Scotohylology with Dr. Flip Tanedo
Ologies Podcast
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Oh hey, it's your three half-scratched-off to-do lists, that you really should combine into one but then you'd have to confront the tasks that you want to do the least. Hi, Alie Ward. What is life? Where do we come from? Why do I have thoughts? Where does my spirit go when I die? Does anything matter? Does anyone know anything? These are just some of the existential crises you're about to enjoy, all under the guise of understanding particle physics. It gets spooky and I love it, come along.

So, you're about to meet UC Riverside's Associate Professor of theoretical particle physics who studied mathematics and physics at Stanford and Cambridge, got a PhD at Cornell, he's also so lovable... [*whispers*] Oh, you're going to love him. So, his life's work and passion is figuring out how an invisible mysterious matter fits in our understanding of the universe and nature. So, we recorded this before the holidays and I have been hanging onto it, so excited to finally release it into the cosmos and into your face.

So, I went to campus on what I later found out was the very first day of UC Riverside's fall semester. It was a broiling hot September afternoon, I took my little grubby purse full of cords and microphones; I showed up at his office door like someone waiting to meet a Broadway star.

Alie: Hello, I'm Alie!

Flip: It's such a pleasure to meet you.

Alie: I just took a COVID test before I left. It's so good to meet you!

Flip: Yeah, I'm super excited. I feel like I should be interviewing you. [*chuckles*] Is there anything you need? Coffee or anything?

Alie: Oh my gosh, no. I mean, other than like a time machine and a hairdresser. [*Flip laughs*] But other than that, no.

So, we chatted in his office and I made him tell me his life story and also explain things that are way above my own paygrade.

But before we get into it, just a quick thanks to patrons of the show who make it possible. You can join and submit questions for just a dollar a month. We're about to record a new slew of episodes so get 'em in before then. Also, thank you to everyone who rates and reviews the show, I honestly read every single one, and as evidence, thank you to Hayungski, who wrote:

> *Alie is the internet dad I never knew I needed and also that I've always wanted. Beware: you can't just listen to one of these so carve out like four to nine years of your life to obsess over every ology.*

So, thank you Hayungski, I appreciate it. And every single person who wrote a review this week, I read it.

So okay, onto the episode. What is universe made of? How do stars die? Why are we colliding particles underground? Who first noticed dark matter? What is the best vintage insult? Are there space ghosts? Strap in to rearrange your perceptions of existence, get ready to cut some bangs, boy howdy, you're going to text a crush and maybe buy a box of Girl Scout cookies because it's about to

get weird, with theoretical particle physicist, dark matter expert, and Scotohylologist Dr. Flip Tanedo.

Flip: So, my name is Flip Tanedo, my pronouns are he/him.

Alie: Doctor? Doctor Flip...

Flip: I guess so.

Alie: Yes! Doctor!

Flip: Dr. Flip Tanedo.

Alie: And recently tenured?

Flip: Recently tenured, yeah.

Alie: When did that happen?!

Flip: This happened, officially, July 1st.

Alie: [*gasps*] That's huge! Congratulations!

Flip: Thank you.

Alie: I don't fully understand what it takes to get tenure because I'm not an academic, but I know it's a really big deal. [*both laugh*] Did you celebrate?

Flip: I'll be really honest with you, we didn't. [*loser horns*] So, the story is, getting to that last year is a roller coaster. And so, I had basically felt every single possible emotion you could feel about this, twice or three times. By the time we actually got the letter I thought, "Okay." There was the exhaustion, the excitement, the fear, everything. It all had been felt. Me and my partner, we'd been on that journey several times. Then I was visiting my parents, I still have my parents' address as my main address and there was an envelope, completely non-descript, and it looked like every other envelope I'd gotten from UCR. I tear it open just to make sure, "What cause is it now?" And then it was a letter from the chancellor saying congratulations.

Alie: Wow!

Flip: I still have the paper somewhere but there's a big tear on the side because I was sloppy about it.

Alie: [*laughs*] Oh, what a great surprise. I hope there's some jalapeño poppers and whatever is the best way to celebrate tenure track. I would go to a buffet, probably.

Flip: I appreciate that. We'll see, we'll see.

Aside: Okay so, I don't come from an academic family so I'm a little murky on the concept of tenure or what the protocol is for celebration, but it means that it's indefinite employment at that institution. You really have to screw up for them to fire you; it's lifelong job security. From what I gather, it's like having your crush propose to you, except with a letter that looks like junk mail, and no one kisses you on the mouth.

Also, I didn't know that some scientists get to name their labs after themselves. I thought our Trichology guest, Dr. Valerie Horsley worked at the Horsley Lab by chance or because of a family legacy. And she's like, "No, you get to name your lab after yourself." So, phew! Asking smart people unsmart questions: it's why we're here.

Alie: And now, okay, help me out with the ology here.

Flip: Oh gosh.

Alie: Wait, I have some propositions. A couple of potential ologies; please know I don't know what these words mean. [*Flip laughs*] Nonbaryonic hylology? Hylology is the study of matter.

Flip: Ooh, I like that, I'm going to save that.

Alie: Yeah? So, hylology is matter and I was looking up what dark matter might be. Also, I've seen in the literature, dark matter cosmology, or dark cosmology. Because physics obviously does not have an ology on it.

Flip: No, unfortunately not.

Alie: [*laughs*] Do you ever hear, like… How do people tend to describe this field?

Flip: Okay, okay. So, the hylology, that got me. Usually, the people doing theoretical dark matter, it might be their main focus, but we do a lot of general-purpose particle physics, so there's a sense in which the thing that we work on are quantum fields. If you want to be more specific, the particular types of things we work on are invisible so they're not actually dark, they're invisible. And one of our senior theoretical physicists at UCR, the person who really founded our group, Ernest Ma, had a paper that had a funny title.

Aside: A few selects from Dr. Ma's publication collection: 2021's "Universal Scotogenic Fermion Masses in Left-Right Gauge Model," or his follow up, "Dark SU(2) gauge symmetry and scotogenic Dirac neutrinos." Scotogenic indeed!

Flip: And he used *scoto* which is the Greek word for 'dark'. So, scotology, which sounds a little bit dirty… [*Alie laughs*] Scotology would also be a good one. But I think dark hylology just sounds super cool.

Alie: Scotohylology really means dark matter.

Flip: Ooh! I like that.

Alie: We may have just pioneered an ology. [*laughs*]

Flip: That is really nice.

Alie: I contributed something to the field, my only possible contribution. Now okay, walk me back a little bit. Theoretical fields I think you just mentioned. So, let's start at the basics. What is it? Most people on Earth have no idea what you do, what the fuck it is. [*laughs*]

Flip: Yeah, all right. So, we care about the fundamental building blocks of matter. So, we know there are atoms. Atoms, these are already a hard sell. If you really think about it, we've never seen atoms, maybe we have these weird electron microscope pictures, but what do those actually mean? But we're pretty happy that atoms exist. And then you just go down the rabbit hole. But the atoms are the main idea that there's some unit of stuff and maybe Einstein taught us that it's not just stuff but there's energy, maybe there's a unit of energy. So, the quantum in quantum mechanics has to do with quantizing energy levels, like, there are discrete levels. I can't give you 1.5 cents; I can give you one penny or two pennies, and energy turns out to behave like that in certain systems. And that was the big thing about quantum. So, that was around the 1920s.

If we fast forward decades, we built this edifice of theoretical physics which is fairly mathematical but all to answer the question of: what are the fundamental things that if you understood them could describe slightly bigger things, and then those describe slightly bigger

things? And eventually one of those things is an atom and atoms make up all this other stuff that we know.

Alie: And did you set out to become a theoretical physicist, a dark matter expert? How does one land in, what I feel like, is the hardest field possible?

Flip: [*laughs*] All right, here is my origin story. I wanted to be an author.

Alie: Really?!

Flip: I had no idea why, but I was very passionate about writing, the idea that one can have a voice. And so, growing up, I was a huge fan of LeVar Burton's, because of *Reading Rainbow*.

Alie: Augh, love. Love, love, love, love, yes.

Flip: *Reading Rainbow*, amazing. [*"But you don't have to take my word for it."*] So, I would watch *Reading Rainbow*, and at some point, in the back of my mind, I realized that this person who does *Reading Rainbow* is also on this TV show *Star Trek.* And in high school, I'd started watching *Star Trek* a little bit, it was still on at the time. I picked up the book, *The Physics of Star Trek* by Lawrence Krauss, and this was a really fun ride because it was the first time I'd thought about a scientific subject as something where there are open questions and these open questions are fun, and creative, and exciting, and any time that I lost track of it being exciting I just watched LeVar Burton as Geordi La Forge, the chief engineer of the *Enterprise*.

Alie: I know it well. Oh my gosh, my sister and I used to watch *The Next Generation* as well, so yeah.

Flip: It was the best. [*Geordi La Forge: "We can't change the gravitational constant of the universe but if we wrap a low-level warp field around that moon, we could reduce its gravitational constant; make it lighter so we can push it."*] So, I think that's what got me into this idea that hey, these black holes in the show, these are real, we should understand these things, there are fundamental questions that are not only abstract and things you'd find in textbooks, but they're fun ideas. And it was the creative spark that was really exciting, that someone could write a science fiction piece about these actual things, and that's what got me going with physics.

Alie: Do you write still, at all?

Flip: [*laughs*] I was never a great writer, and you can ask my collaborators that my paper writing is slow and torturous. But I would like to eventually write something as a popular book.

Alie: Oh yeah, I feel like that is in your future. And also, everyone who writes hates writing.

Flip: Oh, absolutely.

Alie: Everyone hates it and there's the old Dorothy Parker quote, "I hate writing, but I love having written." Which is everyone, it's supposed to be torturous or else I think you don't care. But when it comes to matter and dark matter, I mean, slow it way down for baby brains like mine. But from what I understand, and the first time I ever read this was like, okay, all of the matter that we can see, and touch, and feel, and everything, makes up about 15%?

Flip: Yeah, depending on how you're counting. But yeah, it's a tiny fraction.

Aside: Like, a third of that. So, everything that you can see, and feel, and touch, and smell, that's 5% of the universe's mass and energy. There's another 95% of pure mystery.

Alie: So then, what the fuck is everything else? [*laughs*] What is it?!

Flip: Yeah, this is the mind-blowing thing. We've known about dark matter indirectly for over a hundred years. Like, there's been evidence for this for over 100 years. But I think it hasn't been until fairly recently that this has come to the forefront of "we really ought to figure out what this stuff is." [*Alie laughs*] Because as you said, we spend all of our lives learning science, art, history… everything you learn from a textbook is basically about that really tiny slice of visible, normal matter and the history of that normal matter in this universe, and in this world, and in our culture.

But it turns out, for every… so, what's the fraction? I think if you look at the amount of energy… So, energy is a good measure for stuff. 25% of the universe is made of dark matter and only 5% is made of the stuff that we're used to.

Alie: [*whispers*] Wow.

Flip: So, there's 5 times more dark matter than ordinary stuff, and in fact, it's so much more that we look at our galaxy and we think our galaxy is huge, our galaxy is almost everything, everything we'd possibly care about. Our galaxy is only here because it is swimming in an ocean of dark matter that provides the gravitational pull to keep the galaxy there. The galaxy formed *because* there was dark matter. So, where we are right now with scotohylology… is that what we're doing?

Alie: Mm-hm, yes.

Flip: This is the fish scientist discovering for the first time that "There's this thing, water, that we're swimming through, we should figure out what this water is."

Alie: Wow. And now, the other, let's say… Is the other 70% dark energy?

Flip: Good, yeah. That is a great... I was both hoping and not hoping that you would bring that up. [*Alie laughs*] So, 25% dark matter, 5% ordinary matter, that doesn't add up to 100%. So, the rest is indeed dark energy. And I'm excited that I have no idea what dark matter is and there are great things to do in that field. I have no idea what it is. Dark energy, I have no fucking idea and I'm terrified and there's a reason why I don't work on it. [*Alie laughs*] It's one of those shows, right?

Alie: Of course, very much so. Especially this topic, there's going to be a lot of boggling, trust me. What, I mean, okay... So, about 100 years ago, was that when we realized, I say we, the royal we here, that something is not adding up? When did we realize that?

Flip: I think this was about 100 years ago, the first astronomical observations were… and this is what's really, really trippy, the origins of scotohylology were really in astronomy and people would look at galaxies and look at how fast stars were moving in those galaxies and just using ordinary, non-fancy, Newtonian physics, the type of physics that students drone over in high school, they figured out that these stars moving around these galaxies were going a little bit too fast; it's as if there was more gravity than they had accounted for just by counting stars.

And I'm going to do a great disservice to my astronomer colleagues, but for the most part, the astronomy field said, "Huh, that's curious." For maybe 50 years, 60 years. Because there are lots of curiosities in astronomy. Over the next 100 years, we had more and more mounting evidence that this additional gravity, which in the 1920s, who cares if we didn't happen to count all the stars correctly? But now there's more and more evidence coming from more and more sophisticated measurements that not only is there more stuff, but that stuff cannot be the stuff that we're made of.

Aside: So, there is stuff, all around us, out-massing us and out-energying us, maybe by a factor of 20, but we can't see it and we don't understand it. So, this whole time, we thought that we were a cookies and cream milkshake... We're just the Oreo bits and we're surrounded by an invisible milkshake that can seep through us, we don't know what it is or what it does. So, dark matter, it doesn't interact with light or electromagnetic forces which is why we can't see or feel it. So, why do we know it's there?

Fritz Zwicky first coined the term 'dark matter' in 1933, more on him later. But it wasn't until this astronomer named Vera Rubin, crunched some numbers and hypothesized that dark matter exerts gravity and without that gravity, galaxies would just fly apart and scatter if it all just depended on the normal matter or baryonic matter, which is the atomic stuff that we know of like protons, neutrons, and electrons. So, when did she figure that out? Oh, just in 1978. We just found this out a split second ago in the universal timeline.

Get this, so Dr. Vera Rubin, she did her calculations at this observatory that didn't even have women's restrooms. There were no ladies' rooms at the observatory; she had to cut up a silhouette of a dress and paste it on one of the men's rooms. And then when she was done crafting, then she pioneered some giant theories about the existence of the universe. She died in 2016, she was never awarded the Nobel Prize and they, unfortunately, do not hand those out posthumously, which is a bummer. But you can name your dog Vera, or your cat Rubin, and remember Vera Rubin that way. But anyway, dark matter, it's something else.

Flip: It cannot be the stuff that we're used to from chemistry. And then the fundamental particle physicists, the elementary particle physicists realized we've been spending the past 5 decades trying to categorize the elementary particles of nature, we're trying to have the most fundamental periodic table, and you're telling me that there's something that we're missing that we definitely have to put on here? And this became a big thing, if you'll permit me an aside.

Alie: Yes. [*"I was hoping you'd say that."*]

Flip: So, I'm going to get the history a little bit jumbled, but this is the moral history, this is the way that we're going to remember it. In the '80s and '90s, there was one big, hot question in particle physics and that question had to do with the Higgs boson. So, the Higgs boson that in 2013 won the Nobel Prize for its discovery, big deal, big fucking deal. [*Alie laughs*]

Alie: And now that's sometimes wrongly called the God particle?

Flip: Yes. That is the "God particle." And if you ask physicists in my generation, its discovery was more like the Satan particle where we really had to do some soul searching. Because in the '80s and '90s we had realized, there's probably a Higgs; if there's not a Higgs, things get way more interesting. But if there's a Higgs, something isn't quite right in the theory because for all the reasons that we needed to have the Higgs, if the Higgs had the mass and the properties that we need it to have, somehow it just didn't seem right. It was far lighter in mass than it really ought to have been. So, we now know it weighs about 125 times the mass of a proton, which is pretty hunkin' for a fundamental particle. And our prediction, naively, if I gave that calculation to a first-year grad student, they'd say it's probably way heavier than that, it's like balancing a pencil on its tip. The quantum corrections to its mass would make the Higgs heavier than it actually is.

Aside: And just some very brief background on this. So, Higgs particles make up the Higgs field, which is this big cloud of bosons or particles. So, matter started out zipping around like

photons, just unencumbered by mass, but interaction with the Higgs field is what makes matter interact with gravity and have that mass be gravitationally attracted to each other.

But Higgs bosons, very hard to find. You have to get like, a Large Hadron Collider, say, maybe 27 km under Geneva, and then you've got to race protons at each other, you've got to explode them, and then you've got to measure what's left, AKA a decay signature. And if you're looking through all those pieces and you have pieces and parts for what could have been a Higgs boson, that existed for a fraction of a millisecond, then that's almost, *almost* proof. But for a long time, this possibility of a Higgs particle had vexed science for years. One leading scientist wanted to call it the "God damn particle" but his book publisher was like, "Mmm, let's go softer" and naively made the face palm modification to just call it the God particle, which has been making physicists cringe for decades now. But yes, essentially, things just didn't add up.

Flip: So, this was a huge puzzle. It's analogous to having an ice cube sitting in an oven and you turn the oven on, and the ice cube is still there. So, we call this the Hierarchy problem and for people like me, we write it with a capital H when we write an academic paper, it was a *big* deal. It seemed to be the reason why our theory of particle physics just could not be complete.

Aside: So, prior to 2013, they knew something, *nhh*, wasn't quite right.

Flip: So, we had these great exotic theories, they had funny names: supersymmetry, extra dimensions, compositeness. Maybe the electron and its cousins are not fundamental but are actually made of smaller things.

So, this was the heyday in the '90s of doing particle physics. And right around that time, as we were developing these really awesome theories, people realized, "Hey, in order for this theory to work…" meaning, in order for protons not to decay too quickly, in order for the universe to actually look the way it does, we need to tweak it a little bit. And one output is, we get these new particles that stick around; they don't decay, they're just around. That's kind of weird. And I imagine there was some particle physicist sitting in his office saying this and an astronomer walks by and says, "You have particles just sitting around contributing mass? Umm, have you heard about this anomaly that we have, there's more mass in these galaxies?"

So, particle physicists, who are… I mean, we're kind of smug, [*Alie laughs*] just said, "Oh, okay good, I have discovered what your dark matter ought to be. In 15 years when we turn on this collider, we're going to discover what this particle is, we'll measure how heavy it is, and I will tell you exactly what's in these galaxies that you've been looking at for the past hundred years." This was the promise. And so, particle physicists didn't even care about the dark matter because that was the output of this elegant theory that solved the Hierarchy problem.

Aside: And just a side note, so the Standard Model of particle physics involves this uniform framework for understanding electromagnetic, and weak and strong interactions. And the Hierarchy Problem is the difference between the way a weak force, which is a force that allows protons to become neutrons and then back and forth, vice versa. So, that weak force is actually not weak at all, it's 10^{24} times stronger than gravity, but only at really short distances. So, this was the big strong-weak elephant in the physics room.

Flip: So, that's how I was trained as a grad student. And the year that I graduated was 2013, I had written some papers on extra dimensions and all of these exotic new things that we would predict that we would see at the LHC. And by the time that I turned in my thesis, it was pretty clear that none of those things would be discovered. We had discovered the most basic, the most boring version of the Higgs boson, and none of the things that we predicted for the overarching theory that would explain why it was there. And then we got stuck.

Alie: Ohh. [*"Bummer. What a mind bender, eh?"*]

Flip: And I think this is where this bit of a renaissance in the theory of dark matter because on the one hand, the smug particle theorists like me who would assume that of course dark matter is this thing, all of our best theories predict this thing… Well, that's out the window. But dark matter is still out there. And meanwhile, all these theories that we spent our time building and cutting our teeth understanding, maybe the simplest versions of those guys are out the window too. So, what are we working on?

So, several of us are still working on understanding the Higgs. But armed with all of these new fancy techniques for building theories, several of us went on to think about dark matter because now we can look at this problem with fresh eyes, without the prejudice of, "Well there's this more important problem that has this more important solution and this is just the byproduct of that thing." Now we've been thinking more open-endedly about what dark matter could be, not just what we expect it to be.

Alie: Did you expect to flip a switch on the Collider, some things would go piow-piow-piow-piow-piow and then suddenly a lot of calculations would make sense? How does that even... Do you expect to flip on a switch and suddenly it's *Quantum Leap* and we're on a different dimension? Like, what was expected?

Flip: Yeah, this is a great question because you're bringing me back to grad school where... So, particle physics in particular but physics in general is a really funny science because our community is split between theorists and experimentalists. And the theorists who work more on the mathematical superstructure and the experimentalists who are actually the clever ones who test the theories and see how you do the scientific method, let's be honest.

Aside: So, theory directs experimentalists where to look because this is team effort, there's no I in dark matter... Well, I don't know, there might be, we don't know what's in it.

Flip: As a grad student, the particle theorists who all had our pet theories that we wanted to discover and the experimental grad students were all buddy-buddy, we'd go to the bar together. And they would get so pissed off at us because that was— What you described was exactly how we thought it would work. You just turn it on, and everything works. You just turn it on, you get all the data, and you just confirm this theory versus that theory. Or of course, these colliders and these detectors are gigantic, cavernous, intricate, subtle machines and doing a proper search for a new particle that is most likely invisible is incredibly subtle. So, it *is* a bit of a long slog. So, I think the LHC, depending on what you call turn on, turned on right around 2008 and it wasn't until 2012 that they were pretty sure they saw the Higgs, and 2013 that they had the Nobel Prize.

Aside: So, the Nobel Prize in Physics for 2013 was awarded jointly to François Englert and Peter Higgs for "The theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, which was confirmed through the discovery of the predicted fundamental particle at CERN's Large Hadron Collider."

So, the LHC, by the way, had the juice to discover that decay channel of the Higgs boson where they were like, "Mmm, these pieces parts, these were Higgs at one point," because the LHC is a collider that finally has enough energy to really ramp up those photons and smash them real good, scientifically speaking. And they do it trillions of times over just smash, smash, smash, 100 meters below the Earth, collecting all these data from particle parts starting back in September 2008.

Alie: Do you ever hear theories about, as soon as it went on, that we've shifted into a different universe or a different dimension?

Flip: There are things like that. They're a little bit wonky.

Alie: Yeah, things like, "I thought it was called the Berenstein bears, it's the Berenstain Bears," and all of these things where...

Flip: If only we hadn't turned on the LHC...

Alie: Yeah, we're in a completely different universe. [*Flip laughs*] What about the name dark matter and dark energy? Because it's invisible at best, right?

Flip: Absolutely.

Alie: Who decided that it would be called dark? Who decided that it would have a spooky name?

Flip: That is a great question. I think it was Zwicky, who was a famously cantankerous physicist, in the early part of the 20th century.

Aside: So yes, this was 1933 with Cal Tech's Fritz Zwicky. And when you hear the words, "famously cantankerous," I know you want the story time. And among a lot of different legends, and slander, and feuds, and jealousy, and what sounds like maybe a touch of old-timey verbal abuse, if his enemies' stories were to be believed, Zwicky would allegedly call his colleagues scatterbrains and spherical bastards; spherical because "They are bastards every way I look at them." Oh! Messy, I love it. But a 2008 article in *Discover* magazine features testimony from Zwicky's daughter, Barbarina, that Dr. Fritz was just so brilliant that he had a lot of haters. But he was the one...

Flip: Who coined the term 'dark matter' and what he meant was that it doesn't interact with light.

Alie: Ahh!

Flip: Yeah, so usually we think the things that are dark don't interact with light, but actually, probably there's some junior high student out there who will say, "No, no, no. Things that are dark absorb light, they're actually maximally interacting with light." [*Alie laughs*] If you're an astronomer, dark means you don't see any photons from it. So, I think that's why they use the word 'dark.'

And to the best of my knowledge, I think dark energy, which was discovered a little bit later, as a big question mark, they latched onto the branding that we'd developed [*Alie laughs*] and they use the word dark to mean, "Just like dark matter, we don't know what this is." But at least dark matter we had the idea that this was stuff, these were particles. I'm 99.9% sure that dark matter is at least one particle. Dark energy definitely behaves differently and it's a much weirder thing.

Alie: Do you drive around in traffic and think about this stuff? Can you ever escape theorizing about this?

Flip: Oh! That is a great question. I think the imposter syndrome in me says, yeah, I escape it way too much. [*Alie laughs*] Traffic in LA, as you know, is not a great place to have happy thoughts. But I often find myself thinking about physics in the swimming pool. So, for example, there's this idea that we are fish in an ocean of dark matter, that is something that I was thinking about while swimming. And I guess being in a mathematical discipline, you're sharpening your equipment… having the finest equipment is really having a clear mind and I can sit at my desk, and I can do a calculation, I can write a paper, but the creative spark is usually

something that happens outside of those environments. So, walking around, or having tea on my patio, that's where the magic happens.

Alie: And do theoretical physicists get together and just have, like, brain dumps and try to spark ideas too?

Flip: So, you already know the secret of theoretical physics, that is exactly it. Two of the meccas of theoretical physics in the United States are the Aspen Center for Physics in Aspen, Colorado and the Kavli Institute for Theoretical Physics in Santa Barbara. It's a good approximation of what these things are, are places where you can have summer camp for theoretical physicists.

And why would you need this? Because we all end up being specialists in... It's not even just our particular subfield, but the particular language that we use to understand the mathematics, the particular analogies that we like, the particular intuition that we develop that the *real* sparks happen when you bring us into the same place, you give us a chalkboard, you remove every other distraction, and you let us ask each other, "So what are you working on? Oh, and how do you think about that?" And then everything happens. It's, "Oh, well you know, I've been thinking about this other thing and the language that I use is this, and here's how I do this calculation." And that's how new ideas come about. And oftentimes you can spend two weeks at one of these places over the summer, go back to your home institution, do your teaching, but spend the rest of the year working at these ideas, having Zoom calls every once in a while, but it's kind of the momentum builder of our field.

Alie: And be honest with me, without having to name names, how many astrophysicists out there think that dark matter might be ghosts? [*Flip laughs*] What if dark matter is ghosts?? What if dark energy is ghosts? What if it's all ghosts? What if we're swimming in ghosts?

Flip: There is a famous quote from Nima Arkani-Hamed before the LHC turned on and the quote was something along the lines of, "we might turn it on, and dragons might pop out [*Alie laughs*] we have no idea what's going to happen."

Aside: So, in a March 2008 *New York Times* article, this particle theorist who was at the Institute for Advanced Study in Princeton, told the paper that there was some probability of almost anything happening, even a miniscule chance that, "The Large Hadron Collider might make dragons that might eat us up." Maybe he was just ahead of the curve in predicting the 2011 premiere of *Game of Thrones*, but either way, people were rightly pumped.

Flip: And that kind of encapsulated a lot of the excitement. There is something to be said about, maybe dark matter is something much more exciting than particles. And there are theories where the dark matters could form dark atoms, just like you have protons and electrons, maybe you have something like a dark proton or a dark electron that we can't see but they can see each other, and those form dark atoms. And then it's not hard to imagine, well, those dark atoms could have dark chemistry, that dark chemistry could form dark life, that dark life could maybe... Maybe there's an entire sentient civilization living in our dark matter halo where our galaxy is sitting, and we just don't realize it. But because there is five times more of them than there is us, *we're* the ghosts. *We're* the weird thing.

Alie: Ahh! Wow. Oh my gosh.

Aside: Dark atoms that don't interact with light or electromagnetic forces, just having whole-ass life all around us. Physicists even think that dark matter travels straight through normal matter, just sailing through closed doors, and bathroom stalls, and rocks, and planets, like some kind of spooky cosmic horror movie.

Alie: Do you still look to sci-fi for inspiration at all? Or do you pick apart sci-fi?

Flip: Oh, let's see... That's a great question and it's something where... It's one of the things I'm really thankful to be at UC Riverside where we have this fantastic creative writing department. Until very recently, Nalo Hopkinson was here and she's an amazing sci-fi writer. I actually tried to pitch that idea to her, [*Alie laughs*] about us being the ghosts to the dark matter scientists.

But no, sci-fi is still a huge part of my life. And it's not as simple as, I read a sci-fi story and say, "Hey, I'm going to incorporate that into one of my funny theories." But I love seeing how creative people play with physical ideas. So, I guess you would say I like hard sci-fi. I've never really understood the distinction. But my favorite author at the moment is Ted Chiang, and Ted Chiang, who wrote the short story, "Story of Your Life," which was what the movie *Arrival* was based on...

Alie: Oh yes!

Flip: Most people think the movie *Arrival* is about linguistics, and part of it is. But when I read that story, that story was about quantum mechanics, and it was about a particular interpretation of quantum mechanics, and it was very clear to me that Ted Chiang took some quantum mechanics class or read a textbook and understood it incredibly well and said, "Okay, I'm going to make a universe, literally with these physical laws, with one small tweak, and let's see how that plays out into a dramatic story." And that's something which I draw tremendous inspiration from because that's exactly what people like me do, where we have a question we have to answer: What is dark matter? We have a theoretical edifice, something called the Standard Model of particle physics, it's a couple of equations.

Aside: Remember, that Standard Model of particle physics, that involved a framework for understanding electromagnetic and weak and strong interactions.

Flip: We are constrained that any theory that we make up has to agree with what we currently observe, so has to agree with this Standard Model theory, in the regime where we can make those measurements. And that game of, how do you create a predictive theory of dark matter, subject to these constraints, really reminds me of Ted Chiang playing the game of, "I'm going to take these physical laws, make a tweak, and see how that pans out."

Aside: Okay, so *Arrival* came out in 2016. So, I love you, but you've had ample opportunities to view this, or to have it spoiled. Or maybe you saw it on an airplane and you didn't even totally understand it. But to avoid a spoiler, just fast forward about 90 seconds. If you have seen it, listen, because it'll make you like the movie more.

Alie: What was the tweak that he made?

Flip: He made the tweak, let's see... So, in "Story of Your Life," the main character could view her entire timeline and the principle of least action, this is jargon now, but there's something called the principle of least action in quantum mechanics which tells you that to get from point A to point B, to get from the universe right now to the universe right now, we actually went through every single, possible historical evolution. Maybe I was sitting in this chair, maybe we were in different chairs, maybe I moved over there and came back, all of those things "literally" happened and the path that we took, the most likely path quantum mechanically, is the one that minimizes some function. So, people sometimes call this a Sum over Histories interpretation of quantum mechanics.

And Ted Chiang said, maybe this character can see that entire history and the tweak was because she understood this alien language that was based on this idea. So, in our universe and in the way that quantum mechanics works, one wouldn't actually see the entire history, but there is a puzzle there, and every single student who learns this, puzzles over what it means that these equations seem to imply that these particles know about the future.

Alie: And now, you mentioned something about dark atoms and dark chemistry. You're trying to make sense of dark matter, using a field of math that applies to everything else. Is there a possibility that there's a dark math? That there's a completely different way of trying to quantify everything?

Flip: Oh! Oh boy, okay… That is one perhaps for the philosophy department [*Alie laughs*] and I say that very carefully because usually when a physicist says, "That's for the philosophy department," that's probably condescending, [*both laugh*] that's probably dismissive, that's how we say, "I don't want to think about that." The assumption is, math is logical rigor and so, that just has to be true, and I don't even know how to think about a different reality, a different universe that has different laws of math. I can imagine a different universe where the fundamental constants are a little bit different, maybe there are more particles, fewer particles but I don't know how to think about one where math is different.

Alie: Is there a myth that you would love to bust about dark matter? Like, what is one thing that the public thinks they know about it that they don't, other than that it's ghosts?

Flip: [*laughs*] Oh, that's great, that is a great question. I'll start with a basic one, it's not anti-matter, it's not anti-matter. It's probably also not black holes. So, these are the other two exotic things that you learn from *Star Trek*.

So, it's not anti-matter because if we're swimming in a sea of dark matter and if the dark matter were anti-matter, it would keep annihilating with ordinary matter and produce light. So, the fact that... I was going to say that we're on a glow stick in the universe, but really the fact that our galaxy isn't just being burned up by the anti-matter means dark matter is not anti-matter.

Alie: Nice.

Flip: Until fairly recently we would say it's not black holes because black holes are a totally different thing. But there have been some thoughts recently that there might be little, tiny black holes that were forming in the universe that would behave like dark matter.

Alie: How tiny are we talking?

Flip: There's a range of sizes but the story of little black holes is funny. For a long time, people were worried that turning on the LHC would produce lots of little black holes that would eat the Earth, [*"Sounds like fun."*] but we were pretty sure that the little black holes evaporate and would be relatively harmless. Little black holes are like little particles.

Alie: And do you think that those could just be on Earth in just little pockets here and there?

Flip: Chances are, no. I would bet no, but it is a theoretical possibility. It's attached to a whole bunch of other weird things. I think to make it work out gravitationally, you need to have extra dimensions, maybe a few extra dimensions. But it was a fun thing to think about ten years ago.

Alie: Do you think that dark matter could be extra dimensions?

Flip: That is a great question. That is what I spent my summer vacation thinking about. [*Alie laughs*] So, extra dimensions are a really funny quirk in the history of theoretical physics. I think the modern way of thinking about this is the people who work on extra dimensions don't necessarily literally believe in, "If I could just step in the right way I'm going to be in some parallel universe." But in the mathematics, one realizes that if I can write a theory in three dimensions of space plus one dimension of time, I can write a theory in four dimensions of space plus one dimension of time, or in five dimensions of space and one dimension of time, no problem. It's another number that you add onto your mathematical expressions.

So, it was easy to play with, and in the 1990s one of the huge revolutions in theoretical physics was this observation that particular types of theories with extra dimensions end up giving mathematically equivalent predictions, when you've asked the right question, to a type of quantum theory that is really hard to calculate. This is something called a duality in physics, and it meant that I could calculate something in my wonky theory of extra dimensions and that calculation would actually mean something in an ordinary theory (ordinary meaning three dimensions of space, one dimension of time), that is highly quantum mechanical, but a perfectly plausible theory. And it was a type of theory that we really didn't know how to deal with until we had tools like this.

Aside: Tools like the Large Hadron Collider.

Flip: And so, one of the fun things to play with is we have this really powerful machine to make predictions where we couldn't make predictions 20 years ago. Maybe we could describe cool theories of dark matter that 1) could explain why we haven't discovered dark matter and 2) could motivate interesting, different searches. Because this is where we are right now, we need to figure out what is the best way to test these different theories of dark matter.

Alie: It better happen in my lifetime. I mean, I'm sure you think the same thing given that this is your life's work.

Flip: Yes, yeah. In fact, for me, this is the difference between dark matter and dark energy. Both of them are things we have no idea what they are, I certainly have no idea what they are. Dark matter, we have an experimental program, and we know enough about it that I have faith that we have a sporting chance that we will learn something deep about dark matter in my lifetime. Dark energy, I'm not sure if we'll learn anything about it in the history of humanity.

Alie: Do you have a Google alert set for dark matter just in case there's some news that breaks that you're like, "Wait, what? When did that happen?"

Flip: I have an RSS feed [*Alie laughs*] and I follow some Twitter accounts. Though yeah, there are funny things about things like this in particle physics. I've forgotten what the network is, but there are astrophysical events that it's all-hands-on-board the moment this happens. So, the next supernova is going to be the most exciting thing in decades.

Aside: A supernova, heads up, is this giant explosion caused by a star burning out of fuel and then collapsing on itself and going, kapow. And NASA urges you to imagine a star, one million times the mass of Earth collapsing in 15 seconds. Ahh! What's left behind is this cloud of gasses called a nebula, or if the star is big enough, like 10 times the size of our sun, you might even get a black hole out of it. So, a supernova could also happen with a white dwarf, which is like an Earth-sized star that's run out of fuel, it gets too close to another star, it siphons off some of its matter and then kaplowzies. But will there be, maybe, like a supernova this week, this month you can watch? Is there a Twitter account you can follow? Probably not. They only

happen in the Milky Way a few times every century, but when they do, it is the equivalent of a giant legendary house party for physicists. It is on; it is a rager.

Flip: There's a story of supernova 1987A where we learned a lot about neutrinos. And now that we know gravitational waves exist, now that we have all sorts of really exciting complimentary satellites and astrophysical observatories, there's this network where if anybody realizes that there's a supernova, all of these telescopes, all of these detectors will drop whatever it is they are doing, and they will point at that part in the sky and take all the data that they can. That's a Twitter feed that I like to be subscribed to.

Alie: Yeah. [*laughs*] Can I ask you questions from listeners?

Flip: Yes!

Alie: Okay. I mean, for the most part, we got a lot of, "Whaaat is it?" Who can blame them?

Aside: But before we get to those questions with the amazingly affable Dr. Flip Tanedo, who is your favorite particle physicist, let's scatter some money into the cosmos specifically toward two causes of the ologist's choosing. The first that he picked is The Point Foundation, which is the largest scholarship-granting nonprofit for LGBTQ students, empowering them to achieve their full academic and leadership potential despite the obstacles often put before them. And PointFoundation.org has more info, love them. And the second charity he chose is Feeding America: Riverside & San Bernardino, which distributes over 2.5 million pounds of food per month and partners with over 250 local nonprofits, both of those causes will be linked in the show notes. Thank you to sponsors for making those donations possible.

[*Ad Break*]

Okay. Let's shed some light on your burning dark matter queries.

Alie: Okay, Will Clark, first-time question-asker, also known as PWilly: Is dark matter the absence of matter or something measurable? We now know it's something measurable, right?

Flip: Yes, absolutely. So, dark matter, this is one of the great things where it's fairly ordinary, it is a thing, it is stuff, it is matter.

Alie: It's something.

Aside: That was also asked by patrons Jessica Smith, Ruby Chan-Frey, Anfauglir, Ed Matesevac, Jackie, and first-time question-askers, Lucas Waterbody and Sam Phillips-Corwin. So, let's dip in to the next question.

Alie: Leah Anderson, first-time question-asker, asked: What is a "hidden valley" [*Flip laughs*] (CERN mentions it on their webpage about dark matter)? Is there a potentially parallel universe occupying the same space that we inhabit? What is hidden valley? It is not a side of ranch, I'm guessing.

Flip: That is a great question. So, hidden valleys are a class of theories that were developed by Matt Strassler and Kathryn Zurek in the mid-2000s, I believe. And they are actually related to some of the extra dimensional signatures that I'd mentioned earlier. It's really funny that the listener asked that question.

I was reading the hidden valley paper recently for some research that I'm working on. We were looking forward to the LHC, we all had these favorite theories, supersymmetry, extra dimensions, and the hidden valley authors were thinking about, "What are more exotic things that could come through at the LHC?" We all had this idea, like theorists, that you turn it on, and you just see all the new particles, it's easy. [*Alie laughs*] What if it's not so easy? What if

the new particles don't really behave like ordinary particles, or what if they have really different signatures? And the hidden valleys were a type of theory that were constructed to show other physicists how weird and how unique these experimental signatures could be.

Alie: And you know, we mentioned a little bit about dimensions, but a few folks, including Lyssa Mercier, wanted to know and says: Sorry if this one is a little too sci-fi-y (no need to apologize for that one here) if you consider the theory of multiple universes, could another universe be made entirely of dark matter/energy? You mentioned dimensions, but what's the difference between multiverses and different dimensions, or are they used interchangeably?

Flip: Oh, good. Good, good, good, good, good. Okay, it becomes a question of where do we start agreeing on what words mean, what is a universe? [*Alie laughs*] So, if we assume a universe is some self-consistent, perhaps imaginary everything, so a universe has some number of dimensions of space and time, if there's more than one time dimension I have no idea how to make sense of it. It has some kind of governing physical theory, there's some equation telling you what the particles are, how they move... Yeah, that's a good approximation for what I think a universe is.

So, a multiverse would be [*chuckles*] a collection of different universes that really should not interact at all. So, whether or not the multiverse is real is such a weird question, not because if it is real something exotic is going to happen, but if a multiverse is real, by definition, those other universes have nothing to do with us, you can't traverse them, you can't pass through them. But the idea is they would have very different laws of physics. If you characterize a universe by some list of numbers, the mass of the electron, the strength of the electric coupling, the strength of gravity, there's some list of numbers, and just push them into your theory. A different universe would be one with different numbers.

And what the Marvel cinematic universe has done for us is it's given us this idea that if there's a multiverse, then you can go between them and harvest, whatever, infinity stones and bring them back, [*Alie laughs*] but that's not quite how it works.

Alie: What about *Everything, Everywhere, All at Once*? Have you seen that?

Flip: Oh, I love that movie, I love that movie. [*"Across the multiverse, I've seen thousands of Evelyns"*]

Alie: That's not how that works?

Flip: One of my favorite students in my particle physics class last term brought that up in class and said, "Can we talk about this afterwards?"

Alie: [*laughs*] You love it as a work of fiction?

Flip: I love it as a work of fiction, yes.

Aside: And just a side note, the Academy Awards are on March 12th, 2023, and those who listen to this after that date will know if that film won any Oscars. Oh! Speaking of...

Alie: MB wants to know: Time travel... Yes/no/maybe?

Flip: Oooh! We are definitely traveling in time.

Alie: Right now we are.

Flip: We are definitely traveling in time and that by itself is kind of weird because we know that if you're moving faster the way that you perceive time is different. So, ordinary traveling through time in the forward direction is already pretty exotic, if you ask me. I don't think any more exotic Dr. Who-level time travel is possible, certainly not within our existing theories.

But I'll be fully honest, part of that is because our existing theories put in by hand that causality is really important, and causality is this idea that you cannot have grandfather paradoxes where you go back in time, and you kill your grandfather.

Alie: Yeah. Also, what are these grandpas doing? You know what I mean?

Flip: Yeah! What beef do you have? [*Alie laughs*] I guess that's a big jump for a scientific experiment.

Alie: Yeah, "Everyone's grandpa is such a dick." [*Flip laughs*] Maria wants to know: What would the universe look like if there was no dark matter and what would happen if it suddenly disappeared?

Flip: Great question, great question. Okay, so let's start with if there were no dark matter. If there were no dark matter, there wouldn't be us. [*"I'm not here."*] I think a good benchmark is the quantum fluctuations of dark matter in the early universe, so the universe was hot, small, things are blipping in and out of existence, every once in a while, there would be a little bit more blipping into existence over here rather than over here. And that over-density of stuff, of dark stuff, would gravitate and pull more dark stuff in and that would be what we call a dark matter halo. The big dark matter halos were so strong gravitationally, they're so massive, that they would bring in the little, tiny specks of dust of ordinary matter and slowly, those little specks of dust collect and turn into our galaxy. So, if there were no dark matter, we wouldn't have the collection of ordinary stuff that became our galaxy, and we wouldn't be here to wonder about it.

Aside: So, whatever dark matter is, it's helped collect all the atoms and scattered ingredients to make us. And now, here we are, breathing, living, loving and crying, having good days, eating cheese for dinner and farting into pajamas watching TikToks of earwax removal. It's a beautiful life. Dark matter, thank you, never leave... probably.

Flip: If all the dark matter suddenly disappeared, that's a good question. I'm actually not quite sure what would happen, I have not done the calculation to figure out if our galaxy would stay here or if maybe the smaller galaxies around us would... What's the word?

Alie: Kind of scatter almost, like if you to whip something around and just, you know, the merry-go-round, just scatter off of it, right?

Flip: Yeah. So, in fact it would be very similar to the question that I think we ask a lot of our freshman physics majors: If the Sun disappeared, what would happen to the solar system? Eventually, everything would just fly away because the gravitational pull that was holding them together would be gone.

Aside: So, mass attracts mass. And that is why smaller planets have weaker gravitational forces, and why you can hop like a bunny on our tiny moon, if you can manage to get a ride there. And a few patrons asked this next one such as Anika's Cat Arya, Earl of Greymalkin, Elder Zamora, and...

Alie: Theodore Vician: Is there anti-dark matter to correspond to anti-matter?

Flip: I love that question. [*Alie laughs*] The answer is almost certainly yes and it's almost certainly yes because the laws of physics that we understand seem to imply that everything has an anti-particle, with the caveat that sometimes they are their own anti-particle. So, photons are their own anti-particle, there's no anti-photon. So, dark matter exists, it's a particle, you can define a mathematical operation that turns dark matter into anti-dark matter, and it is an open question whether the anti-dark matter is the same as dark matter.

And I'll mention one last thing, the same question is true for neutrinos. Neutrinos are the other invisible particle and we do not know, still, whether neutrinos are their own anti-particle.

Aside: So, a neutrino is just the littlest, wee, darling little particle with no charge, it's nearly massless, it's so light, and they're everywhere in the universe. They originate from exploding stars and from the nuclear fusion in the Sun and there are millions of them that mosey almost at light speed, right through your dang body every day. Two physicists discovered them in the 1950s, they won the Nobel Prize in physics... 40 years later! Which, I'm sorry, it seems like a long lag time, and I don't feel bad saying that because I know I'll never be up for a Nobel Prize in physics.

Flip: The paper about neutrinos said, you could explain this thing if there were some really weakly attracting, nearly massless particle, but I'm sorry to have predicted a particle that has no chance of ever being detected.

Alie: I love that there's like a "Uhh, so sorry.!

Flip: This is not good science. [*both laugh*] But we found it.

Alie: That's rad. [*"Chief! We got 'em, we found 'em."*] Jackie wants to know: What would happen if I had ten pounds of dark matter in my hand? And then some other folks asked, Jackie also asked: How much dark matter is in the room right now? How much dark matter is in us?

Flip: All right. So, we actually know this.

Alie: Oh, okay!

Flip: I only know the rule of thumb that where we're sitting in our galaxy, in your coffee mug you have about one hundred "proton masses of dark matter." That means that if dark matter weighed as much as a proton, then you would have one hundred dark matter particles. That's about 10 to the minus 22 grams. Here's the caveat: if you tell you that you have 10 to the minus 22 grams of dark matter in a mug, you don't know if that's one particle that weighs 10 to the minus 22 grams, or a thousand particles that each weigh a one thousandth of that mass. So we don't know the number density of dark matter, but we know the mass density of dark matter.

Alie: And we can't measure that on a scale that's actually measuring grams because that is using gravity.

Flip: Absolutely.

Alie: So, it would be a completely different scale to measure that.

Flip: This is something that we have inferred, not from anything terrestrial, but from the motion of stars in our galaxy.

Alie: Oh, that's absolutely nuts. I mean, I just... Does it change the way you live your life at all, knowing that we are surrounded in such mystery? Do you ever just take more chances [*Flip laughs*] or say, "Screw it, I'm going to live for today, get the whipped cream on the ice blended, why not?"

Flip: So, last year, we have a science book club and last year we read Katie Mack's book, *The End of Everything.* And there was definitely a week where I thought, "It doesn't matter how bad things are, the universe is going to end eventually." [*both laugh*]

Alie: I was reading that before bed the other night and I was like, "This is a little depressing but oddly liberating." It's a great book.

Aside: So, we did a two-part Cosmology episode a few years back with Dr. Katie Mack, which of course I'm going to link in the show notes. And I highly urge you to pick up her since-released book, *The End of Everything (Astrophysically Speaking)*. It's really funny and informative; it's terrifying, it's comforting all at once. I'm going to link it on my website.

Alie: Earl of Greymalkin wants to know: What is the best music to listen to while researching dark matter?

Flip: All right, that is a great question.

Alie: Do you need classical music or, like, thrash metal? [*laughs*]

Flip: I'm looking over at my laptop because I have a '90s Indie Rock channel playing on YouTube music right now, [*Alie laughs*] so that's what I use for class prep. For research I think there are these lo-fi hip-hop channels with no words… and this is just a life pro tip for anyone doing something mathematical. You want to have background music, so you're not just hearing the echoes of your room, you want something with no vocals. And for the added bonus, there's a different webpage for generating café sounds. So, I make myself a hot tea and I have all the ambiance of a café but I'm sitting at my desk.

Alie: That's genius. I love it. And life tips from an astrophysicist is something I would definitely tune into at any point.

Flip: Technically I'm not an astrophysicist.

Alie: Are you a theoretical physicist?

Flip: Theoretical particle physicist.

Alie: Now, what's the difference between an astrophysicist and a theoretical? And pardon me because this is just me learning, but what is the difference between the two?

Flip: So, if you're my department chair, an astrophysicist can get money from NASA [*both laugh*] and a theoretical particle physicist gets money from the National Science Foundation. But the two fields are actually blending. I collaborate with theoretical astrophysicists on dark matter. There are topics where you really can't distinguish, but the tools of the trade for a particle physicist are really quantum field theory and an entire tradition of how we think about fundamental particles. Astrophysicists have a slightly different tool kit that patches on with observational astronomy, and cosmology, and a different scale of, what are the interesting problems?

Alie: I thought Lucas Waterbody had a great question: I know we can't observe it but after working on it for years you must get some weird imaginary images in your head when you think about it. What does dark matter look like in your head?

Flip: Ooh! Yeah okay. So, the... I think the honest answer is, I have pictures, but the pictures are never of the dark matter, the pictures are of my toolkit for understanding dark matter. So, if I'm thinking about dark matter as something that could be described with extra dimensions… and I say that very carefully because I'm not saying there are extra dimensions, I'm saying, mathematically, I can do a calculation in the extra dimension and it means something. Then I think about literally an extra dimension, and I have tons of these pictures I draw with my grad students about, what does the wave function look like? Does it ripple? What does it look like at the boundary? Does it interact with other things? Is it wiggly? Is it exponentially

increasing or exponentially decreasing? But that's a picture which is not the same thing as a picture of the invisible quantum field, which is not really a tangible thing, but it's a picture that I hold onto.

The other thing are Feynman diagrams which are these really cute tinker toy-looking things that particle physicists use to describe quantum scattering, so any process. They're actually shorthand for mathematics but it's a way of engaging the visual part of your brain to make sense of something which is otherwise pages of calculation.

Alie: Yeah, and otherwise so abstract.

Flip: So, we think in analogies, that's the punchline.

Alie: It's so interesting to think of a theoretical physicist also thinking in, like, almost tinker toys, to try to get a handle on, like, dimensionality or something. I'll ask one more listener question. Emma Rose wants to know: Does dark matter have a sound?

Flip: Oh gosh, there are so many great answers to that question. One of my colleagues, Yushin Tsai at Notre Dame, he had a great paper about something called dark acoustic oscillations which is literally answering that question; it's in the word. So, acoustic oscillations are about sound waves in the early universe. So, dark matter, which were particles that were forming these halos, when there's a shock to the halo, they form sound waves, so ripples in the dark matter substrate. So, they literally form sounds. It's both exciting and cool but completely mundane. You can imagine sounds traveling in water, if I knock on wood, sounds traveling through wood, it's literally the same kind of sound wave.

Alie: But it's going through dark matter?

Flip: Going through dark matter.

Alie: And it's a sound that we can't hear the matter that we're made up of yet.

Flip: Exactly.

Alie: Unless maybe, somehow, we create something that can capture that.

Flip: It's an interesting question. If dark matter has some motion, does that help us have some new handle to detect it?

Alie: Can you imagine if one day, there's just Geordi La Forge banana-clip eyepieces and you can just 3D-glasses, just see dark matter?

Flip: Oh yes! Yeah!

Alie: Everyone's asshole grandpa is there [*Flip laughs*] as a ghost.

Flip: Oh, it was you guys all along. Sorry about that experiment we did.

Alie: [*laughs*] So sorry.

Flip: We can actually do that using gravitational lensing. So, this was a result from maybe 10, 15 years ago, from… I believe it was Tom Abel at SLAC was one of the first people to do this, where they used astrophysical data to map out where the dark matter is, and they form these filaments...

Aside: And gravitational lensing, side note, let's break it down, it's the way that mass bends a light source so that a shift in light is a clue that something with a lot of mass nearby is affecting it.

Flip: What the dark matter distribution looks like, they look like filaments. When I look at them, they look like neurons, they look like a network of neurons where you have dark matter halos and there are little filaments that connect them. We understand why they form this way but it's a really striking "picture".

Alie: And we think that that is how they are forming and how they're existing?

Flip: Yeah.

Alie: So, that's kind of a fundamentally huge way of visualizing it, right? Just to think that there's all these spidery, webby, filamenty things.

Flip: Yeah. So, *Star Trek: Discovery* used something similar as a concept for intergalactic travel and I was a little bit miffed that they didn't actually use dark matter.

Alie: [*laughs*] It's like, "Call me, you're right here, you're in LA. Take a meeting in Beverly Hills in an hour and half, come on. Meet me at Urth Café, we'll talk it out."

Flip: Oh man, you know your places.

Alie: You know what I mean? What about… What's the hardest thing about being a scotohylologist?

Flip: A scotohylologist. There are a lot of different things. There's the pace of experimental discovery compared to the theoretical creativity. It's really easy to... Well, sorry, it's not easy. But in principle, the time scale to come up with an idea and play with it is relatively short. In practice, you spend a lot of time honing that creativity. But to actually test something is a whole different thing. To convince federal funding agencies and, well, start off with your experimental colleagues who know a lot more about actually doing experiments than you do, to do something and invest resources from elsewhere to do a particular type of search, it takes a long time.

One of my mentors has a joke that I absolutely love. The story is, you have a brilliant theorist who writes down a theory that is just so beautiful and she says, "This is it. This is the most elegant, beautiful theory." So, she goes downstairs, because theorists tend to be on the top floor, so she goes downstairs to her experimental colleague and says, "I have a theory and it's predictive. I predict these three things and I think your lab should be able to do this." So, the experimentalist is excited, and he says, "Okay, let me apply for grants." So, he spends the next quarter writing grants, he sends them off, the funding agencies get back to him, he's able to recruit some new grad students, hire some postdocs. Over the course of the next three years, they decide to build a new experimental apparatus which involves contracting out types of equipment that have never been made before, creating their own high-tech kind of thing, and then they run. And running these things can take ten years.

So, grad students graduate, postdocs move onto new jobs, they hire new undergrads to take care of the experiment. Ten years later, everyone has gray hairs [*Alie chuckles*] and the experimentalist, I'm imagining like a Dot Matrix printer, pulls out the piece of paper and looks at it really solemn, [*sighs*] walks up the stairs to go to his theory colleague, knocks on her door and says, "I'm really sorry, no result. It's not this theory." And she slams her hand on the table and says, "Can you believe that? It took me two weeks of my life to write that paper." [*both laugh*]

Alie: Oh no! Oh, these experimentalists. Oh my god. And so, are you… Do you feel like you have more theories than you will ever be able to write up? Do you know what I mean?

Flip: No, I wish it were like that. There are some people who are like that, and I really admire that. For me, a lot of it really is taking a few core ideas and running with it. Some of those core ideas are mine, some are from my colleagues and my friends, and we tinker, and we cross-pollinate but oftentimes it's very slow and incremental, even on the theoretical side.

Alie: Any life advice you would have from someone who studies the universe and what we are and what it is? Is there any perspectives on life that you would want to share with your younger self or with others?

Flip: Yeah, so it's the beginning of the term here at UC Riverside so I've been thinking a lot about this, what advice would I give to freshmen, what advice would I give to myself, general advice. You know… who was it, Baz Luhrmann did the graduation song. I think they attribute it to Kurt Vonngeut but it was actually someone else who wrote the article "Wear Sunscreen."

Aside: So, the "Wear Sunscreen" opus was actually penned by a *Chicago Tribune* columnist, named Mary Schmich, who wrote the article for the graduating class of 1997 and then it was released as a song in 1999. [*"You will not understand the power and beauty of your youth until they have faded. But trust me, in 20 years you'll look back at photos of yourself and recall in a way you can't grasp now, how much possibility lay before you and how fabulous you really looked."*] It's a doozie.

Flip: Here's my "Wear sunscreen" advice. Ladies and gentlemen, do your homework.

Alie: Just that?

Flip: Do your homework. And I have context. So, when you're doing dark matter research, any type of research, in fact, forget research, anything that you're doing in your life as an adult, there are no solutions in the back of the book. If you're doing anything exciting, you don't know if you're doing it right and you have no feedback, and all you have is the intuition that you build up that you're going in the right direction. It's painfully true in dark matter research where you can say, maybe dark matter is this type of particle and just be completely wrong.

So, I tell the first-year physics students that I hate homework, I hated doing homework, I hate giving homework, I absolutely hate grading homework. [*Alie laughs*] But I give homework as a service to them because that's my commitment saying, "There's something that you should do, and I know what the right answer is, I will help you get to the right answer, and if you get the wrong answer, that's great, we can work together and figure out what needs to be adjusted so that you have the right intuition to get to the right answer." And that's the critical thing, it's building that intuition of, "I've gotten this wrong before but now I am wiser because of having gotten something wrong."

And that I think is the general life advice and is exactly how theoretical physics works, where a lot of the work that we do is conjectural and we work it out and then someone says, "Oh, but if you do it that way, the proton decays." Oh yeah, dummy. Okay, now I know that this type of theory needs to have this type of tweak and I've built up a toolkit that I could only have had by making the mistake.

Alie: And that is something I feel like people who are outside of science in general are so afraid to fail but there's so much failure in learning.

Flip: Absolutely, absolutely.

Alie: It's the only way we learn anything, right?

Flip: Absolutely.

Alie: So, don't be afraid to fuck up a little.

Flip: Absolutely. And this is like the joke about the clever theorist. When I die, if any of my research papers have any element of literally being true, I'd be ecstatic, but a lot of the speculative work is, "I think this is the way things work." And even the ones where I get it completely right, the universe might just not be that way. But there's value in 1) going through the process of being creative, and 2) learning why the universe is not that way.

Alie: What about your favorite thing about what you do?

Flip: Oh gosh. I love that on any given day, there are new things to learn and either it's some experimental result that I want to understand, or some related field where I never had the chance to take that class as a student but I see that there's an opportunity where dark matter might be able to do something and then I can dig in and say, "I have an excuse to spend my time reading this textbook or reading this recent article or talking to my colleague from a different department." That's the fun part.

Alie: Is just always learning and getting to get outside that discipline?

Flip: Yeah, yeah.

Alie: That's great. I love that for the rest of my life I'm going to be walking around thinking about a gram of dark matter in my coffee cup, and sparkly webs, and maybe ghosts.

Flip: Maybe ghosts. [*both laugh*]

Alie: You don't have to commit to that on the record I just... for my own fun.

Flip: Well, I would add... My 'yes and' would be, thinking about all the dark matter scientists who are thinking about us and *we're* the maybe ghosts.

Alie: Ahh, I love them. Thank you so much for doing this, this was a joy.

Flip: Thank you, Alie.

Alie: Oh my gosh, yay.

So, ask the smartest people you can find, the simplest questions because that's why they study this and probably no one at their own Thanksgiving even understands what they do for a living. So, thank you to the incredible Dr. Flip Tanedo for letting me barge into his office with so many questions... Ah! What a gem. You can follow him at Twitter.com/FlipTanedo, we'll link that in the show notes along with The Point Foundation and Feeding America: Riverside & San Bernardino. Links to sponsors are also in the show notes.

And if this episode had too much swearing for you, you can feel free to hit up our *Smologies* episodes, those are linked in the show notes, those are shorter versions of classic episodes. They're trimmed of language, they're shortened for shorties, you can find them at AlieWard.com/Smologies. Thank you, Mercedes Maitland of Maitland Audio for making those with assists from Zeke Rodrigues Thomas of Mindjam Media.

We also have bleeped episodes and transcripts by Emily White of The Wordary. Those are up at AlieWard.com/Ologies-Extras, bleeped by Caleb Patton. Erin Talbert admins the *Ologies* Podcast Facebook group, Susan Hale handles our merch and so much more. Noel Dilworth does scheduling, Kelly R. Dwyer made the webpage, Nick Thorburn wrote the theme music. Assistant editing and engineering was by the man and mullet, Jarrett Sleeper of Mindjam Media with additional editing

from Mark David Christienson. And lead editing was done by Canadian treasure, Mercedes Maitland of Maitland Audio who is linked in the show notes.

And if you stick around until the end of the episode, I tell you a secret and this one is that Dr. Sarah McAnulty, squid expert and teuthologist from her episodes, you may know her. She was in town, and she stayed at our house for a few days, which was wonderful, and we watched *Puss in Boots* and, first off, I always thoughts that *Puss in Boots* was a duo, and like 15 minutes into the movie was like, "Okay, so there's no Boots then? It's just one cat named Puss and he's wearing boots? Okay." But also, if you've watched *Puss in Boots,* I think the animators have definitely done at least, like, guided mescaline therapy or a hit of DMT at a party, or maybe they grow their own shrooms, but it is a trip and I definitely cried at a cartoon cat, so there's that. Okay, berbye.

Transcribed by Aveline Malek at TheWordary.com

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