Episode 40, Snowlines and No Rhymes
Dramatis personae:
- Ben Tippett
- Catherine Niesh
- David Tsang
- Taylor Mali

The Titanium Physicists Podcast
www.titaniumphysics.com

Ben: Oh, hello old friend. It's good to see you. Let's talk about this word "fascination". It describes an unquenchable urge which compels our hearts to quest, and be captivated. As long as there are elegant explanations to complicated phenomena science will never lose its romance. Over the years I've traveled the world, indulging in my fascination with physics. And now, I find that a new hunger has woken within me: a fiery need to share these great ideas with the people around me. So, I have assembled a team of some of the greatest, most lucid, most creative minds I've encountered in my travels. And I call them my Titanium Physicists. You're listening to *The Titanium Physicists Podcast* and I'm Ben Tippett. And now... *allez physique!*

01:11

[Intro song; *Tell Balgeary, Balgury is Dead* by Ted Leo and the Pharmacists]

Ben: Come with me, let's walk. From the center of our solar system out to the edge. We start at the Sun, nice and hot. Okay, there's mercury, the hot one. And then Venus, eighty percent the mass of the Earth. Alright, and then there's the Earth, hello. Oh, there's Mars, it's the red planet. Mars is only ten percent the mass of the Earth, if you didn't know (it's kind of a mystery). Alright keep on goin' out: there's the asteroid belt, nice, lots of asteroids. Alright, now: the gas giant planets, they're huge and full of gas. There's Jupiter, its orbit is five times the radius of the Earth's orbit and it weighs about three hundred times as much as the Earth does, which is, you know, it's huge. Now Saturn. It's the one with the rings of course, and it weighs about a hundred times as much as the Earth does and its orbit is ten times the radius of the Earth's orbit. Alright, now keep on going out. Now the ice giants. Awesome. Frozen solid. There's whitish colored Uranus. It's heavy and cold and about fourteen times the mass of the Earth. And there's dark blue Neptune. It weighs about seventeen times as much as the Earth does. Nice. And past this, you know, dwarf planets, the Kuiper belt, full of frozen rocks and then the Oort cloud where comets live.
So, if you've ever given any thought to where all these planets come from. Fourteen billion years ago the universe was only full of hot gas. Mostly Hydrogen. Super uniform, so everywhere you went, you'd see the same gas, at the same temperature. So it's boring, and now, now we've got a solar system. Some of the places have planets, and others just have space. And some of the objects are kilometers wide while others are tens of thousands of kilometers wide. And some are hot, and some are cold. What variety! What spice!
So, how did it all get here? How do you go from a cloud of amorphous gas to a world of wonder and color?
The topic of today's episode of *The Titanium Physicists Podcast* is the formation of planets in our solar system.
Now, there's a poetry to these events. We're talking about the elements which shape worlds. We're talking about the mighty forces required to turn a lump of undifferentiated whatever into something wonderful. And

who better to talk about it today then the poet Taylor Mali?
Taylor is a slam poet and a teacher and a great advocate for teachers. He's a four time winner of the National Poetry Slam competition and he's known for his quest to remind people that teaching is a noble and important and virtuous profession. You might be familiar with his poem *What Teachers Make*. His YouTube performance of the poem has five ma-ma-ma-million views! You might have also read his book *What Teachers Make: In Praise of the Greatest Job in the World.* Welcome to my show Taylor Mali!

Taylor: Ben, thank you very much. I am very much looking forward to finding out how planets are formed. I also, in my job as a poet, am concerned with taking things that are amorphous and turning them into something wonderful.

Ben: Wonderful. Listeners you can find more about Taylor from his website www.taylormali.com . And of course you can find a link to it from the Titanium Physicists homepage.
Alright, so Taylor, for you today I have assembled two of my favorite Titanium Physicists. Arise Dr. David Tsang!

David: [maniacal laughter]

Ben: David did his undergraduate with me at UBC and his PhD at Cornell University. He is currently a post-doc at McGill and Caltech researching black holes and neutron stars, and planets.
Arise Dr. Catherine Niesh!

Catherine: [sad trombone sound]

Ben: Dr. Catherine did her undergraduate with me at UBC. Her PhD at University of Arizona in planetary science. She's currently at the Florida Institute of Technology studying planetary science. Hooray!

05:19

Alright, let's start talking about planetary formation. Planets, stars, they come from gas in space. Where does the gas come from to start a planetary system?
What you need to have is a really big star. So what happened was, early early in the universe there was nothing but hydrogen/

David and Catherine and Ben: And some helium...

Ben: / gas collapsed, in little places. They'd be little pockets where the hydrogen gas would be slightly heavier than the hydrogen gas around it, sure, and it would collapse down, and make a really big star. And what happens to really big stars?
Well, eventually they churn and they turn helium and hydrogen into heavier elements, and then they run out of fuel and they explode. And they blow off a whole bunch of more complicated heavier elements into space. A big supernova.
And what do you call one of these big clouds of gas? You call them a nebula.
And so the deal is that before our solar system existed there was once a great big cloud of this kind of gas, full of heavier elements than hydrogen and helium, and then eventually what happened is *it* collapsed. So there was some place where it was slightly heavier than it, and you know gravity attracts around the heavy places and the gas collapsed down in on it, and it made our sun.
But it wasn't only our sun. There was some gas remaining, outside. Because, if, on average, the gas is swirling a

little bit as it collapses, the angular momentum of the gas is going to keep it from falling in to the star. And what you're left over with is kind of a puck shape of gas swirling around the new-born baby star. And essentially it's this gas, this mix of different elements, that turned into all of the different planets.

Taylor: Ben?

Ben: Yes?

Taylor: For a poet, you need to start with a lot more humility. Not just because the United States is a shockingly religious country, but, it would be so comforting and refreshing to hear a physicist talk about this subject by saying there's a whole lot we don't know. You've gotten so technical, so fast, and I wish that you could be comfortable with broader strokes at the beginning, saying: "In the beginning…"
And I don't even know where we're talk…
Like, you've mentioned fourteen billion years ago, and to the average person, that in itself, you could spend an entire podcast just letting people know the scale of what fourteen billion years ago is...when that is.
I would like you to be a little bit more humble and talk about, you know, we don't know where this came from/ I'm not going to ask you to ascribe everything that you don't know to God, but there are others who might. But take broader strokes and just say: we don't know what happened here, but this is how the planets formed.
Am I outta line?

David: Well no, I mean, we know that/ we know where the gas came from. It came from an older star. A first or second generation...

David: Well mixed with some hydrogen, helium...

Ben: Yeah, so there was/

David: The big bang.

Ben: / so these stars change the elements inside of them, and then eventually they blow up. And so we know all of the gas that constitutes all of the matter that we're built out of came out of one of these stars. And we understand the physics of how these stars work pretty well.

David: And we also know roughly how old the universe is. It's roughly fourteen billion years but you know, give or take a few billion

Ben: Yeah, and we know that the early universe was filled with hydrogen and helium because you can take a telescope and you can tune it to the right frequency and still see all of the light that was emitted from this early hydrogen and helium.
Okay. So where were we?
The idea here is you start out with a big cloud of gas. And the gas has a little bit of rotation to it. And the cloud of gas collapses down on itself and you end up with a big pile of matter in the center which turns into the Sun. But that's not all.
You also have kind of a disc of gas that's rotating around the star.

Taylor: But wait: some matter condenses and becomes a light-emitting star and some matter condenses and becomes a planet?

Ben: That's right. So, we want to talk about how you go from having this big cloud of gas circling the star to having essentially what we have today: a whole bunch of planets.
And we want to talk about the different models involved, the different forces involved, but also we want to talk about, say, how we know that it's true.

10:08

Catherine: So there's basically something we call the "snowline" in the solar system, beyond which, you know, water ice is the important thing, can condense and so you stop having terrestrial planets, made of rock and iron like the Earth, and you start having planets (I'll call them planets even though they're moons) that are roughly half rock and half ice, icy satellites.

Taylor: Hold on, as a poet I'm still thinking about the fact that you said "water ice", which implies that there are other types of ice?

Catherine: There are other types of ices, yes. Anything that is solid and typically that is a gas or a liquid on Earth is called an ice. So theres nitrogen ice and methane ice and ammonia ice

[laughter and oooing]

Taylor: Did she just say something controversial?

David: No no, Ben had told her not to say

Catherine: Just joking. Yeah.

Taylor: Okay.

Catherine: Yeah, so you have all these great places in the outer solar system that are, you know, big snowballs. And that's only possible really because the temperature changes as you get farther and farther from the Sun, so that when the solar system was forming these ices were solids and could stick together to form planets.

Taylor: I only know the Kuiper belt from a poem that I wrote about the demotion of/

Catherine: Oh yeah.

Taylor: /the planet Pluto to a dwarf planet, but Pluto is largely/ is it made up of water ice?

Catherine: Presumably yes, it is mostly water ice. Although, once you get out to the Kuiper belt you can have these more exotic ices as well. We see nitrogen ice on Triton's surface and we think that Pluto might be a lot like Triton, which is Neptune's largest moon. So out there in Pluto regions it's cold enough that you can start forming ices out of other things. But predominantly we think it's probably mostly water ice.

Ben: So, there's this word that Catherine brought up: snowline. You know what a snowline is, right Taylor? Like on a mountain.

Taylor: That's the place on the mountain where either the snow starts or stops.

Ben: Yeah yeah, it's where it stops, right? Because the idea is that as you go up the mountain the temperature drops, and so there's a place, on the mountain, where the temperature is below freezing, and all that we would

get as rain turns into snow, and that's the snowline. This is absolutely fantastic because I'd always imagined that if somebody took me, and put me in a bubble and threw me out into space, I would freeze to death. The short answer is no, the average temperature near the Earth is above freezing. The deal is that there's the Sun right there. I mean, if you were in deep space you'd definitely freeze to death, like out by Pluto, but near where the Earth is there's the Sun pumping all that heat out. So if you have a spacecraft and you spin it properly so that it cooks evenly, the average temperature inside the spacecraft will be a nice warm temperature. You won't be freezing to death. And so the deal is, the farther out away from the Sun you get, the cooler it gets, the less intense the radiation from the Sun becomes, and so you get colder and colder as you move farther out, and so there's a radius that's about the radius of the asteroid belt I think, where gas, molecules of water, will start to freeze, will like clump together as ice crystals. And that's the snowline.
And the deal is the different chemicals that make up the solar system, this primordial disc of dust and gas, the primordial chemicals all have kind of snowlines, where within some radius close enough to the Sun they'll be gas, and farther out from a certain point they'll clump together as crystals. Dave, you want to talk about how dust and stuff clumps together a little bit?

David: Sure. So in this big disc, this protoplanetary disc we call it, that surrounds the early sun, we have all this dusty material that sort of sinks down into the middle of the disc. And that stuff as it sort of/ it's orbiting around a star, but it's, you know, not moving that quickly relative to its neighbors, I mean it can sort of clump together, just based on electrostatic attraction, like when you rub a plastic rod with like some fur and then pick up a feather.
So, this stuff can sort of clump together and these clumps can sort of grow and grow, up to about, about a centimeter size. Maybe a little bit bigger maybe like, you know, like up to a meter. But then, these big sort of clumps of stuff start getting dragged by all the gas that's around them, and they experience this gas drag, which sort of slows them down and pushes them towards the center, and into the star. And then some stuff happens that we don't understand. We're not really sure how you get bigger than a meter, but eventually you/ nature does, and it makes objects that come out to about a kilometer big, and those sort of big rocky kilometer sized objects like the asteroids, smash together, and they form sort of the cores of planets. So, Earth formed this way.

Ben: Actually, let's take a step back here. So Taylor, earlier you were like "you physicists, you need to say when you don't know what you're talking about". So there is a mystery here. And apparently there are a few different guesses as to how it works. So what happens is, somebody will come up with a hypothesis of how the stuff starts clumping together, and then they punch it all into a computer, and then they make the computer do you know a really really long complicated really really involved simulation. So they're really debating here. We know the mechanisms that will let the stuff clump together to make a golf ball sized clump, and those golf balls, they'll gravitate a little bit, and so dust and stuff around it will kind of stick to it slowly, but once they achieve a certain size what happens is/ we're used to imagining space as a big empty area right? But in this case, we're talking about stuff inside of this disc, this gasy sandy disc, and what happens is, these golf ball sized little rocky things, they hit things. And it slows them down, and as it slows them down/ they're in orbit/ and as it slows them down they lose the energy that they were using to circle the Sun, and slowly they drop into the Sun. And the big mystery here is that they'll kind of move towards and fall into the Sun faster than it will take them to get big enough that they can be called a planet. So this is a real mystery. Nobody's quite sure how it goes. It's fantastic if somebody wanted to become an astrophysicist working on it this is one of the projects that they'd be working on.

David: So, once you're about a kilometer big you don't have to worry about gas drag so much anymore. But to get between a golf ball size and a kilometer? That's a long way.

Catherine: That's a lot of golf balls.

David: We're not really sure.

[?]: That's a lot of golf balls.

David: So we're not really sure how that happens. There's a bunch of different ideas that may or may not work, but nobody's really sure.

Ben: Okay, so the moral of the story is: somehow we're still debating how it works, all of these golf-ball sized clumps clump together to make kilometer sized clumps, okay? And it's fun because a kilometer sized clump, that's about the size of an asteroid.

David: It's like the little guy who goes and picks up all the golf balls, like at the driving range, he walked across and suddenly all the golf-balls went in that direction. [?] all together.

Ben: And we call one of these things a planetesimal, 'cause it's planet-y but also infinitesimal/

Catherine: It's small.

[laughter]

David: Smaller than a planet.

Ben: So once they get made things really start to cook. This is where everybody really loves building numerical simulations 'cause you can say: you're populated with a certain population/ and of course the way these're distributed through the early solar system really depends on what the initial ball of gas looked like, right? For instance, the chemical composition/ we mentioned snowlines earlier, right? So, whether or not you have gas water inside some radius from the star, and then beyond that it's all ice. So the chemical composition of these planetesimals is going to change as you move from the inside to the outside of the solar system and then the distribution also depends on, you know, infinitesimally small perturbations, right? It's one of these chaos theory things. If things started out slightly different you'd end up with these planetesimals distributed in a different way. And it's fun because, you know, you look out right now, we've got these, what's the? Kepler telescope?

Catherine: Used to, it's broken now.

Ben: Is it? Oh no.

Catherine: Yeah.

Ben: Well there's the broken Kepler telescope, it's out there looking for planets. In the news every week we hear "Kepler telescope discovered another solar system with other planets around it". And these planets often have a remarkably different constitution in terms of where the planets are in these solar systems. So some of them have, you know, Jupiter sized planets really close to the stars. And others have entirely different distributions. And so it all comes down to what the initial ball of gas kind of looked like. Where the little perturbations in it were. Because those perturbations, they're gonna be the cores for what forms as planets. Alright, so we have these planetesimals, these asteroids flying everywhere, [?] we have a great big solar system full of these asteroids. And what are they doing? They're mashing together. So each one exerts a gravitational attraction on the other one, and they all have their own kind of velocities: some of them moving up, some of them moving down, some of them moving left, some of them are moving really quickly, and they're slamming into each other! And when they slam together sometimes they combine. And so they're building up. And the deal is that the larger the planetesimal ball is, the heavier it is, the more it will gravitate, and the wider it will be. And so the larger it is the more often it will get hit by other planetesimals. So the larger it is the faster it will grow. And so in this what you'll have is not a whole bunch of different planetesimals all growing kind of at the same rate, is that you'll have a couple that are really big and they're just gonna get bigger way faster than the other ones.

Taylor: Is it by the same philosophy that we'll all be speaking Chinese eventually?

Ben: I think it's the same philosophy that the rich get richer because they're born rich and that let's them get more money faster.

19:40

Taylor: Well let me ask you a question about gravity, and the moon. One of my mentors is the former US poet Billy Collins, and when Billy Collins was out on the veranda of a rich person's house talking with the Irish-American novelist Frank McCourt, and Frank McCourt was taking a sip of his whisky, and he said to Billy Collins: *It's a beautiful sunset, isn't it?* And Billy Collins, apparently, said: *Yo, back off, I am a poet. You stick to your miserable Irish childhood and leave us poets the Sunset. That is my territory, and also, keep your...Irish hands off the moon*. So I have a question from the point of view of a poet about gravity and the moon.

Ben: Okay.

Taylor: What we hear is that the high tide is the result of the moon's gravity.

Ben: Yep.

Taylor: How can that be when just a couple of miles above the Earth there is no gravity?

David: There is gravity.

Catherine: There is gravity.

Taylor: Oh.

Catherine: Gravity just gets/

Taylor: Okay next question.

Catherine: /lower and lower as you go further away.

Taylor: So, really? But but.

David: The reason that satellites are held in orbit is because of gravity. It just happens that they're falling such that they exactly miss the Earth. And so that's why they keep going around in orbit. So they experience that pull of gravity but it's exactly enough to keep them moving in this circle.

Ben: The pull of gravity causes/ they're still moving forward so they're moving kind of sideways relative to the Earth, the Earth's pulling them down and they're moving sideways and the deal is they're gonna keep moving sideways as they fall towards the Earth, and when all of the different numbers add up just right you'll be in orbit and what that means is it will twist your direction so that you'll keep on kind of moving with the same speed but you'll end up moving in a circle instead of falling straight to the ground.

David: So the Moon is actually always falling towards the Earth and we're always falling toward the Moon.

Ben: Yeah. The Moon's applying a slight force us. We're pretty far away from the Moon, and it's also not very heavy. And so it's not like you could jump higher when the Moon is straight above you, I mean maybe a little bit, but not very much right? The Moon exerts a fairly small gravity on you. But the tidal forces from the Moon are really neat, because what happens is even though the Moon is little and it's far away, the Earth is really big. And so different points on the Earth are going to feel the pull towards the Moon with slightly different forces, okay? So if you're on the far side of the Earth from the Moon you're going to fell less of a pull, and if you're directly under the Moon you're going to feel a greater pull, and if you're on either side of the Earth you're going to feel kind of halfway between. And so the deal is something liquid like water, right? So water will take on any shape. Because of this force of gravity from the Moon changes depending on where you are on Earth the water on the Earth kind of sloshes into that shape and that's what causes the high tide.

David: So actually the highest tide comes when the Moon and the Sun are on opposite sides of the Earth, and that's why you get the highest tide during the full moon, because you get that extra squishing from the Sun as well.

Taylor: But, does the Sun have gravity?

David: Yes, that's what keeps us in orbit around it.

Taylor: Right. I see. I'm thinking of this circular fountain in the middle of central park that has not a level ledge around it, but a ledge that has been tipped towards the inside, and as a kid I used to run around the ledge, and imagine a/ like an Indy 500 race-car track that was all banked curve, and if you ran this/ the edge of this fountain, if you ever felt yourself falling into the fountain all you had to do was run a little bit faster.

Ben: Yeah that's right. Hey, you know who you've something in common with now?

Taylor: I feel certain you're about to tell me.

Ben: Albert Einstein!

Taylor: Oh did he?

Ben: Yeah yeah this was his big revolution.

Taylor: Oh yes.

Ben: Okay so Isaac Newton imagined gravity as a force. It was like there was an invisible string or a spring between every object in the universe. So the Sun was pulling on the Earth, but the Earth was moving already and so the Earth never falls into the Sun, it just spins around the Sun in a circle. And Albert Einstein said "No, no, what it's like is: space-time itself, the very concepts of distance and time, are curved", like that fountain you were talking about. Like a velodrome with bikers driving in a straight lines but ending up going in circles. Einstein says the reason planets orbit the Sun isn't because of some mysterious force, it's because the Sun is twisting and squishing the curvature of the universe, so that a straight line is a circle. The Earth is always moving forward but because the universe is banked in a certain way the Earth will spin in a circle around the Sun.

Taylor: My mind just got blown.

Ben: Congratulations.

[laughter]

Ben: You and Einstein.

Taylor: Hey Ben?

Ben: Yeah?

Taylor: I'm with you for just a little bit longer so start looking for your concluding punch.

24:37

Ben: Okay, quick story. The deal is we have all these planetesimals. They're sticking together, right? But the ones that are inside essentially where the asteroid belt is now, there's not that much stuff. All of this/ the water is in gas form, so it's not really sticking to the Earth. Out past the snowline it's full of ice. And ice sticks real good to stuff. And so what happens is these planetesimals get really big really fast out there. Jupiter, Saturn, this is the reason they're so big. They get really big, so heavy in fact that hydrogen sticks to them. Now hydrogen gas doesn't stick to the Earth. If you take a bottle of hydrogen gas, say you're a/

Taylor: Hindenburg.

Ben: /blimp, and you cut it open the hydrogen will fly up into the top of the atmosphere and then fly off into space, 'cause hydrogen is really really light. But, these bigger planets, Jupiter and Saturn, they were so heavy originally that they could get this hydrogen gas that was floating around in the disc to stick to them. And that made them get even bigger even faster. It gave them access to a type of mass that the other smaller planets couldn't get to stick to them. So what we end up with is these big planets, Jupiter, Saturn, the ones farther out from us in the solar system, are really really big compared to the inner planets in the solar system, because they're out past the snowline. Because they could grow much faster. There's more stuff out there that can stick to them, and then beyond that because they exceed a certain mass that lets hydrogen stick to them, and that's why they're gas giants.
Okay, a really cool thing is, eventually your system evolves until all you have are these little protoplanets. You have planets that are, you know, the size of the Earth, or Jupiter, but the older solar system's still a pretty crazy place. There's still a whole bunch of rocks orbiting the Sun. Really heavy rocks orbiting the Sun, flipping around each other.
Now, are you familiar with the Voyager spacecraft?

Taylor: Yes, I've heard of it.

Catherine: Not on Star Trek.

Ben: Not Star Trek Voyager, the one that took all the photographs of the planets in the solar system.

Taylor: Yes, yes.

Ben: So the deal is, they're in the process of leaving the solar system, and they're moving at speeds that they couldn't have achieved using rocketry, because rockets aren't strong enough to get them moving that fast, and the the trick they used to move that fast is called gravitational sling-shotting, have you heard this?

Taylor: Yes, and had we more time I wanted to talk about this. Slinging around the planet, and getting faster.

Ben: Yeah yeah, so essentially what happens is it slings around the planet, but the planet, so Jupiter, is also still going around the Sun, and so it steals a little bit of Jupiter's speed and ends up moving faster as it leaves Jupiter's orbit. It gets a big kinetic energy kick. Jupiter slows down a little bit, this planet speeds up a little bit. So what happened in the early solar system is, this happened on a crazy scale. It was like one of those demolition derbies, with all the cars mashing into each other. There are these planets everywhere flipping around, and there's Jupiter, Saturn, both really heavy planets/ what happens is, any planet on the outside of the asteroid belt, Jupiter is close enough and it's so heavy that it will pick you up and it will toss you out of the solar system, or toss you at the Sun. It'll pick you up and throw you in one direction or another. So all of the planets inside the asteroid belt, Earth, Venus, we're all safe from Jupiter's crazy sway. But Jupiter, Saturn, both heavy enough that they totally mashed up everything outside. So there's a good reason why the planets are distributed the way they are, and it has to do with the fact that Jupiter and Saturn are so heavy.

Catherine: Well actually Ben neglected to mention I think one of the coolest things about the early solar system, and that's what's beyond Saturn and we think it was Neptune, then Uranus. We think that Neptune/Uranus actually flipped their orbits at some point early in the formation of the solar system and this caused all hell to break loose, and it caused all the asteroids in that region around the Sun to get dumped into the inner solar system and just caused massive cratering events on all the terrestrial planets there, and something we call "the late heavy bombardment". So we think this happened quite a long time after the solar system formed. So the solar system solar system has been dated at about 4.5 billion years, but we see evidence for this huge cataclysm closer to 3.9 billion years ago. So the solar system might have had a bit of a break there for a few hundred million years before Jupiter and Saturn kind of jiggled around and caused Uranus and Neptune to change spots and dump all these critters into the inner solar system. And the reason we know that is because we have rocks from the moon, the Apollo astronauts went there, brought rocks back to the Earth, we also have lunar meteorites, and a lot of these have been dated at around 3.9 billion years ago. And so that's where the geology sort of ties back into our theories of how the solar system formed.

Taylor: Do physicists smile, even on the inside, when they say the word Uranus?

Ben: Oh yeah.

[laughter]

David: We had to try really hard not to make Uranus jokes.

Taylor: Okay good. That humanizes you a little bit in my eyes.

Ben: Well, that was certainly entertaining. Thanks David and thanks Catherine, you've pleased me. Your efforts have borne fruit and that fruit is sweet. Here's some fruit. Dave, you get a, a Durian!

David: NOO!

[laughter]

Ben: And Catherine, you get a uh apple.

Catherine: Yum yum.

29:56

Ben: Hooray. Listen tiphyters, I love the show and I know you do too. But for every listener of the show I know there's one hundred other people who would love to listen but just don't know how.
I want you to spread the word. There are three ways you can do this. First is iTunes. iTunes is still the biggest place around to go find new podcasts, and iTunes puts the shows with the most ratings at the front where everybody can seen them. So, if you've got a minute, give us an iTunes review. It'll increase our rank and more people will see us. The second is to teach people how to listen to podcasts. Everybody has a smartphone or a tablet these days, and a very low percentage of these people know how to listen to podcasts. So, if you know somebody who might like this show, ask them if they know how to listen to podcasts. If they don't, point them to the Stitcher app. It's free and easy to use, and it works with every handheld device. Surely your grandmother will thank you for it. Or you could try the Podiversity app which is a curated podcast app. It chooses the podcast for you to listen to. It's really great. Anyway, the third way to spread the word is to tell people online about us. The internet is full of explanations about physics. If you see someone on the internet talking about a topic one of our episodes covered, toss a comment, tell them about the show.
Okay, so, that's the main part of today's show. Remember that if you liked scientists talking about science in their own words you might want to listen to other shows on Brachiolope Media Network, like the *Weekly Weinersmith*, with Kelly and Zach Weinersmith talk to academics about their research or *Science... sort of*, where we talk about science in the news, or even *Technically Speaking* or *Astrarium*, the show about engineering and the show about astronomy. They're all wonderful.
The intro song to our show is by Ted Leo and the Pharmacists, and the end song is by John Vanderslice. Until next time, my friends, good day, and remember to keep science in your hearts.

[Outro song; *Angela* by John Vanderslice]

32:21

Catherine: Oh. What do I do?

Ben: You have to make your sad/ You're / Oh, right, are you still the NASA Goddard Spaceflight Center?

Catherine: I am not, no.

Ben: Okay, so where you at?

Catherine: The Florida Institute of Technology.

Ben: [typing] She's currently at the Florida Institute of Technology.

What do you study?

Catherine: I'm a planetary scientist.

Ben: Okay, and do you remember your sound?

Catherine: No idea.

Ben: It's okay, just make a sound.

Arise Dr. Catherine Niesh!

Catherine: [laughing] I can never think of a good sound. I need you to tell me what to do.

Ben: Just go MooOOo.

David: [donkey sounds]

[laughter]

David: Like clown nose. Do a clown nose.

Catherine: I'm trying to think of when I talk to my daughter, you know? When I talk to her.

Ben: Go wah wah.

Catherine: Wah wah.

Ben: Dr. Catherine's undergraduate/ Dr. Catherine did her undergraduate with me at UBC, her PhD at University of Arizona in planetary science. She's currently at the Florida Institute of Technology studying planetary science. Hooray!
Okay.

Catherine: Wah wah.

[laughter]

33:38

Taylor: You know, you/ Ben, thank you for having me on this podcast, and I think probably the, the biggest compliment that I can pay you is that this makes me wish that I had a podcast where I had three poets and invited one physicist on/

David: that would be awesome

Taylor: to explain things in a poetical way. And if Catherine asked me a question I could say "that has nothing to do with poetry and therefore I'm not interested".

Ben: That's awesome.

[laughter]

34:24

Taylor: What's the temperature, in Fahrenheit, on the surface of Mars?

Catherine and David: Fahrenheit?

David: Oo [ew?]

Catherine: [laughter] Well let's see, it's

Taylor: Are you all Canadian or what?

Ben: Yeah, we're all Canadian.

Catherine: I actually/ yeah, we're all Canadian.

David: Yep.

[laughter]

Catherine: Let's see, it's easy though. So minus forty C is minus forty Fahrenheit, that's where they overlap. So it's got to be close to minus 40 Fahrenheit. It's a little bit below that. Though it varies quite a bit. It can be quite cold, like minus a hundred C, I have no idea what that is in Fahrenheit, up to, in the warmest places it can almost reach room temperature. But that's very rare. Most of the time it's/

Taylor: That would presumably be on the Sunny side of Mars/

Catherine: Near the equator.

Taylor: /when/ near the equator

Catherine: On a summer day.

Taylor: Mars is closest to/

Catherine: Right.

Taylor: Do people talk about Mars having a summer and winter?

Catherine: Yes, mmhmm. Absolutely.

Taylor: Okay, that's news to me.

Catherine: Yeah, the seasons on Mars are not too different from Earth because it has a very similar tilt, twenty three degrees. The only difference is its year is twice as long, it's got a two year/ so they would be twice as long, the seasons there would be twice as long. Also it's a much more elliptical orbit so it gets a lot closer and then farther from the Sun. The Earth is more circular.

Taylor: Oh so it's/ so that must mean that the range of temperature is bigger.

Catherine: Right, yeah, mmhmm.

Taylor: 'kay.

David: Also, the internet tells me that the average temperature on Mars is minus sixty Celsius so that's minus eighty Fahrenheit.

Catherine: Okay, i didn't know the conversion, yeah.

Taylor: So, with the right down jacket, I mean, I was in Fairbanks once, and it was negative forty, and you could go from your car to the coffee shop/

Catherine: Right, so/

Taylor: / and/

Catherine: /the pressure is the problem. The pressure is very low on Mars. Six millibar on average. So the temperature, you're right, if you bundle yourself up well you'd probably be okay, but the pressure is not gonna work with your body. You're gonna get pinched and pulled, and you know, expanded beyond where your body should be, so

Ben: Isn't there a scene in the original *Total Recall* where he goes outside and his face explodes?

[laughter]

David: Yeah, his eyes start bugging out and/

Catherine: doesn't explode but

David: doesn't explode but

Taylor: but they turn on the oxygenator just in time

[laughter]

David: yeah

David: So there are actually colder places on Earth.

Catherine: Yeah.

David: I think just the other day they looked at temperature maps of Antarctica and found places that were like minus ninety, ninety-five Celsius. So, what does that convert to in Fahrenheit?

Catherine: I mean the issue with Mars is that there's no liquid phase to water, for most of Mars. You go straight from solid to vapor, which is not good for the human body, you know, you need liquid water in your body to survive. But on most of Mars you'd go straight from solid to vapor. So, not a great thing for a human.

Taylor: Got it.

37:21

Taylor: Okay, now I've got a very important yes or no question for all three of you, in order. Ben, Catherine, David, that is going to be the order, and the question is: do you agree with Neil deGrasse Tyson's/ I know he was part of the group that demoted Pluto/ are you in favor of Pluto not being one of the planets? Ben.

Ben: Okay, yes.

Taylor: Catherine, are you in favor of Pluto not being one of the planets?

Catherine: Yes.

Taylor: David?

David: Yes.

Taylor: Alright, it's good to know where we stand.

[laughter]

Taylor: I hate all of you but it's good to know where we stand.

Catherine: So can I tell you a story? Just briefly.

Taylor: Please.

Catherine: Have you heard of Ceres?

Taylor: In a round about way, but remind me.

Catherine: Okay, so in 1801, Ceres was a planet. It's the largest asteroid in the asteroid belt. 'Cause they didn't know there were other asteroids there. And so like"O, we found this thing, it's pretty big, we should call it a planet". And then they started finding more things, and more things, and more things, and they were like "oh wow, there's a lot of things here, so you know what? we're not going to call Ceres a planet anymore, we're just going to call it an an asteroid belt".
So my question to you is: should Ceres be a planet? Because Pluto should only be a planet if Ceres should be a planet.

Taylor: My real complaint with Tyson is that when the Rose Center for Earth and Space did its redesign of our solar system, Pluto was dismissed summarily. Pluto, because it's the smallest and the most distant, or *was* the smallest and the most distant planet, became children's favorite planet, 'cause it's the farthest away. And, so students go to the Rose Center for Earth and Space and they are out there and they are counting out My Very Excellent Mother, you know, Just Served Us Nine, and they're looking for the Pizza of Pluto and it's not there.

[laughter]

And I feel like scientists, and I'm not blaming you guys, but I'm gonna throw you in the boat with all of them, I feel like you people missed a teaching opportunity to show that science is not, as it often seems to be from the outside, it's not all decided. And that there are debates in science, and that there are issues that we thought were confirmed and complete. And No! The debate is still out there! And this was a perfect opportunity to explain to the laity that because science is much more of an active search than the rest of the world usually thinks of it, we've decided that we can do better and that Pluto, really we know better now, and that Pluto no longer qualifies. So I'm looking, I was looking for a little plaque/

Catherine: Yeah.

Ben: /saying/

Catherine: No, I totally agree.

Taylor: /"are you looking for Pluto? Sorry, we killed him" And there was no such plaque.

David: It was more that now we have a new class of objects. We've discovered all these new dwarf planets, that are out near Pluto, and it was a demotion of Pluto but it was also an emergence of these, of these new very interesting objects.

Catherine: But I agree. It wasn't sold very well. I mean, some kids don't think Pluto is even there anymore.

Ben: Oh no.

David: Yes, true.

Catherine: Yeah, so/ and Pluto it's still and amazing place. I mean, it's going to be so exciting to see the surface of Pluto for the first time, in two years, and I think that was the missed opportunity, in addition to what you were talking about. You know, it's this amazing place, it's another world in our solar system. Yeah, it's not a planet, but you know my favorite place in the solar system isn't a planet either. There's lots of great places in the solar system and we need to explore them all to really understand what's going on.

Ben: And don't you think that dwarves deserve their own planets?

[laughter]

I mean, are we being like dwarf-racist and saying that their planets don't exist?
I don't know yeah, so the short story is that out in the Kuiper belt there are other Pluto sized planet-y things, and so they were like "Hey! Why don't we just make a new class of planets and make Pluto the king?"

[laughter]

Yeah man. Hail Pluto! King.
Yeah I agree. Neil deGrasse Tyson's kind of a villian in a lot of people's eyes now.

Catherine: It wasn't him. It wasn't him it was Mike Brown.

David: Mike Brown.

Catherine: Caltech. Who really killed Pluto. He found all the other Kuiper belt objects.

Taylor: Neil deGrasse Tyson says that he was complicit in the death of Pluto. I've heard him say that.

Catherine: Yeah, he does. He just likes the publicity, I think.

[laughter]

David: Mike Brown's twitter handle is actually #plutokiller.

[laughter]

42:06

Taylor: Yes or no question for the three of you. A physicist can't answer the question what caused the big bang?

David: No, cannot.

Taylor: would a physicist be comfortable therefore saying "as far as we know God caused the big bang"?

Catherine: It's an unscientific question, so I'm not interested in that particular question. It's untestable.

Taylor: Way to join the conversation and just

[laughter]

throw a monkey wrench in there. And I would warn you that if you as a scientist are completely uninterested in anything that is unscientific, to say it's an unscientific question/

Catherine: Is accurate.

Taylor: Sure, therefore I'm uninterested. Then if there are people that are not interested in science, they would say "well that's a scientific question and I'm not interested in science". And I thought the whole point of this podcast was to explain science to people who are not necessarily interested in science, or know a lot about it, so please don't be so quick to dismiss things that are not your area of expertise.

Catherine: No no no, my point is that it's not science at all, and we're trying to get people interested in science. And my point is that isn't science.

Taylor: And so, what a wonderful opportunity that is to open the door to other things and then get the conversation back on to science. And I'm not, I'm totally not a god freak, I'm just trying to interject a little bit of tension where I can.

[laughter]

Ben: Well well, it's fun. Talking is fun. Talking about ideas is fun.

43:39

Taylor: I sense when I talk to scientists that they're really only comfortable talking about stuff that they can prove scientifically. They're vaguely comfortable talking/ like "well, we're not quite sure"/ but as a poet, I celebrate, I absolutely celebrate the things that I don't know. And I don't get the sense that scientists have the same chemical in their brain that allows them to be proud and to celebrate what they don't know.

David: Oh, we love things that we don't know.

Ben: Yeah that's the/

Catherine: Yeah!

Taylor: Then you're doing a bad job of telling the rest of us that.

David: We love things that we don't know because then we're going to try to know them.

Ben: We're kind of like Caesar's armies. We're happy talking about the battles we've won, but the fun is going out and winning more battles. And so, as a scientist, the fun thing isn't learning these things that are true, that somebody proved in the nineteen seventies, the fun thing is to go out to the very limit of knowledge where everybody's guessing, and to make your own guess, and say "well, what if it works like this?" and then your computer starts burning up and you have to buy a new computer and everybody gets mad at you and you run out of funding and you know it's greasy fun, the limits of human knowledge. But, there is a certain elegance to the explanations that physics bring to things even though it's not on the frontier of knowledge, because the canon of physical knowledge that we have already is self-consistent in an amazing way. Like, if you asked two people to describe the same scene, let's say they had lunch together, and you take them and you put them in two rooms afterwards and you make them explain their lunch, you'll come up with two vastly different stories. One person will be like "oh, they were bitchy the whole time" and the other person would be like "I was so sleepy" and you'll be like "what, they didn't even have lunch together". The laws of physics on the other hand, the story that physics tells, where we've tested, tells a remarkably self-consistent thing to the point that its elegance is worth praising and worth making podcasts about.

Taylor: Nicely done. Let me ask you a question about the/ when people talk about the theory of evolution, don't/ do you scientists have a different definition of the word theory?

Ben: Yeah.

David: Yes.

Taylor: Is that where a lot of the problem comes from?

Ben: Yeah.

David: Yes.

Taylor: That way back when somebody decided to call something that was really proven and tested a theory because you guys have higher standards of whatever, and now people who don't know any better grasp onto that word "theory" and they are bringing their own definition to it?

David: Yep.

Ben: I think in the modern lexicon you would use the word "law" instead of "theory". So you would say it's the *law* of evolution, which is a lot closer to what they're talking about. It's been proven time and time again. We know that things work according to it. Of course there are frontiers and scientists are out there chipping away at the frontier and having/

Catherine: Right right.

Ben: / lots of fun arguing. So before you were like "scientists only want to talk about what they know". And part of the reason that is that your scientific reputation in the community depends entirely on having a long history of only saying things that are mostly true. And so, if you can go through life and say things that are remarkably true the whole time, everybody decides that you're the best scientist ever. And so we carry over that attitude into the public sphere when we start talking, and so scientists are ofter very conservative about what they're uncertain about, and what they're excited about because they only want to say things that are true, to keep, you know, a scientist in Cairo from calling them out and saying "hey on a podcast you said that all fish are blue but there's a red fish, so..."

Catherine: But Ben...

David: Egyptian scientists are annoying.

Ben: Yeah.

Catherine: Ben, true, true is the wrong word. We don't know anything, you know, for certain. I would say "plausible". We want to say things that are plausible.

Ben: Yeah, see?

Catherine: See? I'm already calling you out. [laughs]

Ben: It's a matter of the lexicon. In the public sphere people like expressing certainty. And in science there's always a measure of certainty. You're always sure how certain you are based on experiments and observations that other people have done. And so you can be very certain of something, but you don't want to come out and say "we're a hundred percent certain" because you know that that's not true. And that's the/

Catherine: Right. Right.

Ben: / rhetorical trap that scientists get caught in.

Catherine: And you know Ben, we do call them laws right? Kepler's laws, Newton's laws. I think maybe Darwin isn't old enough to have gotten to that stage but, yeah, I think you're right we should call it the law of evolution.

Ben: But Kepler's and Newton's laws aren't true. Like, general/

David: Yeah

Ben: / relativity blew those out of the water.

Catherine: Oh, there you go!

[laughter]

Ben: And it's/

David: Not really.

Ben: / it's the *theory* of general relativity, right?

Taylor: So are you saying that scientists are so afraid of being wrong in the eyes of other scientists that they resist calling things that are virtually true "laws", and the general public zeroes in on that uncertainty and gives it a bigger credence than it deserves?

Ben: Yeah.

David: For scientists precision of statement is a huge virtue. We always want to be very precise about what we're saying. So that you don't imply anything that isn't true. It's a virtue. People treat it as the ideal of being a scientist. And so, that's why we're often very precise in the language, and that's unfortunately where other people who are not so precise will take things and run with it.

Taylor: Well that's why the world has been debating about climate change.

Ben: That's right.

David: People who wish to cloud things will find one excuse or another. So, even if things weren't referred to as a theory, in the case of climate change, it's certainly the case in evolution, but nobody refers to in particular a theory of climate.

Taylor: You mean the causes of climate change have not become so obvious as to rise to the level of theory the way you guys define the word theory?

Catherine: Yeah, I don't say that. It's a very complicated system. Just like with star formation, and planet formation, they're trying to model it. But there's so many different inputs, and you have to kind of make them all work together, and it's difficult to do and/

David: It's not concise enough I guess, and/

Catherine: Right, there's no simple equation you could write down that says "yep this solves climate change and this is how we describe our climate". This one equation. Like, you know you can do with Newton's laws or Kepler's laws. It's/ there's a lot of different inputs, there's a lot of different things going on within the Earth system, and so it's not something you can simply describe. On the other hand, I mean, our models are to the point where most scientists agree that they are roughly approximating what the Earth is like, and what the future of our climate will be, with error bars obviously attached to those. So within the scientific community there really isn't a debate, but, as I think Dave was saying, you know, people will glom on to any uncertainty, just as they do in evolution. 'Cause we don't understand evolution a hundred percent either, and say "aha! they don't know this one thing, therefore they don't know anything".

David: Right, as scientists we love error bars. Have you ever seen plots of data you see like little bars that show how we're not really quite certain where exactly the number is, but it's somewhere in this area. We love those things because then we can very precisely say "this is exactly how well we know if this thing is true or not".

Taylor: You know I think my next book of poetry is going to be called *The Error Bar*.

[laughter]

Taylor: If I open a bar it also might be called *The Error Bar.*

David: Speaking of which, tonight I'm drinking eighteen year old scotch.

Taylor: Oh, I'm drinking a nice red wine. Or at least my guests are. I wish I could/ I wish my wife were listening to this live and she could come refill my glass.

[laughter]