop. And then whatever we do here on Earth, it's going to get more complicated when we try to send it to one of these icy worlds. It's going to have to be autonomous. It's going to have to land. It's going to have to go through ice. It's going to have to swim. So, it's going to be interesting. And that's kind of where I am right now. I'm building a new, exciting team here. We hired some great talent, and we're on that next instrument development cycle looking at how we can map the rest of our planet, understand it, and protect life. So that's perhaps a little bit more than you bargain to ask for, for just the high school intro.

Zach Mason: No, that's great. Yes. Thanks for sharing all that. There's so much to unpack in there. But I think what I'd like to really touch on. And you mentioned it a little bit, kind of dancing around it. But why is it so important? You've developed multiple mapping technologies. I'm sure that has taken so much effort and funding and brain power on your part. Why is it so important to map our oceans and specifically coral reefs? What would you say to a layperson, someone who's not a scientist, how'd you convince them it's worth their time or worth your time?

VC: Yes, I guess most recently, the thing I've been telling people, they say, "Why should I care about this?" I asked them, "did you have COVID?" More often than not they said "yes." And I said, "okay, did you take Remdesivir or any of these other drugs?" More often than not, they say, "yes, I did, and it made it a lot better." And I said, "did you know that that drug came out of a coral reef and a sea squirt?" And they were often surprised that they did. So, the first thing I tell people is humans are kind of unique creatures on the planet. We don't have much genetic diversity, despite how we somehow create differences amongst each other. We're all remarkably similar. Like, really remarkably similar. Because we're all related to about seven women who left East Africa. There's really no genetic diversity, which makes us incredibly susceptible to viral pathogens, bacterial pathogens, a host of different things. Coral reefs are these creatures that are fascinating because, unlike humans, when they get attacked, they don't really have anywhere to go. They kind of have to mount biological warfare, and they've been doing this for 150,000,000 years. As a result, they have some of the most sophisticated chemical warfare compounds that have ever evolved on our planet. They have direct applications to human health. So often, the first thing I tell people are, coral reefs will literally save your life. They are the 21st century medicine cabinet of our planet. And the reason why it's so important to map them is when you lose the species of coral, when you lose a certain individual in that reef that's supported by that reef. And in the case of COVID the drug I'm talking about, one of them was Remdesivir, which came out of a sea squirt that lived in a reef. When you lose that creature, you lose with it all of the evolutionary tricks that it had figured out over the course of three billion years. Humans have been around for a very small amount of time, roughly four million years. And so, we don't have many tricks. We only really have one trick so far, and that's our brain. But that one has its perils as well. So that's one main reason people should care, is that if we don't map these things, if we don't understand how they're changing and what's happening is they're going extinct. Right now, on our watch, due to our presence and actions, we're sort of shooting ourselves in the foot in the future, because come the next viral pathogen, if we did not save that one sea squirt that no one thought was important. But then someone came along and realized it had the most biologically active compound that could treat this drug that we'd never heard of, you lose your chance for survival. It's as simple as that. The health and the vitality of that reef is intimately tied to human health. The second thing is these are creatures, that are one of the few creatures, that can protect us from our own climate induced crisis. Namely, they grow in the ocean. They form these natural sea walls and barriers. And that has so many different benefits. The most recent one that I can point to is we just saw Hurricane Ian batter the west coast of Florida. Before it made landfall, it had to go through a coral reef. And that coral reef, if it's healthy, it can have a lot of dissipative power in reducing the amount of damage that that storm can cause. It can reduce the storm surge, it can reduce the amount of energy in that storm, and ultimately, it saves lives. It literally saves lives. It prevents that from happening. So, in the Pacific, we've seen examples of this with tsunami events where corals can protect from huge amounts, I mean, much bigger than storm surge. We're now talking 60 foot tall tsunamis. And when they get broken, they repair themselves. If you can't say the same for a seawall that you've poured billions of dollars of infrastructure money into, it does not repair itself. In fact, it degrades naturally over time. Corals do the opposite. They grow. You could no task for a kind of a more handy tool to have at your disposal. And so that's reason number two for me of protecting corals is not only will they save you from your disease, they will also prevent your house from being blown away or storm surge, taking away all of your things. And that's incredibly important. And then the final third one is human life as we know it depends on reefs. We literally eat about thirty percent of our diet, comes out of fish species that start their lives in coral reefs. They're more than just, I think, the rainforest of the ocean. They're sort of the biodiversity hotspots. They keep that whole thing together. They are more like the metropolis, I think, of the sea, the Manhattan. That's what I think of as a coral reef. They're loud, they're congested, they're teeming with life and smells, and ultimately, they form the backbone of ocean life and infrastructure. And if you remove that, the last time that that happened, it wasn't good for life in general. And we saw a number of large extinctions as a result. So that would be the third one. The fourth one, the one that I kind of think is an unsung trait about coral reefs is that if you're a space agency, you're looking for life on other worlds, what are you likely to find from a distance? Coral reefs are one of the few objects that we can see with the unaided eye in orbit that's a living structure on Earth. Trees are individually quite small. They do form large forests, but they still, percentage-wise, don't cover quite as much area as these creatures do. And they're incredibly clever. They're animals, and they can photosynthesize. They're kind of like having a solar panel on your back and also being able to eat sandwiches. To me, just from a life form perspective, I think they're some of the most evolved and fascinating creatures to study and protect in our home world. It would be what I would like to find on other planets elsewhere are organisms like this, organisms that make cities long before humans did. These were making cities that I'm now sitting on in Florida. This is former Coral Reef Ridge. They create these calcium carbonate skeletons that can grow to hundreds of stories tall. There're very few organisms on Earth, if any, that can do that. And so, for me, these are these kind of terraforming level event organisms, organisms that can fundamentally change the face of the planet, change the atmosphere of the planet, change the chemistry of the planet forever. For me, the fourth main reason to keep them around is you don't want to mess with something that powerful and that impactful on your home world. If you do, you may not be around to see the ramifications of it. Does that answer your question?

ZM: Oh, for sure, yes. Thank you. I've actually never heard that fourth reason before. This is an interesting perspective, for sure. I really want to ask you about NeMO-Net, something we haven't talked about yet. If you could kind of briefly explain, what is it, why it's important, and how it will benefit the advancement of coral mapping technology. And then if you can elaborate maybe on your motivations behind starting this project.

VC: Yes, I think I neglected the biggest one. Maybe I could talk about it on its own. So, NeMO-Net has a long title. It's the Neural Multimodal Observation and Training Network for Global Coral Reef Assessment, which is the typical NASA acronym. Mouthful. But it started off as a NASA Advanced Information Systems Technology project. It was a large grant that I applied for from NASA headquarters to use the NASA supercomputer. And you may be asking, "why am I using a supercomputer for coral reefs?" So, the instruments I had developed, MiDAR and fluid lensing and FluidCam, they were mapping coral reefs at unprecedented scales. We were mapping entire islands at a sub centimeter scale. We were really getting a diver scale view of those coral reefs. But the challenge is there's just a lot of ocean. There's a lot more ocean than there is land so you can imagine it's taken us the better part of, like, three, four decades to take and interpret the imagery we're getting on land, from satellites and from aircraft into things like, how healthy is this forest? Where is the forest? Is it forest or not? Is it a crop land or not? That information helped create the national park boundaries. It helped enforce and engage people in a way that they could not before. But it really requires a global effort of mapping, which is different than imaging, right? Once you can image it's one thing, it's a second to have a map that you can interpret from that image. So around that time, I said, okay, we cannot map all of the oceans ourselves. We really need to train a supercomputer to do it. And it was working very well using a machine learning technology called a convolutional neural network. We added lots of fancy bells and whistles. So, at the same, machine learning that's being used to track your ads and to sell you things that you didn't know you wanted, we turned to applying to mapping coral reefs and all of the ocean systems, all of the shallow marine ocean systems. So, seagrass, meadows, sands, what have you. And very quickly, we learned that to do this, we need a lot more help, right? We can have a team of a thousand PhD trained coral reef biologists classifying all of my data sets, and that would take them about four million years to do it. So, I was like, okay, that's not going to work. We need something faster. So, we decided right in the beginning of the NeMO-Net project, we are going to engage citizen scientists to help us. So, we took little pieces of data from my airborne missions around the world, 3D images of coral reefs. We added all the fish that were in the environment where we saw them in a video game, that became what people now know as NeMO-Net, which is the video game component, where you get to start off classifying and coloring corals in three dimensions for us. You classify a little bit of coral that gets sent to the supercomputer. The supercomputer determines, is this classification reasonable or not? If it isn't, it'll send it back out to the video game, and you can rate other people's classifications. It becomes massively competitive. As you get better at classifying coral, you rank up in the food chain. Start off as a plankton, you end up going up to a sea turtle, and then finally you're like a manta and a whale shark. And what we found was, very quickly, there were five to ten year olds that were outperforming PhD trained coral biologists in classification accuracy. We had introduced training in the game for them to learn about different coral types, but they were learning about them one at a time. They just had this passion and aptitude that reminded me of again, that thing my sister likes to talk about, which was this untapped potential in the world, which is intelligence, right? There're so many intelligent people going around that just need a diversion, or they want to help. They want to see these environments for themselves. They want a grassroots effort to kind of protect and preserve their own reef. In a lot of cases where we map these, like for example in Guam, the local community was really instrumental in playing the game. We have about one-hundred thousand users now and it's going up a lot. And it's primarily from people that are just either they want to see what these environments look like and experience them firsthand, which is one of the biggest challenges for ocean conservation, is just getting people there and to see them. A lot of people lived in landlocked, countries or spaces and so they don't have the opportunities or resources to go and see a coral reef. But here in the game, they can see it. It's right in front of them. They can put it on. We have an augmented reality component that they can project it onto their desk and literally take a little scuba trip without having to get seasick or suit up or anything. So, it kind of took off and went viral. During the Pandemic, we had about three-hundred million people accessing it in one month, which was insane. Every time we do a mapping mission, there's just a huge spike in new users and then a lot of them continue and stick around and play. NASA interviewed one of our users who's done something like ten thousand classifications, which is just nuts. And its free talent and labor that's going into training this. So far, what we've seen is that all of this training data is because there's this self-correcting mechanism where people can edit other people's contributions and the computer kind of checks and verifies. The accuracy is very high. In fact, it's the highest that's ever been published in coral reef mapping. That's partly because we have an instrument that can see at the centimeter scale, but it's also because we have the most sophisticated AI that's been trained by hundreds and hundreds of thousands of user inputs. So unsurprisingly, it's the best because we have the best talent on the planet being put to the task. While they're doing that, they're learning about there's videos about ocean conservation and how you can get involved. Sylvia Earl makes many guest appearances and it's really quite fun. We are fortunate to see that that accuracy is continuing. And we're now, later this fall, we'll be publishing one of the first global maps of coral cover using this technology. And what we've been doing is in areas where we have people play the game with the 3D models, we tie that to satellite data where we do not know what a pixel is. It could be a rock;

it could be coral. But now that we have some really fine scale data in that region, we can train that satellite layer. And now we have a global map that's been informed by lots of individual centimeter level observations. That's so far proved a really powerful tool in mapping these things at scale and with the fidelity you need to distinguish organisms like corals, which are really biodiverse. I want you to say that NeMO-Net, one of the hardest things to do is beyond just training a machine learning system, they're hard creatures to map. In one square meter in the Amazon rainforest, you might have ten species, which is considered quite biodiverse. In a coral reef you have a hundred times the biodiversity per square meter often. So, your problem of ten species quickly becomes a thousand. And now you have a much harder task ahead of you, both on the training side, getting users to identify all those details and then on the supercomputing side, it just becomes very expensive computationally to separate all that. But so far, with NASA's generosity, and a lot of talent that people play in this game, it's worked out really well.

ZM: And then just a couple of quick follow up questions about Nemo Net. Do you happen to have a rough geographic distribution of NeMO-Net users? Is Nemo Net available and being used outside of the United States?

VC: Yes. Actually, we published a map in one of our last papers and it's quite surprising. We at first thought it's going to be limited really to the United States. We had some of the videos in the game are bilingual, so they're in Spanish and English. More recently we've been translating it into Korean, Chinese, Japanese and a number of other languages. But, from day one it was globally spread. It was very interesting. In fact, some of the largest users were in areas that you thought had they even seen a coral reef. We had tons of users in Europe and Russia and in completely landlocked places. A lot in the United States, a lot in island countries that have corals. So, throughout the Pacific, the Caribbean, there's a lot of interest. But then just like huge spikes in users from Sweden and it's like great, maybe we should continue translating into different languages. So, I think at the time when we had released it, so many people were in lockdown and they were looking for an educational activity to do and it's also very relaxing and kind of, I find, therapeutic activity to classify it. There's nice music and there's a soundtrack that ends up getting released as an album separately. It's just quite relaxing. I think a lot of people found some comfort and solace during the pandemic in doing this. Quite broad geographic spread. There is still a heavy tilt towards countries that have IT infrastructure set up so they have access to smartphone apps. We released Android versions and desktop versions to try to expand the access pool. But that's one of the limitations. It's just in a lot of areas where you may not have Internet or reliable power that's harder to access. So, we started adding, like, a downloadable option where you could just pre download a number of levels and play them. And then when you got Internet access, again, you could upload the results. And so we've seen that also happen in areas where there's more spotty Internet access.

ZM: Actually, real quick, where if someone wanted to access the maps and images that you've gathered using your mapping technology, how would they access that?

VC: So that's a good question. Right now, the main portal we're trying to put everything on is the NeMO-Net homepage. So, if you just go to NeMO-Net dot info [nemonet.info], you'll find some of the 3D data sets there, all the papers that have been published, and then those papers have all of the ancillary data sets that you can download. There's also a NASA portal, my old lab maintains, that has some of the sources of data sets. I will warn people that if you really want the full data set, it's like drinking from a fire hose. So, one island mapped at sub centimeters scale over fourteen square kilometers is like forty terabytes. So hopefully you've got a good internet plan and you're ready to download. If not, in the game, you can view those snippets of the levels. And then on the Miami side, University of Miami, my new lab, is also hosting a lot of the data sets there. And we just ask users to submit which areas they want and then they can download them. Then later when we do the maps, we publish the map separately with the data set so users can kind of measure the accuracy and see them. But yes, 3D data is a little tricky in that it's very big. When you go to download the latest video game, let's say Assassin's Creed, it's like a sixty gigabyte file and a lot of that's just coming from detailed 3D models. So that's our day to day life. It's just very large 3D detailed models. And having to serve that up is quite a challenge, but hopefully one that gets fixed as computing capacity increases.

ZM: Yes, it's a problem that I think a lot of people are having right now. I want to be respectful of your time. I know we're kind of pushing up against the end of the interview, but do you potentially have time for a couple more questions? Maybe like two more questions?

VC: I'm good till noon.

ZM: Okay, great. Awesome. Okay, how does it make you feel, I guess, that people outside of the United States are using NeMO-Net? I know we had touched a little bit about your experiences growing up and studying outside of the country and people not having the opportunities that maybe people who are, I think you called it the genetic lottery or the birth lottery, being born in the United States have. Do you think that maybe this could give them that opportunity or at least inspire them to pursue something in the sciences?

VC: I really hope so. A lot of the messages we put in NeMO-Net are targeted to really getting kids and young people interested and involved. I think this is one of those moments that I kind of had in high school, where I wanted to make some difference and get involved in a project. And there's this formidable barrier that you see as a kid. You have to have a PhD, you have to be trained, you have to have all of these resources. How do I do that? How do I get involved? And NeMO-Net kind of just short circuits that and says, you know what? No matter where you are, and we have players from ages like four to ninety-five, you can contribute to a modern scientific campaign and see those results in action. And that, I think, motivates people. It gets them realizing, wow, you can make a difference. Because, again, we got ourselves into this climate mess by individuals, individual actions that were accidental, right? They weren't intentionally trying to cause global climate change, but that's what happened. If we just have a little bit of intention and everyone does that, imagine how different the planet could be. Imagine how different our ocean resources can be. I'm hoping when people access NeMO-Net, they feel that level of empowerment. And we're trying to think beyond NeMO-Net. How do we get stakeholders engaged? And that's one of the projects that we were awarded recently by NASA and NOAA was to take NeMO-Net into the next four years. How do we operationalize it for an agency like NOAA? How do we ensure that the logical stakeholder can not only share this with other people, but actually use it for their own decision making and conservation efforts and rewilding efforts? And so that's to me, one of the most exciting things to see is as a technologist, really, at the end of the day, is what I am sort of like a recovering physicist and technologist oceanographer. Often so many technologies - there's the hype phase, there's the excitement, there's the wow, you can see this. But then often they'll fade into the distance. And what you really want to see, it's a success story, is that technology going directly into impacting people's lives on a global scale. And then agencies, big agencies saying, we're going to take this data and use it. And that, to me, is like the most exciting impact because it outlives you right. It finally can really have that global reach. So NeMO-Net was one of the first times I got to feel that kind of, I don't know, interest from around the planet. It gave me a lot of hope to see so many people fascinated and interested in coral reefs and in the marine environment and how to protect it. And then we get so many users just writing to us saying, what's the next step? What can I do next? And that's where we can convert people into aquanauts and terranauts and tell them, this is how you can get involved in Earth science and how you can help make a difference. It's quite special.

ZM: I know that you have done a lot on the technology side. But have you interacted with a lot of these stakeholders in places like the Pacific, remote island areas, and can you describe maybe their relationship that they might have with the coral reef?

VC: Yes, it's quite interesting because this is something that bothered me a lot in a lot of the scientific fields I was in, is this, we kind of coined the term parachute science. Where a lot of scientists will go to these countries, they'll go and do the mapping mission and they leave. And that's it. It's kind of cut off. There's no more communication. They answer only to their program managers, the scientists, or who's funding them. They don't really have any motivation to work with indigenous communities or people of color. From the very beginning, I try to set out to say, look, I don't want to fall into this pattern. I'm really happy to say on our last mission to the Pacific, we were there for a month and a half in Lanai and in Guam. We had almost every day an outreach event. We went to local schools, we got kids involved, we've got adults involved. And the benefits are like, it’s kind of a no brainer when you think about it. But there's just right now, the funding agencies don't prioritize it, but they should. And one of the things that in coral science is particularly, I think, notable, is a lot of folks in these countries that have grown up around these reefs for thousands of years and maintained them have better conservation practices than the Western scientists who often will come in and say, this is how you should do reef management. Notable cases are things like in Palau and Fiji, where they have been traditionally protecting their reefs for a couple of thousand years and they've actually been cross breeding corals to be genetically resilient to higher sea surface temperatures and higher acidities. They institute temporary fishing bans in different areas of the reef to allow fish stocks to recover. And by doing that, they've actually maintained some of the healthiest reefs in the world. I think for us, it's almost an obligation and responsibility that you have to work with everybody that's there. Understand what their needs are, try to address them as best you can. Make sure that those data sets get to them, and make sure that they - a lot of them are playing NeMO-Net right now, which is fantastic because they're contributing data when we're not even there anymore. In Guam, we also did local capacity building where we trained student pilots to fly our aircraft and we left a number of them there with our instruments. So now, the next mission is on Tuesday, they're mapping the same reef every two weeks and they're going to have as a consequence some of the finest scale habitat mapping and actionable data sets around. That's kind of the model I would love to see adopted, is that whatever new technologies or ideas that get invented in one area get transferred back into these communities because they're the ones that really care about them. They're the ones that are at the forefront making sure that they're healthy and can also tell you, hey, I swam out to this coral today and it's not looking so hot. It's got a disease or a crown of thoroughness outbreak. You can't get that kind of data yet from satellite and from other observations. So, I think that's quite essential. And we've been really lucky to have all these communities be very receptive to us and hospitable and just make us feel like we're part of the island.

MM: Thank you. So, you mentioned that you spent a month and a half in Guam and Lanai in Hawaii. I was wondering - this project is all about coral reefs in the Pacific specifically, specifically in Hawaii. So, I was wondering if you could sort of elaborate on that project in Lanai. I know you'd previously mentioned that that location was very unique and different than other ones that you've mapped before. So, can you tell us a little bit about that?

VC: Sure, yes. The Pacific never ceases to surprise me. It's always got something up its sleeve that's new or happening. Every time you think I've seen every type of coral, you're like, no, I'm just beginning. So, Lanai and Guam actually have some parallels. They both have issues related to invasive species that are causing impacts on coral reefs. And in the case of Lanai, it's ungulate population. So, someone introduced deer, back in the 1800s, for sport shooting. The deer were from East India where their natural predator is the Bengal tiger. But there are no Bengal tigers on Lanai. And so, as a consequence these deer have now multiplied to the point where there are, I think, around forty thousand deer for a population of three thousand people on the island. They're very cute and they're very sweet, but they are voracious grazers and so they've overgrazed a lot of the island. As a result, whenever it rains, which is like always in Hawaii, all of that runoff smothers the coral reefs and all of the marine animals. So, there's these sea turtles that nest there in Lanai, that now because all the coral has died because it's basically just been choked by the mud, they're struggling, and a lot of the fish wildlife is struggling. A lot of the native Hawaiian population on the island that is dependent upon fishing in those areas, there's no fish in the areas where there is this runoff. So, Lanai is kind of an interesting case in that they're now trying to use technologies like mine to map all of these areas, introduce fencing for controlling the deer population, trying to reduce the deer population. And, as a result, trying to see, hopefully, a recovery in that reef. So, in Lanai, we actually could see really stark contrast in areas where there was tons of runoff and the coral is completely dead or bleaching. It was recently alive and is undergoing this bleaching stress. And then, yes, you go to the North, there's less of that runoff, and the reef is actually quite healthy, some of the healthiest reefs I've seen in the Hawaiian Islands. So that was kind of, to me, an optimistic case where this is what you could have again, right, if you just control these deer. And introducing a Belgium tiger is not the solution, even though it would reduce the population. Now you're going to have separate problems. So, I think that's one valuable lesson. In Guam, it's the same story, except it is a venomous tree snake, a brown tree snake that was brought over, I think, on a Chinese vessel at some point in the 1960s. They multiplied. They're from Indonesia, I think, and they're not supposed to be in Guam. And as a result, they've wiped out the native bird population on Guam. And the native bird population was the seed dispersal mechanism for all of the trees. So now Guam has not enough tree cover. So, when there's rains, you have the same erosion effects and landslides. So, there's not just effects on the coral, but also people's houses just get swept into the sea. And so that's a big problem for Guam, is trying to eradicate those brown tree snakes. To me, it's almost coming from particle physics, where I thought things were complicated. It's actually very simple in physics, things have very clear cause and effect relationships. Whereas when you get to natural ecosystems, you're dealing with these food webs and these interdependencies that are nonlinear that have evolved for maybe billions of years. Then you just poke it once with the wrong you introduce the wrong thing. A tree snake. Who would have thought a tree snake would cause a decimation of a coral reef, right? And suddenly, boom. It's like the biggest thing that ever happened. I think that's kind of what is exciting about Earth science, is it's full of these complicated relationships that you could not predict from first principle like you do in physics. But at the same time, it means you've got to be vigilant. And then also it means that institutional knowledge, the indigenous population knowledge, is invaluable because they understand those systems like a particle physicist understands cork glue on plasmas. They know the root and the interdependencies of these things. And what happens when you put it out of whack. You just remove the wrong thing, or you introduce the wrong thing. So, both of those cases, the thing that's very encouraging to see is the governments, the local NGOs [non-governmental organizations] and nonprofits are really looking at large scale technologies like fluid lensing to not only map the system, but to then look at how it's changing over time and the impact of their policy decisions. So, it's data driven, policy making, which is the best kind of policy making. It's not the, I'm thinking this will work, let's see if it does. It's much more of the, hey, I've got data to show and prove that this is effective and that's what we're going to do to help preserve these places. So, in some of the cases, they're trying to rewild these reefs. They're trying to help them recover. Many of the reefs will recover on their own if these pressures are removed or they're mitigated, and they're done so intelligently without introducing a new problem in the process. Which is kind of what we do as people best. It's accidental saving and then destroying something else. So, yes, both the projects were tremendously impactful. To see the technology being taken up by local stakeholders, being used to direct their restoration efforts and conservation efforts, and then to have people get engaged on the islands. Like, a lot of the folks in Lanai had just never seen the coral on the East side because they don't want to go to the east side. Only the fishermen go there and the fishermen know, okay, this is bad. Right? And so, getting people to see that data set. We're going to be releasing that data set in the coming months and then sending it off to Lanai and putting it in NeMO-Net so they can kind of see firsthand how bad it is and what can be done and how healthy it could look just in other areas of Lanai. It is quite healthy. Like, the West side is like a completely different story than the east side. The same thing in Guam there. The government's been very proactive in doing this for the last four years I've been working there and we're going to be going again next year. And they'll have kind of the best data set in all the Pacific to help make these management decisions because they have yearly data sets of their entire reef at the centimeter scale. So, they don't need to beat around the bush. They're just like, look, this is our coral cover, and this is what we're going to do to make sure it stays that way. Because for them, there's a direct tie to the tourism industry. Just like in Lanai, it's their main economic backbone. And that tourism industry is almost completely reliant on the health of that coral reef. No one wants to go to the island if they can't go snorkeling or they can't splash around with water because it's murky or anoxic or something. So, they want to keep that vibrant, and so far, it's promising.

MM: That kind of ties in really well to my next question. First off, you've talked about invasive animals and runoff and corals just face so many problems and issues. All of that being said, there's lots of science happening, mapping, and disease treatment, and all of these things that are bringing people together to work on these issues. Are you hopeful for the future of coral reefs? I know that's a loaded question, but I felt we're getting near the end, and it's a good one to end on. Where do you see in ten years or fifteen years sort of the direction of coral reef health going?

VC: That's a good question. It's hard to be an optimist sometimes in Earth science because you're primarily reporting on depressing things and people don't necessarily want to hear it. Often, it's kind of like if you were an astronomer and said, there's an asteroid coming to Earth.

There was a film recently, right, where it says, people just may not want to believe that that's the case. The difference is that asteroids are not fun to swim around and full of vibrant sea life. If you can get people interested in these environments, you can get people to care, then I think that there is no end to what hope the future holds. I think it's quite bright if you can get people involved and engaged. I think right now one of the biggest challenges in coral reef conservation is really just the people angle, getting folks to care about these systems. There's a lot of personalities in coral reef conservation, and we got to cut it out. We got to work together and realize it's not about one person or their publications or something else. This is about the extinction of a species on our watch, an extinction of a species that is really essential to our survival. So we better get our act together and work with indigenous communities that have been there for thousands of years, who often know what they're doing. Give them the tools and resources and new knowledge and technologies that they can use to protect their own reefs, and then empower them to do so. So, when we create a marine protected area, enforce it. Make sure we've got the right kinds of resources going there to make sure that that can maintain a healthy reef system. We've seen it work very well in isolated cases, and there's lots of positive conservation stories to be told. Just coming from California, seeing firsthand when I was a kid, the creation of a lot of these marine protected areas in California and then basically a resurgence of sea otters, again in environments, kelp forests, again in my short lifetime was extraordinary. I got to just watch how firsthand people said, this is important. Grassroots people got involved. The government listened. The government created policy and then gave the resources to ensure that that policy translated into action, actual conservation. So, I think with corals there are lots of success stories like that. I'd like to see more of them happening. I'm hoping technologies like NeMO-Net and fluid lensing can play their part, but they're not the only solution. A lot of it comes down to just people, the decisions they make, what they want to do with their day, and then hopefully we get more and more people in the water. I mean, one side effect of climate change is more and more people are getting in the water whether they want to or not. And so hopefully in that process, they're learning it's vital to care about these things and they feel some empathy and sympathy and kind of camaraderie with the coral reef and then that translates into conservation. When we had gone to the school in Lanai and I asked how many kids have actually snorkeled on the coral reef, there was like two out of one hundred and fifty. And you think, oh, my gosh, everyone in Hawaii would be snorkeling. But no, it's not always the case, right? Sometimes you have to just share with people, look, this is what's there, this is why it's interesting. Then maybe a lot of the elders, adults snorkel there, but the younger generations were on their phones. The fact that we met them on their phones with NeMO-Net and got them interested in going back out on the reef was kind of a nice full circle for us to see that you can distract a kid into getting back into this and caring about it. So, I hope that answers your question.

MM: I am definitely going to get my cousins, my little cousins involved in because I think that would be really cool to show them, hey, this is why I like the ocean. So that's really great.

VC: I was just going to say it's a really exciting time to be alive, because in all of human history, it's one of the few times where we actually know what's going on, right. We have some clue that something is happening. That's not the case for the residents of near Mount Vesuvius or any other of these huge natural disaster events. Here we have the power and resources to do something about it. And to me, there could be not a more optimistic time to be alive, to have this kind of a problem and to have the tools and the ability, even through storytelling, to engage people to care because they can change the fate of where we're going.

ZM: Yes, I guess one last follow up for me, really is what advice would you give to a young person interested in kind of following in your footsteps? It's not an easy path to get where you are right now. What would you tell them?

VC: Oh, never stop being curious. Never stop asking questions, why? The main reason why I went into theoretical physics is my parents just got sick and tired of like, I kept saying, well, why is this the case? Why does this work this way? And you got to a point where there's unsatisfactory answers. And then the only satisfactory answers I started getting were from pretty high level theoretical astrophysicists or particle physicists. That's how I got my questions sated. And then once I got most of my curiosity out, I said, okay, now what do I do with this knowledge I've gained? I've got to share it. I've got to be able to enact technologies that will use it for the benefits that I want to see and not for creating weapons or something else. People have a lot of agency, and I think coming to that realization young and getting people to realize you can change the world if you want to. It's a completely different mindset. If you wake up every morning and think, how will I change the world today? How will I try to make this better? How will I try to understand how this reef has evolved? So, being curious, I'm a big proponent of physics and mathematics. They are the language of the natural universe. I think one of the things that we're missing in our country is a fundamental fluency in these languages. One of the things I did, like, in Russia, is that mathematics education was dealt with like you would language instruction. It's something that's expected and that you should be fluent in. And there's no stigma associated with it. There's no nerd or not nerd. It's just they're differential equations. They don't care about your preferences. But those differential equations describe the natural world. They describe even coral reefs. They describe the physics and mathematics you need to apply to any field. What I would say is, if you have a strong background in physics and math, and then you come into a field like oceanography or biology, it's almost like the fruit is there for the picking. There's so much low hanging fruit to accomplish that it looks extraordinary to an outside viewer. But really, it's like, this is so easy because it's literally the thing I learned in astronomy, and no one's done it in this field. I've made my career doing that, and I'm sure I'm not the only one that could do that. So, I hope that some young person is listening and thinks, you know what? I can take all of these things I'm learning from this field and apply it to this other field, because I think that's where you'll find tons of new discoveries. They come fast and quick whether you want to or not. Sometimes they're painfully slow, but they're a lot faster than if you're in one field and you only stick with that field. It's fun to be interdisciplinary.

ZM: Awesome, well, that's actually perfect timing. And I think that's all the questions that I really have right now. Madison, do you have anything else?

MM: No, I'm good. Thank you so much for doing the interview with us.

VC: It's been a pleasure speaking to you both. Thank you so much for the opportunity. I will send you the recording when I'm done. I'll just hop onto another call now, and then I'll compress it and send it along.

MM: Since you have the recording. That's great because I was going to say we'll send it to you, but you already have it, but yes, we'll keep you updated on the timeline. I think Zach has a better understanding of exactly when maybe this will be done, but we do still have several interviews to finish before we publish anything.

VC: Well, it was tremendously fun talking to you both. You had great questions, so thank you. Good. Hope to see you in Miami sometime.

MM: Yes. Have a good one.

ZM: Thank you. Bye.