Episode 82

Titanium Physicists
Episode 82: Snowing Diamonds
Physicists: Sabine Stanley, Erin Wenckstern

Transcribed by Denny Henke

Never be afraid. There is nothing which is known, which can't be understood. And there's nothing which is understood, which can't be explained. For over 50 episodes now, my team and I have brought you to the very frontier of knowledge in physics and astronomy. And still, our mission goes on to present you with your birthright, an understanding of the universe. I've traveled the world seeking out a certain type of genius, masters of not only their academic disciplines, but also at explaining their research in understandable ways. And I bestowed upon these women and men, the title of Titanium Physicist. You're listening to the Titanium Physicist Podcast. And I'm Ben Tippett. And now, allez physique!

For better or for worse, there's a mystique to science. It’s a romantic notion that scientists can see farther or deeper than regular folk. And I'm not sure if attributing superhuman characteristics of scientists helps or hurts the cause of science, honestly. But you can't deny that there are stories of scientists who have leaped into legend by predicting the unpredictable or seeing the invisible. Let's go through some simple examples. Charles Darwin in 1862 noted that there was an orchid from Madagascar. And this flower, it had a really long, tube in it and the nectar was at the bottom of the tube, and it was almost 12 inches away from the opening, that's too deep. So he noted that the point to nectar in a flower is to bribe insects and animals to pollinate them. And he concluded that there has to be an insect with a 12 inch long proboscis, which had evolved alongside this weird orchid and then one was discovered 40 years later. Well done Charles Darwin. Another example, the famous chemist, Dimitri Mendeleyev, was the creator of the periodic table of elements. He constructed the table by sorting all of the different chemical elements according to atomic weight and then lined them up by rows according to their chemical properties, and in doing so, he discovered that there were a few missing entries in the table. And in doing so he predicted the existence and chemical properties of the yet undiscovered elements we now call cadmium, gallium, technetium and germanium. The idea here is that by systematically looking at things you can also recognize when something is missing. You predict its properties by looking at the hole it leaves behind, the hole that should be filling. And it seems so logical and obvious after the fact, but for people who aren't scientists, this process looks mystical or even powerful. Anyway, one of my favorite such stories is the story of Neptune. Neptune the planet, not the God. Now, you know, the planets Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and out past there, there are the dwarf planets, Pluto, Eris, Sedna, all the other ones. Okay, so the deal is, out past Saturn, the planets are very, very dim. Uranus had been seen by a few astronomers over the century, but it wasn't until William Herschel with his telescope in his 1781, that he recognized that it was a planet. At first he thought it was a comet, but then it was a planet. But Neptune was so dim and so far from the sun, that it's actually invisible to the naked eye. You can't see it without a telescope. So how was it discovered? Well, if you watch a planet for a little while, you can figure out how long it takes to go around the sun and predict where it will be from night to night. And then the 1820s a table of these predictions for Uranus was published. But Uranus didn't quite follow the predictions. It was kind of a mystery as to why for 20 years. And then two astronomers Urbain Le Verrier and John Couch Adams, independently used the comparison between the tables and what Uranus was actually doing, to predict the existence of another planet. And when telescopes returned to look for this new planet, Neptune was discovered sitting in almost exactly the location they independently predicted.

5:01

Now today on the Titanium Physicist Podcast, we're talking about the unusual and fascinating properties of the ice giant planet Neptune. Speaking of drawing attention to things that are missing. Our guest today is an impressive journalist and columnist from Toronto. His commentary on race and racism in our cultural institutions and journalism are not to be missed. He is a contributing editor at *Maclean's* and a regular columnist at the *Globe and Mail* and was also one of the original hosts of *Canada Lands Commons*. For links to his work and twitter account look to our website, and welcome to the show. Andray Domise.

Andray: How are you doing?

Ben: Now, Andray, I've got two amazing Titanium Physicist for you today to help us decipher the strange and unusual properties of the farthest out planet. Arise Erin Wenckstern!

Erin: Woohooo!

Ben: Erin Wenckstern got her undergraduate degree in astronomy and physics and a certificate in meteorology from York University and she's currently a meteorologist at the Weather Network. And arise Sabine Stanley.

Sabin: I have risen!

Ben: Dr. Stanley got her PhD in geophysics from Harvard University. And she was a professor at the University of Toronto for 11 years. And she's currently a Bloomberg distinguished professor in the Department of Earth and Planetary Science at John Hopkins University, where she studies planetary magnetism. All right, everybody, let's talk about Neptune.

Andray: I'm very happy to have you walk me through that because I know way less than I probably should about our planets in our solar system.

Ben: Well, you're not supposed to know anything.

Andray: The thing is, when I was young, I don't know how many people have ever said this to you, but I've asked more people and it turns out this is a semi common fear. I used to read books on space. So like, you know, and these are like kids, like giant picture books. So I would flip through like you know, Earth, Venus, Mars, etc. And then when I got to Jupiter, the immensity of this planet, it scared me. Like when I would see detailed pictures of Jupiter, and like the the the giant Cyclone at the center of it. I had a fear as a child that I would fall into the pages of the book, hurtle through space and be sucked into the planet. And ever since then I've had, probably a paranoid fear of the outer reaches of our solar system, so I haven't really learned as much as I should.

Ben: Andray, you don't know much about Neptune because Jupiter scared you.

Andray: Jupiter scared me and turned me off of like all of the rest of any sort of planetary investigations on my part.

Ben: That makes sense. But let's break down the planets just for people who didn't spend their childhood terrified in books. So the deal is that the planets in our solar system can be divided up into four different types. There are the rocky inner planets. So Mercury, Venus, Earth and Mars are all rocky inner planets. And what makes them rocky inner planets is that they're mostly made of rock. Most of the mass there is made of rock. And then out past there, there are two gas giant planets. That's Jupiter, your old friend, and Saturn, the one with rings. And then out past there, there are planets we call ice giants. So the ice giants are Uranus and Neptune and they're bigger than Earth, but smaller than Jupiter and Saturn. And then out past there are what we call dwarf planets. So Pluto used to be classified as a regular rocky planet, but now it's classified as a dwarf planet.

Andray: I kind of feel like they shouldn't have done my boy Pluto like that. I'm still waiting for the scientists who can take up the charge of the the lesser folk and get Pluto reinstituted.

Ben: Pluto separated like Quebec is going to and now it's the capital of its own country of planets like Quebec City is going to be when Quebec separates.

Andray: I feel like that's an unfair comparison.

Sabine: I feel I have to chime in here now. Two quick points. Everyone is worried about Pluto but Ceres was the first object that got demoted from planet to dwarf planet status. Ceres is an asteroid, is the biggest asteroid in the asteroid belt. And we used to call it a planet, but then we realized it wasn't alone. And so it got demoted to dwarf planet. So everyone's upset about Pluto, but they might also want to be upset about Ceres. And I kind of feel like Pluto is this great new type of object. So it's sort of this, this first of the next things and I think that's great. I don't think of it as a demotion. I think of it as a you started your own club because you were so cool, Pluto.

Ben: Okay, so the deal with the gas giants and the ice giants is that the chemical composition of these planets is different from the inner rocky planets. The gas giants, so Jupiter, Saturn, oh, we call them gas giants because they're puffy. But more notably, they're really really really heavy. They're heavy enough that they can trap hydrogen and helium gas and that's part of why they're really big.

10:00

But out past there, there are other planets called the ice giants, which like we said, aren't as big as Jupiter and Saturn but are also very, very big. Neptune, for example is 17 times the mass of Earth. But before we say anything else, planetary physicists and astrophysicists use a really strange, to the rest of us, vocabulary when they're describing what things are made out of. So in this case, they call gasses, the only thing that are gasses, as far as they're concerned are helium and hydrogen. Okay, so the reason the gas giants are called gas giants is because they're full of helium and hydrogen. Ice giants, the word ice, when it comes to planetary astrophysicists, describes things like water ice, is an ice. But also, ammonia, if they, if they find ammonia and they'll call ammonia an ice. And they call methane an ice too. So when they're talking about ice giants, they're not referring to a state of matter that you know, like in your freezer, there's ice. Instead they're talking about chemical composition. And so it's a little bit tricky because they're like, oh, this planet is an ice giant. And what they mean is there's a lot of the mass of this thing is made up of water ice, methane ice, ammonia ice, these chemical components. Does that kind of makes sense.

Andray: Sorta, yeah.

Ben: Okay, so the deal here is that Uranus and Neptune, the farthest out ones are chemically composed of different materials than the planets closer in. So let's go over some pretty simple facts about Neptune. One aspect is the farther away your orbit is from the sun, the longer it takes to go around the sun, right. So like, Mars and Jupiter both take longer than the Earth to go around once. Mercury takes less time, less than a year to go around the sun once. Neptune is the farthest out planet, proper planet, it takes 165 years to go around the Sun once. Another way to put that is, in the time since it was discovered, Neptune has had one Neptune year. It's 30 times the distance from the Earth to the Sun. That's how wide its orbit is. So it's 30 times farther out. And if you think about it this way, with like a campfire or even like one of those old fashioned heat emitting light bulbs, the closer you get to a heat source, the warmer it is, because Neptune is 30 times farther out than we are, it's receiving about 1000th as much heat from the sun as Earth gets. So it's so far away from the sun that space out there is really, really cold. Okay, next thing you need to know about it is that it is blue. Neptune's blue. It's not a coincidence. I don't think that they named it after the God of the sea. Actually, that's an interesting aspect of it. Because it's not visible to the naked eye, people had to name it things. And so in every language, pretty much, it's got a slightly different name than in English. But in all the different cultures that name Neptune, they name it after something thematically oceanic. I don't know. So the thing to imagine is, it's this planet, it’s enormous, and it's really far from the sun.

Andray: I got a question, using current technologies, how long would it take for us to, let's say, take an exploration trip out to Neptune?

Ben: So that's a really good question, because we've only ever sent one probe to Neptune, and it was a probe called Voyager 2. Do you remember hearing about Voyager 2 when you were a kid?

Andray: Yep. Yeah, remember Voyager 2.

Ben: Yeah. So the deal with that though, and the reason we haven't sent any since, is because it takes a lot of energy to climb that far away from the sun. The sun exerts gravity on everything in the solar system. It's usually not an issue on Earth. We're not, it's not like we're fighting the sun's gravity. But essentially, it takes a lot of energy to move that far away from the sun. So, NASA scientists, rocket scientists, when they're sending things out that far, instead of just depending on technology, what they do is they, they use a technique called gravitational slingshotting. Instead of sending your probe all the way out there in a straight line, you send your probe to the next heavy object, you’ll send it to Jupiter first. And every time it gets into orbit around a planet, it manipulates its orbit in a way that the, that the motion of say Jupiter, as the probe is moving around it, the gravity and the motion of Jupiter, will end up throwing it, giving it a whole bunch of energy to throw it farther out in the solar system. So when it comes to our technology, all we really need to do is get it to like to Jupiter and then we can start orbitally maneuvering these objects to go farther and farther out. To pick up more and more speed to make it farther out into the solar system.

15:04

Andray: Because I have childish tendencies, I’m imagining this, like James McAvoy curving his bullet in that movie *Wanted*.

Sabine: That’s accurate.

Erin: I think the best way to picture it, is a complicated dance of do-si-do with planets.

Andra: Okay. All right. So it's like where you swing your partner round and round, except the probe is being swung around the gravitational pull of a planet.

Ben: Yeah, it's just like, imagine that like four of the square dance partners are huge, fat men. And the do-si-do partner is, like, a little girl. And so every time they do it, they really whip her. And so, so, essentially, they're stealing some of the energies from the planets going around the sun and they could using this this technique, you can end up going really fast.

Andray: I'm sorry. I'm just, aw, God, again, because I'm so childish, I'm imagining Miss Trunchbull, from Matilda, swinging a little child around by her pigtails.

Erin: That's exactly how you should picture it.

Andray: Okay.

Ben: So there's an aspect to this that has to do with timing, right? You don't just want your probe to go flying from Jupiter. You want your probe to go flying away from Jupiter in the direction of the next planet on, say Saturn. Right? So astrophysicists in the 70s did a calculation just kind of they were just futzing around. And they were like holy crow, we're entering in a to a period that's only a few years long in duration, where all of the planets are in exactly, all of the larger, like gas giant planets are, kind of in exactly the right place for us to gravitationally slingshot one after the other. And you get to do a procedure called the Grand Tour, where first they go to Jupiter and then Saturn and then Uranus and then Neptune. So the long and the short of it is, it took about a decade-ish a little bit more than a decade, for the Voyager 2 spacecraft to go from Earth, past all these gas giant planets, taking photographs and data as it passed each of them. And then finally passing Neptune and getting gravitationally slingshotted from Neptune out into deep space. And so now Voyager 1 and 2, having done the Grand Tour, are moving really fast out into interstellar space, and they're never coming back to the solar system. But the important detail here is that, that procedure, taking about a decade to get up to Neptune, that can't be repeated until all the planets are back in alignment with each other. So if I wanted to do it in a rocket ship, it would probably take me much longer.

Andray: Okay, and when is the next time we can throw another child at Miss Trunchbull?

Sabine: If you think about how the planets are organized, it happens almost at the rate at which Neptune orbits so it's about once every 170-ish years or so. But I could be wrong about that.

Ben: There was actually a rush at NASA because they discovered that, oh no, this this window is just coming up, and so there was a huge rush to build the probes and all of the equipment surrounding the probes, you know the antennas on earth in time to launch Voyager 2 Voyager 1 in this window. So it's actually, it's, it's kind of pretty neat because they were like, oh no, we're running out of time and they built the spacecraft and launched them just in time. And so it was, ah, getting out there in that short, relatively, decades, but that relatively short amount of time still required a special alignment of the planets.

Andray: Got it. Okay, so I guess by the time that that alignment matches up again, we're probably going to have far greater degree of technology, maybe even perhaps like chemical proportions, a thing of the past.

Ben: Maybe.

Sabin: Hopefully, yes.

Ben: That's the hope. The hope is that we don't die out from global warming.

Andray: Yeah, I was gonna say, assuming that we're all still here, you know, and the Earth is not, like, steadily reclaiming its territory at our, you know, over our sun bleached bones.

Ben: Right. But one aspect to that though, is that we have only sent one probe past Neptune. It's the farthest out one right? Only one probe has ever gone there. And it's important because when it comes to really subtle information about the place, you really do need to send something out there. Most of the data we have from Neptune either comes from Voyager 2, which flew past it, gathered a lot of data. Or from, essentially, the Hubble Space Telescope, or telescopes on the ground on earth with really good adaptive optics systems. So modern telescope, space telescopes, tell us stuff about Neptune. But also, essentially, in terms of feet on the ground. We only have one probe that's ever gone there. And so part of that means that there's a bunch of mystery when it comes to this weird planet because we don't really have as much data as we would want.

Andray: You know, when Voyager 2 passes Neptune and sends back images, how do we how do we actually get those images? I mean, it was sent, it was sent away in the 1970s. So we weren't using digital technology back then. How on earth do we, do we receive data.

Sabine: So basically, there are giant communication dishes on these things that beam back radio signals in different bands. And they can code the information in those radio bands. And it can take a really long time to get the information back. Because the farther away something is, the more degraded the signal becomes. So you have to send it for a longer period of time. So we can kind of pick it out of the noise that gets sent along with the signal. So the farther the Voyagers have gotten, the longer and longer it's taken for the data to come and reach us. But you can do it even before we had digital. Again, by basically changing how you make those radio waves behave.

Andray: I, I understand what you're saying. And everything that you said was in perfectly coherent English. But for me to conceptualize how that works is just beyond my capacity.

Ben: We had broadcast TV before digital TV, right?

Andray: Well, fair enough. Yeah.

Ben: Yeah, it's like that.

Andray: Oh!

Sabine: You could also think of it as we could send Morse code if we really wanted to, right.

Andray: Right.

Sabine: A certain set of dashes and dots and things like that. So an equivalent version of Morse code, let's say,

Andray: Okay, got it.

Ben: So with that in mind, we've sent one probe there, and we've looked at it with a bunch of telescopes. Neptune is a planet of mysteries. And one important aspect to it is that the more data we get about it, the stranger it acts. It's weird.

Erin: So like Ben, you're mentioning, the only real great information we got about Neptune was from the Voyager 2 missions, and that was in the late 80s. I believe. Since then, we've had the Hubble Space Telescope doing monitoring, but we haven't got that much information. And when we went by in the 80s, for the longest time, we had just seen it as this distant, cold, dark blue planet. And when we quickly approached it and got these images back we discovered that the atmosphere, that it was actually a very turbulent and dynamic atmosphere. And similar to what we discovered on Jupiter, if you've ever seen a picture of Jupiter you'll notice that it has this massive storm on it called the Great Red Spot. And when Voyager went by we actually discovered that Neptune has something very similar. And they aptly named it the great dark spot. So it's really interesting to see how this planet is so far away, yet it has extreme weather, and it has a climate and the dynamics of the atmosphere are so incredible. It kind of shocked people probably to see how vibrant this world was, even though it was billions of kilometers away. So with the atmosphere, there's a couple of things we know, there's not a ton of information. Again, we're, all scientists are kind of grasping at straws and trying to do the biggest discoveries on such little information. But we do know is that it has these vortexes and we don't exactly know how they form which is interesting. But we have a couple of theories. And so I'll kind of walk you through some of the theories. And the biggest influences, probably have to do with the fact that it is a rotating, big planet and it has jet streams. I don't know if you've ever heard of what a jet stream is we have them here on earth too. Have you ever heard of one, or?

Andray: Somewhat familiar with jet streams.

Erin: Yeah. So jet streams are basically fast flowing winds in the upper atmosphere. It's where all of our airplanes like to fly because they basically get a boost from the wind and don't have to use as much energy to travel across, you know, the Atlantic Ocean, if you're traveling with the jet stream. So it's basically, you can think of it as, like a river in the air in the upper atmosphere, and we have them on Earth as well. And we have them on Neptune. And we discovered that they're pretty fast moving jet streams and they create this, this type of setup where the winds are moving so fast that it adds instability into the atmosphere. So if I can explain it in an easier way, if you're canoeing on a still lake, you're paddling along, and you watch your paddle drag through the water. All of a sudden you see these vortexes spinning around as you drag your paddle through. That's because you're forcing the water to move faster than its surroundings. And it creates these little vortexes. So you can kind of think of that, similarly to what's happening in our atmosphere and what happens in Neptune's atmosphere. So that's part of the explanation. Another theory, or at least part of the theory, is to think of it with a lot of convection. So we know that Neptune is really cold. But at the same time, it's putting out a lot of energy. And we think that's because it has internal energy. And that's forcing a lot of heat from the inside to meet the cold air and atmosphere on the outside. And that forces a lot of convection, and maybe potentially the formation of these vortexes. But, again, it's really interesting because the only images we have of these things or any documentation comes from the Voyager 2 mission. And then when we come to modern day technology, the only one that can detect it is the Hubble Space Telescope, unfortunately. And we only get two images a year from the Hubble Space Telescope. It is kind of busy doing other work, so.

25:10

Andray: Okay, I have another question then.

Erin: Mmmhmmmm.

Andray: If you were to shoot a rocket ship directly at Neptune, and let's say that we wanted to explore what Neptune is like inside of its atmosphere, would that be possible or just be like throwing a stone in a river.

Erin: We could definitely go into the atmosphere. But you know, sooner than later, you're going to start to really feel the pressure from this. So Neptune, again, as Ben has mentioned, isn't, you know, formed the same way or composed the same way as our rocky planets. So it has a bigger atmosphere. And it just gets, gets denser and denser, and the pressure gets so immense, that you wouldn't be able to go any further. Unless you had some sort of, you know, special fun, I don't feel physics kind of spacesuit that you can go through, or in a rocket ship. But what you would experience is an increase in pressure. And then also the atmosphere itself is very different than what we have on planet Earth. So the atmosphere on Neptune, as you start to kind of descend into the planet itself, you'll notice that it's mostly made out of hydrogen and helium, but there is methane. And Ben, you already mentioned that it, it is a blue planet, and it is a blue planet because of the methane. So methane does a really good job of absorbing all of the red hues and wavelengths of light and reflects back or scatters the blue light. So what you see is a very blue vivid planet. And that's because of the methane and the atmosphere.

Andray: Okay, so whatever you threw at it, it would just swallow it up.

Sabine: Yeah, that's true. I mean, if you descended it into the planet, it would eventually crush up. We've done something similar at Jupiter with the GALILEO probe in the mid 90s. And it kept returning data until it got crushed by too much pressure and couldn't send anything any anymore. And then at the end of the Cassini mission at Saturn, that Cassini spacecraft descended into Saturn until it eventually broke apart and crushed under pressure too.

Ben: That dark, great, dark spot, is crazy. It's like, it's like had you as a kid, leave through, past Jupiter, you would have found another monster at the end of the book.

Andray: Yeah. That's why I stayed away from reading the solar system books and now you're just, like, recreating and reanimating my childhood fears, but that's okay. I'm gonna work my way through this one.

Ben: You were the one who asked about dropping something into it.

Andray: Yeah, asking for a friend. And by friend I mean my childhood self.

Ben: It’s this, like, the spot is called an anti-cyclone. You ever heard of an anti-cyclone?

Andray: No, what is it? What is an anti Cyclone?

Erin: So an anti-cyclone is exactly what it sounds like. It's an anti or it's not a cyclone. So when I say cyclone, a few images kind of pop up in your head, hopefully, or if not, totally cool. A cyclone on earth is what we refer to as a low pressure system. So if I'm talking about a hurricane, typhoon, but, whatever you want to call it, that is a cyclone. So it's a rotating low pressure system that's typically really stormy. But an anti-cyclone is the opposite. So it's a rotating high pressure system. And that's basically the gist of it. It's a, it's a big area of high pressure that's rotating in a clockwise fashion. If you're in the Northern Hemisphere, you're watching this high pressure system will rotate clockwise. If it's in the southern hemisphere, it's going counterclockwise. So that's basically what an anti-cyclone is, and you've actually experienced one on Earth. If you've ever had really clear conditions and nice weather, you're in the middle of, probably, an anti-cyclone, which is pretty neat. So, if I could quickly explain, exactly kind of what it is and how it forms on Earth. It forms a little bit differently on Neptune. But an anti-cyclone on Earth forms because we have the sun heating up our atmosphere. And it unequally heats it up, unfortunately, so we end up with areas of really hot weather and then areas of really cold weather. And this begins to form circulation. So you can start to think of it as heating a pot of water on the stove. And when that starts to bubble up, that's convection. And it leaves a void at the bottom or an area of low pressure. And you start to get this circulation where the air wants to go from high pressure to low pressure. And this happens in our atmosphere, it happens at the equator the most. So you get a ton of activity, all this rising air and it starts to drift towards the poles and it begins to cool and sink back down. And it, when it cools and sinks, it starts to rotate and become a high pressure system because all this mass is now coming from the upper atmosphere and pressing and cooling as it descends down to the surface. So that's what we mean by an anti-cyclone and hopefully that was a a decent explanation.

30:01

But you've definitely experienced one here on Earth. We have some semi-permanent features of them. One of them is the anti-cyclone in the Atlantic Ocean, we call it the Bermuda high. And it's responsible for the really nice weather throughout the Bermuda region off the coast of the US. But it's also a big driver of how hurricanes travel across the Atlantic. So it really guides hurricanes. And it's a really big feature that we have to watch out for.

Ben: Wait, hold on, when the weather guy on the TV talks about high pressure systems and everything's kind of spinning, that's an anti-cyclone?

Erin: When we talk about high pressure, yeah, it's, it's this downward descending motion and it has a clockwise rotation to it. And the rotation happens because we are on a rotating planet, right? So it's this effect called the Coriolis effect, which means that air parcels get deflected because of a rotating planet and atmosphere.

Ben: So you got a glob of air and it heats up and then it goes up into the atmosphere, and then it starts to come down. And the earth is turning under it so it starts to rotate. But it's a nice it's a nice weather's. It's like a sunny day, instead of a cloudy, rainy, everything's blowing at 300 miles an hour day.

Erin: Yeah, exactly. But it is if you're in the middle of it, just sometimes you get a big anti-cyclone in the upper atmosphere over, just say the US or something. And on the outer edges of it, the stability and the sinking air begins to break down and you can get a lot of convection because it is a very warm and humid air mass sometimes and you can get this thing called the ring of fire. Where all along the outer edge of this circulating air mass, you get these convective storms in the afternoon and it's really neat to watch. It just kind of lights up in the afternoon and then dissipates back again.

Ben: Okay, so on Neptune, this anti-cyclone, it's dark because there's no clouds at that level because it's clear day and then you can see the dark spots are the clouds that are under the main clouds that we see when we look at it.

Erin: Well, we have a lot of clouds in the upper atmosphere. And then we have clouds that kind of form on the outer edges of it, I believe. And sometimes when they're dissipating, you can get clouds beginning to form inside of it. But it's a little bit more, again, on the outer circulation of these vortexes that you see convection and these big towering clouds. And that's how they actually can measure the speeds of these clouds by watching them individually and trying to track how fast they're moving. So one of the most interesting parts about Neptune, I have to say, and you should find it also super interesting as well, is the fact that it holds the strongest planetary winds in our solar system. Anyone want to give it a round of applause? I don't know if it gets a trophy or something.

Ben: Yay.

Erin: But these winds are supersonic. We have wind speeds over 2000 kilometers per hour. I think some studies suggest that it could be up to 2400 kilometers per hour. And to put that in comparison to what we see here on Earth. We have winds in our most dangerous cyclones, the highest winds, we have we've ever recorded was just over 400 kilometers per hour. That was with Cyclone Olivia. So that’s a hurricane near Australia back in the 90s. That was the fastest wind speed we've ever recorded. And on Neptune, we record them well over 2000 kilometers per hour.

Andray: Okay, so never mind, you know, being crushed by the by the atmospheric pressure, if you like, sent a piece of machinery down there. It sounds to me like it would just be shorn apart by the winds.

Erin: Well, the difference with the wind speed is that you have to remember that it's not at the same pressure. And the actual density of air up there isn't as dense as it is on the surface of our planet, right? So the effect wouldn't be as great until you start to reach down further into the atmosphere and you get to the same pressure levels that we're at.

Ben: So they move fast, but they don't push very hard.

Erin: Yes, until you start to go down further. So yes, they're moving fast, but you really feel the impacts once you start to dive down further into the atmosphere, and then pressure just gets too intense and you'll be crushed.

Andray: I feel like I'm forming an entirely new wrinkle in my brain devoted just to holding the information from this conversation.

Ben: Yeah, Neptune. That's called the Neptune lobe.

Erin: You can bring it up at dinner parties, you'll you'll sound really cool.

Andray: I am totally going to do that. Mike, my kids can't even talk yet. And the first thing that they're going to say when they're capable of having conversations is talking about Neptune wind speeds and the difference between wind speed and pressure.

Erin: I've done my job. I'm completely satisfied as a meteorologist now.

Ben: So why are the winds so fast on Neptune? So on Earth, hey, it's cyclone season. Why are there cyclones? It’s because it's summer and the ocean got really hot. And so there's hot air moving around, right? But that's because of the sun. On Neptune. It's 30 times farther away from the sun than we are and so the sun is in having as much of an effect because it's a lot dimmer.

35:03

How come the winds are so, you’d think that out there that things would move really slowly because everything's really cold?

Erin: Yeah, that would be, that'd be your first guest. But the weather on Neptune happens for a different reason. Here on Earth, like you mentioned, weather is really narrated by the fact that the Earth is unevenly heated, and we get these imbalances of cold air vs hot air and that's trying to always balance itself out. It doesn't like to be in a state of high pressure, it wants to be in lower pressure. So it always tries to even itself out. But on Neptune, the winds happen because of different reason. So again, what's interesting, too, is that we don't have so much information about Neptune that a lot of scientists can't really narrow down exactly why we have these monstrous winds. There are a few theories and they're really great theories. But again, it's not hey, this is exactly why the winds are so strong, end of book. There's basically three kind of schools of thought. So the first one is the fact that we know through measurement that Neptune puts out more energy than it receives. So it puts out about 2.6 times more energy out than it receives from the sun. So that really tells you something. It tells you that it has internal energy, and that there's heat inside of Neptune a lot of heat, and that is fueling, convection and, and these cells to formulate, and these jet streams to start to pick up because of these storms that form on the planet. Another one is the fact that it is really cold on this planet in the upper atmosphere. So that means that there's lower viscosity, and I know that's kind of a bigger word, and maybe not everyone knows what that means. So, so I like to think of a drop in temperature means a drop of viscosity. So if you think of it, the relationship as a room full of kids, and you can think of these rising temperatures similar to the effect of giving these kids a bunch of candy. So once you give them a bunch of candy, they're running around, they're going nuts, they’re kind of on a sugar high and they're all bumping into each other. If you try to walk through that room, it's going to be a lot harder, it's going to slow you down kind of thing. But if you're going to be talking about temperature, decreasing and a decrease in viscosity, it's like giving all these kids, instead of candy, giving them iPads. So now you walk, try to walk through this room, there's no problem at all. Everyone's sitting down doing their own thing. And the viscosity has decreased. So the winds have no problem really slowing down. There's nothing to really slow them down. There's no source of drag, basically, does that make any sense?

Andray: I'm gonna lie and say yes.

Laughter

Ben: So the idea here is you know the word viscosity, right?

Andray: I mean, viscosity, I take to mean the ease with which objects can slide over one another.

Ben: Yeah, like the flow speed. Right? So like engine oil is low viscosity and the Quaker State guy’s all bragging about it.

Andray: When your viscosity breaks down. What's next? Yeah, your entire life.

Ben: So what Erin is saying is because the temperatures so low at the top of their atmosphere, because they're so far from the sun, the air isn't viscous at all. And so there's fewer forces slowing it down. Once it gets going. I guess comparatively, our atmosphere, compared to Neptune's is like gravy, it doesn't flow very well is. So even if it does get going, it'll just kind of slow itself down. But there are fewer friction forces.

Andray: Gotcha. Okay.

Sabine: And I think it's interesting to point out that that's completely the opposite of what happens with things that aren't gases, right? That's up in the atmosphere. But when we think of things like peanut butter, for example, or honey or something like that, when you heat it up, it becomes less viscous. So it's a rising temperature that lowers the viscosity instead of a dropping in temperature. So it's a completely opposite effect of what happens in the upper atmosphere.

Ben: Yeah, viscosity breakdown happens when your engine gets too hot. I'm gonna cut that out, that’s stupid.

Laughter

Andray: No, Leave it in.

Erin: Leave it in.

Ben: I don't know what viscosity breakdown is. It's when you're when your engineering gets really viscous, right?

Andray: I, ah, I, sure. I’ve never investigated what that is. And I've never dared ask a single mechanic I have ever brought my car to what viscosity breakdown is for fear that they're going to consider me a mark and just rip me off.

Ben: So the long and the short of it is this planet has an atmosphere where the winds are going crazy. They're just whipping around because there's nothing to slow them down. And because it's far enough from the sun, that their viscosity is really, really low.

Erin: So not only does Neptune host these tremendous winds, the fastest winds in the, in the solar system, on any planet at least. It also has some very stinky clouds. So I don't even know if you'd want to go on a rocket ship and visit it because what you would maybe discover is that these clouds are made of hydrogen sulfide. And if you've ever heard of that before, it's smells like rotten eggs and it's not very pleasant.

40:04

Erin: So I'm pretty sure if you went to go visit Neptune, you quickly wish you didn't, because these clouds might be in part of the atmosphere created from hydrogen sulfide. Again, this is more of a speculatory thing. They've discovered that there's probable detection of hydrogen sulfide in the atmosphere. And when they extrapolate and say, you know, a certain pressure, hydrogen sulfide would condense and form into clouds. So we've never actually observed that there's these clouds on Neptune, but we're hypothesizing that these would potentially become the stinky rotten egg clouds, which is just lovely.

Andray: So I have twin daughters. All right. I've been changing diapers in this household for 16 months now. Now once you've been able to change the diaper genie in this house, I think I'm qualified to say I am prepared for whatever Neptune can throw at me smell wise.

Ben: Incidentally, there's a question that might start popping up before we get too far down this, which is, we've mentioned that there's a lot of methane. And actually there's ammonia too in the atmosphere of Neptune. And you might wonder why, because those are kind of, those are molecules that we kind of associate with things that are alive.

Andray: I mean, I associate ammonia with things that are alive, again, because of changing diapers.

Ben: Well, yeah, I mean, like, but...

Andray: I mean, it might smell like something died but I should really assume that's it, you know, it originally was something that was alive.

Ben: Yeah. But something needs to live before it can make that smell, right. Like rocks don't make the smell of ammonia and rocks certainly don't make the smell of methane. There's actually a fairly simple reason for this. And it's kind of delightful and it has to do with how all of these planets formed. I just want to go through that with you for a couple minutes because it's totally bonkers. Like if you ever heard about how the planets formed?

Andray: Okay, from what, from what little I know, being a himbo who is only interested in a few very narrow topics. I always thought that they were ejecta from the sun itself.

Ben: Oh, cool. That's interesting.

Andray: Is it interesting as in this is correct or interesting as and that's a completely dumbass assumption. And we're here to correct you...

Ben: No, I've never heard that before.

Andray: Okay.

Ben: It's true to a degree that, okay, so once upon a time, there was a star in space that blew up. And it blew a whole bunch of different, it was a huge star, much bigger than the sun. And when it exploded in a supernova, it blew a whole bunch of different elements into space. So there's hydrogen and helium, but also elements that it had made inside of its core, like carbon and nitrogen and oxygen, stuff like that.

Andray: Okay, sorry, when I say the sun, I sorry, I should, I should clarify. I don't mean like the sun in our solar system. I mean, like, a gigantic sun, like blew up and then like threw matter and like, objects into space and then this is how we ended where we are.

Ben: Oh, well, that's pretty much it. But well, no, the devil’s in the details there and I want to get into that, but that basic picture is right. Although for a while there I thought you meant like the sun was spewing out atoms that eventually turned into the planets...

Andray: Oh, okay.

Ben: Which is a very...

Andray: No, there...

Ben: It's a very sweet picture. I'm like, wow, that that sounds like it comes from the 1700s.

Andray: There are several origin stories from like different different ethnic groups on earth that do believe that, you know, our planet is like, the seminal emission from the Sun God, but no, that's not what I believe.

Ben: Okay, so you painted your picture right. This, this, this star blew up, it spewed essentially atoms all over the place. And then this big cloud of atoms cooled and most of it fell into, it fell into, it started feeling its own gravitational pull. And most of them fell in and became the sun as it is currently today. But some of them didn't, okay, some of them ended up in orbit or around this star and all the planets around us in the solar system are made from the components of that cloud. The notable thing here though, and like I said, the devil is in the details, is how that cloud of gas turned into these planets. And it has to do with, essentially, a whole bunch of atoms aren't going to not stick to each other. If it's cool enough, and you've got two hydrogens and an oxygen and they bump into each other, they're going to stick to each other and make a water molecule, right.

Andray: Okay.

Ben: Similarly, if you've got a carbon atom that's floating around, and there's four hydrogens that bump into it, they're going to stick together and make a methane. If there's three hydrogens and nitrogen, they're going to stick together and make an ammonia. Now, here's the second important bit, it has to do with condensation, right? You have a, you’re taking a shower, there's water vapor in the air, and then it starts to condense on things that are cold. Right?

Andray: Right.

45:00

Ben: You get water droplets forming on these cold things.

Andray: Right, like on my mirror? Yeah.

Ben: Yeah, the deal is that these atoms will configure themselves in different ways depending on their temperature. Water, if it's cold enough will make ice. If it's, if it's too hot, it will stay in vapor, and in between then, it might make liquid water. The thing is, as the solar system collapsed, the sun starts putting out heat, the closer you get to the sun, the hotter things are. And so the idea here is that if you get really close to the sun, maybe Earth's orbit, methane, ammonia, even water, liquid water, it's too hot that close to the sun for it to condense into a crystal. And so it's going to stay vapor like a gas. And that gas vapor isn't going to clump together to make a planet instead it's just going to stay gas. And so the deal here is, you know what a snowline is in, in, in, like on a mountaintop, right?

Andray: Yeah, yeah.

Ben: The higher you get up in the atmosphere, the colder it is. And so there's going to be an altitude where water passes the freezing point, and then it's going to freeze and so you're going to get snow at that elevation or higher. In the early solar system there were snow lines, just in pretty much the same way. So silicates, things like rocks, if you heat that up hot enough, it'll turn into a gas, right? But out at say, Earths, Earths distance from the Sun, it's cool enough at that distance from the Sun, for rock to solidify, the silicas to solidify into crystals, and these crystals will clump together and make a planet. The farther out you go away from the sun in the solar system, the farther away from the Sun you are, the cooler it gets, and the more different types of crystals will, will condense.

Andray: Oh, okay, hold up. This is all starting to come together for me now. So you're saying that molecules that cannot condense, let's say at a close enough distance, like the earth can, that the farther away they are, the more likely they are to condense. And when like, I don't know, a whole squad of them gets together they form a planet.

Ben: Yeah, yeah.

Andray: Okay.

Ben: But the deal here is that the more, the farther away from the Sun you get, the more different types of crystals there are going to be. So at Earth's distance, you don't get any ice crystals. You have to go past Mars' orbit to get ice crystals. So the planets inside of Mars orbit aren't going to be made of ice crystals, they'll be made of rocks. So even farther out, say Saturn's orbit, past there, you're going to get snow lines for methane and snow lines for ammonia. Ammonia gas and methane gas will start condensing into crystals. And so you can build your planets, if you're out past Mars, you don't just have rocks to build your planets with, you also have water ice crystals. And even further out, you don't just have rocks and water ice crystals. You also have methane crystals and ammonia crystals to build your planets with and that's why the chemical composition of the planets depends on how far away from the Sun you are.

Andray: Got it. All right.

Ben: But also, the farther out you go, the more types of crystals there are. And the bigger a planet you can make out of that stuff, the long and the short of it is, the reason that we see methane and ammonia out in the ice, these ice giant planets, even though we associate them on earth with biological processes, the reason you see them farther out is essentially, they're just really simple molecules that you can make out of hydrogen and carbon, or hydrogen and nitrogen or hydrogen and oxygen. And that far away from the sun, ah, they're going to, it’s past the snow line for those particular molecules and so you can build planets out of them. In fact, that's why we call these things ice giants, because they're made, in part, out of these methane ices and ammonia ices.

Andray: Okay, so when you said that, like ice on Neptune doesn't necessarily refer to its physical state, what does it refer to then? I assume that like Ice giants were giant planets that were made of ice. Like, ice as in, you know, it's some form of solid matter created from condensed gases?

Sabine: Yeah, it's a great question. So planetary scientists use the word ice to mean a certain category of compositions. They mean things like water, ammonium, methane, things that all kind of behave the same way in terms of when they melt or when they evaporate. And it's not necessarily what phase the material is in. So it's not that it's a solid water ice like you skate on at the skating rink. So liquid water, water vapor, solid water would all be called an ice. But so would liquid methane, solid methane, vapor methane, those would all be ices. So would the ammonias. So it's really just meant to categorize all these materials that happened to behave similarly in one category.

Andray: All right, got it. So I'll just say thank you for that and I will, will investigate further.

50:01

Ben: You asked earlier about the composition. You were, like ice giant doesn't that mean it's a big ball of ice? And the answer is kind of interesting because you would think that it would be a big cold ball of ice because it's really far from the sun. So it should be really cold. Right? And also, it's made of ices. All signs point to ball of ice, right? The deal though, is, it's not. The internal structure of Neptune is totally bananas. I mean, first off, from the outside, what we see is their atmosphere. Erin already talked about how many weird cool clouds there are. And essentially, the blue that we see is all the methane in the atmosphere and then clouds. But if we were to fall into Neptune and somehow survive the trip, we'd find that the internal structure of Neptune is really interesting. There is an ocean under the atmosphere. It's kind of an ocean world. And the ocean goes, like, in terms of the radius, like 30% of your trip in towards the middle will be atmosphere. And then it's going to be ocean for another 40% of the way in.

Andray: Okay, when you say ocean, is this like ocean in a liquid form because I don't know what to believe anymore.

Ben: Yes-ish. Definitely yes-ish.

Andray: Okay. I hope you understand, like, my grasp on reality right now is a man hanging off of a branch off the edge of a cliff.

Ben: Just imagine yourself falling peacefully into Neptune, it’ll feel great.

Andray: That’s not making me feel any better.

Ben: And then at the center of Neptune is a core of rock, like rocky rock like or silicates, Earth, iron actually. And it's about the mass of the Earth, the central core. So it's like imagine we had an Earth and then we surrounded it with liquid and then we surrounded that with atmosphere, gas and clouds. Okay, but the interesting thing here is, is that as we go from the clouds down to the middle, the temperature increases. It gets hotter, the closer to the middle you get, dramatically hotter. By the time you reach the surface of the ocean, the temperature is about 2500 Kelvin. And for your information, a sunny day on Earth in Canada is about 290 Kelvin. Like 20, 20° Celsius is about to 290 Kelvin. As you go towards the middle of the planet, things get much, much, much hotter in the thousands of Kelvin. When you get to near the surface of the rocky core. It's about 7000 Kelvin. Which I mean, we're not giving you a test on these numbers. You just said some things has to be like, okay, it's hotter than a kiln in there. It's just really, really, really, really hot. It's hotter than anywhere else on Earth inside of this planet. Even at the part that has the ocean, it's still really, really, really, really, really, really hot. Got it. Okay. And the second thing you need to note is that, that there's a lot of stuff in Neptune. Like, it's about 17 times more massive than the planet Earth, which is absolutely meaningless. But the, the sense I want you to get from this is that, the pressure, you know, like atmospheric pressure, you go up to the top of a mountain and there's less atmosphere and you're like, yeah, the pressure’s here, and then you go down into Death Valley, and there's more atmospheric pressure, and then you go to the bottom of the swimming pool, and there's even more pressure. Andray: Right, right.

Ben: Right. It's the stuff that's between you and space is essentially weighing down on you causing this pressure. There's so much more stuff in Neptune, that the pressure in these regions is also really, really, really high. Like up to a million times more pressure than an Earth atmosphere worth of pressure.

Andray: Well, I guess a question that now comes to mind as you’re, as you're talking about like the structural makeup of this planet is, so when our billionaire overlords finally annihilate this planet and have catapulted themselves into space, leaving the rest of us behind to feast on each other's brains, if they decide to make a quick stop on Neptune to harvest water, are they all going to die when they drink it?

Sabine: First of all, choosing Neptune to go to would be a terrible choice for the billionaire overlords. They should go to one of the icy moons in the outer solar system like Europa or Enceladus, because there the water’s much more similar to water that we experience here on Earth. And it would be much easier to land, you could pick up some ice and then you could fly off again. Whereas in Neptune, you would actually have to go quite deep, you'd have to experience really hot temperatures and pressures, scoop up some water somehow and then leave the planet again. So I just think it would be bad planning on their part.

Andray: Okay.

Ben: And the water there's full of ammonia and methane.

Sabine: I figure if they could get out there and do all this, they'd be able to clean the water somehow.

Andray: Right. So I guess that was just a really roundabout way of asking is the water on Neptune somehow potable.

55:04

Sabine: I wouldn't suggest going there and just drinking it straight up or anything. I think you'd have to clean it up somehow, but it is extremely hot. So potable on earth is usually about whether microbes live in it and that's probably not the issue on Neptune.

Ben: Okay, so you've heard me hedging, though about whether or not there is a water ocean on Neptune.

Andray: Yeah. And that's, that's why I asked the question about the potable water. I want to know more about this water ocean because you're like, you're, you're saying a lot of ish when it comes to this ocean and I'm trying to visualize what it is and what it looks like.

Ben: Well, okay, so here's the thing. Okay, so what temperature does water boil at?

Andray: 100° Celsius.

Ben: 100%. Perfect. Okay, so...

Andray: Alright, got it.

Ben: The deal here is that the water that we're talking about here is 2500 Kelvin. So it's about 2200 Celsius.

Andray: Wait. The water is 2200° Celsius.

Ben: At least.

Andray: Why is it still water?

Ben: Ah! Ah ha, ah ha! Good question! Part of it is the atmospheric pressure at that temperature. So you know how if you go to like a mountaintop, you go to Denver or something and you try to boil water, it boils at a lower temperature than 100 Celsius.

Andray: I'm just going to take your word for it. I don't know if it that, okay.

Ben: Yeah, yeah, the higher you get it in the atmosphere, you go to a mountain top and water will boil at less than 100° Celsius. And if it comes to potability, which we mentioned earlier, if you are purifying water by boiling it, you have to boil it for longer when you're up in high altitude because it's boiling at a lower temperature.

Andray: I see.

Ben: So the converse is true. If you apply a lot of pressure to it, the boiling temperature is going to increase. So that's, that's the first answer to your question. How could there still be water at that temperature? Were talking about water under a lot, a lot of pressure. But actually, there's so much pressure there, and so much temperature, that it's not really water the way we would recognize water, water. You know, it's made of H_2O, two hydrogens and oxygens as molecules. But those molecules are bumping together really fast and really hard. And that means that they're not going to kind of stay as H_2O molecules anymore. They're going to ionize. Some of them are going to be ionizing. And so this water is something called ionic water. It's water where some of the molecules have been smashed to pieces. There's still two H's for every O, it's just that, you know, they're not, they're not together anymore.

Andray: If they're still, if there's still two hydrogen atoms in an oxygen atom, and they still compose water, what about it has been smashed up?

Ben: Yeah. Okay, well, let's think about it in terms of Lego.

Andray: Okay.

Ben: So imagine you got a big box of Lego. And you take all that Lego out of the box and you start to assemble Methanes. For every, every, every C brick, you've got 4 H bricks that you put together. And ammonia, every nitrogen brick, you've got 3 hydrogen bricks that you stick. And water for every oxygen you brick, you've got 2 hydrogen bricks. And you make these little, little molecule Lego guys, right? You have so much Lego. And so when you put it in the box, it's a really long tall box. Right? And it's like, it's like the height of an office building, really tall box. The pressure of the Lego at the bottom is going to be huge on the bottom of the box, right?

Andray: Okay, sure, yeah.

Ben: There's gonna be lots of lots of pressure on those Legos at the very bottom. And in addition to that, it's really hot, which is kind of like the whole thing is shaking. So you have your big box of Lego and you shake it. There's so much pressure and so much violence shaking at the bottom of the box that those Legos, even though there's two oxygen, or, two hydrogen and one oxygen, the quantity of Legos and the proportions of Legos is still the same. But those Legos, little molecules you make, they're going to break.

Andray: I see. Okay, all right.

Ben: Yeah. So that's what we mean by an ionic ocean. It's kind of like water, but it's so violent that water is just barely holding it together.

Andray: Okay, I see. Got it. So me approaching a deadline is what that water is like.

Sabine: So, ionic water already sounds very strange and not something that we experience a lot of here on Earth, but that's already happening at about, let's say, one third of the way down into Neptune. As you go further down, it gets even hotter and the pressures get even higher. And different ways to arrange all of the components of the water can happen. So rather than ionic water, we have recently discovered that deep inside Neptune water is going to form a new phase that's called super ionic water. So you already know it's a cool phase because it has the word super in it. Right? We always put the word super in front of things that are cool. Right, there are super colliders and superconductivity and all that stuff.

1:00:02

Sabine: So, super ionic water means that it's going to be really cool. And basically what happens at these pressures and temperatures is that you think again about water, water is H_2O, so two H's and an O. All of the O's, all of the oxygen atoms line up to form a lattice. So they form this grid, and they stick to each other. And then all of the hydrogens, which are hydrogen is just protons, all of the hydrogen get to flow freely through that oxygen lattice. Kind of like, you know, mice in a in a maze or something like that.

Andray: It almost sounds to me like you're describing the H_2O atoms doing the Electric Slide.

Sabine: I like that description. So this new phase of water, super ionic water, happens in the deep interior of Neptune and in Uranus, and we just discovered it very recently here on Earth. Or, I should say, that experiments were finally able to make it here on Earth. By taking water and putting it under really, really high pressures in an experiment and seeing whether or not they could make super ionic water.

Andray: Does super ionic water have any properties or uses outside of just being really cool?

Sabine: Well, we don't know that much really, actually, yet. We know it exists. We're trying to figure out how it behaves physically, right. So we know it's solid. That's a key thing now. So super ionic water is this, so Neptune, now you can think of it as having this giant solid center to it. We're trying to figure out what are things like its viscosity? What is its ability to conduct heat to get heat out of the planet? How electrically conductive is it? Can it hold currents? And these are all questions that we really don't know the answer to. And we need to do some more experiments to figure out. And to make it even more complicated, Neptune isn't pure water. Mixed in with that water are things like ammonia, methane, and you got to ask yourself, what happens to the Ns in the NH_3, the nitrogens in the ammonia. What happens to the carbons in the methane? And so all of those materials might be going through really weird phase changes too. And in fact, methane, people have discovered if you think of methane as having a carbon atom in it, you put it under high enough pressure and temperature the carbons change form and can actually form diamonds. And so deep inside Neptune we think that it might actually be raining or snowing out diamonds...

Andray: What?!

Sabine: ...to form, almost, yeah, yeah, we got snowing diamonds in Neptune.

Andray: So, hold up, when Rihanna said, when Rihanna said diamonds in the sky, she wasn't playing around.

Sabine: She was not she was talking about Uranus and Neptune.

Andray: I'm really fascinated by the idea of, like, going to Neptune and extracting strange materials from it. Like, you know, I don't know about like mining it for diamonds or whatever, or trying to like, extract natural resources. Just I want to see the really cool stuff that's there.

Sabine: Yeah, I think we all do. It is really cool. I think probably the best we're going to be able to do, or, the at least, the thing that will happen earliest is we will make this stuff on Earth. So we're already doing in experiments, what you do in an experiment is you take a little bit of whatever material you're thinking about. So maybe it's water and you got a little bit of water, and you squeeze it really, really hard. And it turns out, the best way to, or one way to squeeze it, is to put it between two diamond points. So there are physicists who take two big diamonds, and they're really nice diamonds and they have little tips in the end. And they squeeze them together really hard with whatever they're trying to squeeze in the middle of them. And because diamond is so strong, you can squeeze it a lot before the diamond breaks. And so you can get really high pressures at the tips of the diamonds. And so we can actually put things under really high pressures in small canisters that we could like sit on our desk if we want. But it's expensive because you need giant diamonds.

Andray: This will be just like another way that rich entertainers and recording artists flex on us. It’s like I know you got the diamonds, but do you got the Neptune diamonds baby.

Sabine: Exactly.

Ben: The thing Sabine is describing, they're called diamond anvils. Literally where they take two diamonds and smash them together really hard. That's not the craziest thing about diamond anvils. I mean, you can get tremendous pressure, and it lets us study situations where these pressures are really, really high. But the coolest thing is diamonds are transparent, right?

Andray: So it’s like you can see what's happening inside of them as you're subjecting them to these strenuous experiments.

Ben: Yeah, that's that's the start of it. In fact, I've seen, I've seen some physicists do this, where they'll, they'll actually put a little microscope up and look to see what's happening in the middle of their diamond anvil, as they're crushing it together. But that's not the craziest thing. Because they're transparent you can shine a laser into the middle. So the the inside of Neptune isn't just high pressure, it's also really, really, really hot. And so what you can do to replicate that, is you put it in your diamond anvil, you crank up the pressure and then you shine a laser to cook everything inside the middle of it.

1:05:05

Ben: And that, that, that's enough to replicate the interior. Incidentally, there's another experiment that you can do to replicate really, really, really high pressures and really, really, high temperatures. And they've done this, essentially, to see whether or not you can get diamonds condensing out of these situations. And that's where they take, they'll take, like a block of say, acrylic plastic, some medium, and then they'll make shock waves inside the medium. They'll shine a laser on it a really high powered laser that will generate shockwave, and inside the shockwave there's lots of pressure because a wave is a, it's kind of like a soundwave, just like all of the atoms get really, really close together. And it's really hot inside of a shockwave. But the neat thing here is, they'll take two shock waves, they'll take one slow moving one, shoot that in first and then shoot a fast moving in shockwave in second. And when the two shock waves hit each other, then it gets you know thousands of Kelvin hot and involves pressures comparable to inside of Neptune. The highest pressures that we can see on Earth today are generated inside these double Shockwave experiments. Totally bonkers.

Andray: Okay, here's, here's another, here's another question. Is, uh, I've heard tell that Neptune has rings.

Sabine: All of the giant planets have rings. And this is like...

Andray: Why is it never rendered with rings? I only ever see Saturn.

Sabin: I know, right, Saturn gets all this press for having these amazing rings. But all the giant planets have rings. Now, the reason is that Saturn's rings are the most spectacular. They're the ones you can actually see through a telescope. You know, they're the ones Galileo saw when he saw Saturn through a telescope. Jupiter's rings, Neptune's rings, Uranus rings are all much fainter. They're much darker. The particle sizes are different. So they're not easy to see. Turns out that we discovered Neptune's rings through a method called occultation. Where basically you try and look at a faraway star, and you watch Neptune pass in front of the star. And when Neptune passes in front of the star, it's going to block out some of the light from the star. Right, you suddenly put a hand in front of the flashlight. And so people were going to do this because they wanted to understand what Neptune's atmosphere was made up. But what they saw was that there was dimming of the light at like three or four different places, even before Neptune got in front of the star. And then after Neptune passed on the other side, there was dimming of the light again, and this meant that there was rings surrounding Neptune around the planet. And this is how we've discovered, we saw Uranus' rings as well. Then when Voyager 2 went by, they actually got pictures of the rings.

Andray: Oh, okay. Yeah, so I just, I kind of feel like the other planets got shortchanged. Because like Saturn is the only one that we ever see iced out.

Sabine: Well Saturn is the only one that you can actually see the rings really nicely. So they are the most beautiful rings, the most spectacular rings. So maybe it's maybe it's fair. I don't know.

Andray: All right, well, Saturn, Saturn got that, nobody else got that, so. Yeah, it doesn't really seem fair. Okay. And then another question I had is, this is something that blew my mind. So we know that, like, on Earth, right, the moon travels in the same direction that the Earth spins, if that makes any sense.

Sabine: Yep.

Andray: But Triton, one of Neptune's moons doesn't do that, it spins in the opposite direction.

Sabine: This is true.

Andray: How?

Sabine: That's a great question. So in order to understand why it's weird, we have to think about how we think moons typically form. So Earth's moon and also a lot of the moons in the outer solar system, so all the giant planets have a bunch of moons. And those moons we think usually form out of the disk that surrounded the planet. And eventually gravitationally attracted material to it and form these moons around just like the planets form from that disk surrounding the sun. Now in the outer solar system, you can sometimes have other moons that seem to do weird stuff, right? Because if you formed in the disk, you'd expect to be going around the planet in the same direction that the planet is spinning. But once in a while you find a moon, it's usually a small moon, and it's usually going in either the opposite direction or it's on some high angle to the to the plane of the equator of the planet. And those are usually just captured objects. So in the outer solar system, there is a whole bunch of small stuff. Things that we see in the inner solar system, like comets or asteroids, stuff like that. And in the outer solar system, if one of those big rock-ish type things or ice body type things gets close enough to a giant planet, it could get captured by its gravity. So we've seen small, irregular moons things that aren't really spherical around Jupiter, Saturn, Uranus and Neptune. But Neptune in the only planet that has a giant spherical moon that is on a retrograde orbit, so it orbits in the opposite direction, and it orbits at a big angle compared to the equator.

1:10:10

Sabine: And that's because it's a captured moon. We think it's basically a captured dwarf planet from the, far out where the Kuiper belt is and Neptune captured it.

Andray: Okay, I just, some of the stuff that happens on these these faraway planets is just like completely mind bending to me. So another question I have is, is it possible to land, let's say if we wanted to have like a, you know, exploration of the deep solar system, can you land a spacecraft on one of these moons?

Sabine: Absolutely. And we would love to do that. And in fact, we have landed on another moon in the outer solar system. That's a moon named Titan, which is orbiting around Saturn. And we landed on that with the Huygens probe, which was part of the Cassini mission. So we have plans to go back to Titan. The Dragonfly mission is sending basically a drone that's going to land on Titan, take some data, then fly up again, go land somewhere else take more data and some of that. So we can do this in places like Triton, we would love to go to. Triton, this moon of Neptune that's on this retrograde orbit. It's basically a Kuiper belt object, one of these things like Pluto, but it's closer to us. So we could actually go and figure out what these Kuiper belt objects are like. And Triton also, is really geologically active. It has these cryo volcanoes or geysers that are spewing up water and ammonia ice. It has winds, it has all sorts of different features that we're used to seeing on an active planet. And we think it's happening on Triton because Triton experiences all these strong tidal forces because of its weird orbit around Neptune. So it keeps getting squished and squeezed and pulled apart and stuff like that and that heats up its interior and makes it really active on the surface. So we really would like to go there and see what's going on with Triton. We've only ever actually taken pictures of a very small portion of the surface. And that was with the Voyager 2 mission. We need, we have, we don't even know what the whole moon looks like.

Andray: And another question I have, I'm not sure if you've read a book series called *Remembrance of Earth’s Past*. It starts with a book called *The Three Body Problem*. Alright, so in, I'm not sure if I'm spoiling anything for anyone here. But there is a point in Earth's future where people have, you know, left planet Earth and they’re habitating on some of these moons orbiting the gas giants. Is that, is that actually plausible? Like, they're not on the moons they're on habitats that orbit the moons themselves. Like, they’re artificially constructed habitats. Now is, is that something that is remotely possible? Or due to these tidal forces that you talked about, would they also be destroyed? Like is there any possibility for colonizing out around Neptune? Or is that just a pipe dream?

Sabine: Well, from my perspective, I mean, you could argue we already have an artificial habitat orbiting a planet it just happens to be orbiting Earth, and that's the International Space Station. So we know it's, in theory, possible. I don't know if you'd want to do it orbiting around Triton for the some of the reasons that you mentioned. But you could orbit Neptune. Or you could find some other moon that you want to orbit that isn't such on such a weird orbit around its planet. I don't see any reason why you couldn't, in theory, do those things.

Andray: Okay, I'm just trying to figure this out. Because when I hear a Jeff Bezos say that, you know, it's humanity's next step, to move into outer space, I'm thinking that they don't want to take the rest of us behind. So I'm trying to, I'm trying to figure out how plausible their project is. Because if this is remotely possible, then it is our obligation to then start the revolution.

Ben: Yeah, pretty much, well, okay, so in those books, humanity by that point had mastered hydrogen fusion as a fuel source, I think. So, which means that anywhere you go in the solar system, there's lots of hydrogen, you just scoop some up, throw it in the fusion reactor and then that's all of the heat and power you need to run your civilization. That said, well, one concern you seemed to have involved gravity, or, tidal, tidal heating. When you asked if it was plausible, because you said, Triton is heating up inside because of the tides, right. The reason that that's working has to do with the size of Triton compared to the difference in gravitational field from one place to another. So if you've got something the size of a moon, it can feel kind of an kneading, a crush, a crush as it orbits the planet. But on anything human sized, there isn't enough of a difference in the gravitational field from one side of your habitat to another to generate that tidal kneading.

1:15:00

Ben: So I don't think it's something that we would need to worry about specifically. So even though Triton would get all kneaded up and heated on the inside, I don't think our International Space Station Neptune version is going to.

Andray: Okay. I guess my last question is, I know that you know, we are fascinated with deep space exploration because we want to find out, like, the nature of the universe, and we also want to create new things. But, and the reason I keep touching on this, like, you know, colonizing outer space is, is humanity ready for that? Like, are we ready to not just like send probes and objects out into space to discover the nature of things? Are we at a point, do you think, where we're ready to send ourselves out there?

Sabine: So I'm going to answer that with a big no. And, even for you know, forget about the technological issues, and all of that. I still have a problem with the fact that if, we need to think about how we are deciding to explore space or travel into space and what we're doing when we go to another planet, let's say Mars and suddenly land on it and decide to take it over or do things on it, we're fundamentally changing that object, and do we have the right to do that? Is it, is it something that we should be doing? Also, when you think, and you mentioned it with those billionaire overlords? You know, the people who are going to be able to do this first and stuff, are going to be the most privileged, rich people in society and how are we going to be leaving behind other people that we shouldn't be leaving behind? And so I think until we've solved some of society's problems, we should not be thinking about trying to go out there and do all the same horrible things we did on Earth at other places.

Andray: Yeah, cause didn’t we like just accidentally spill a bunch of tardigrades on the moon. Like, whoops, aw, shoot, sorry.

Ben: Somebody needs to get yelled at for that one. But no, I'd say, I'd say no for a similar reason, specifically that we were still wrestling with abuse of power in the 21st century. We're still wrestling with individuals in our society that we trust with a certain amount of power over other people, to not abuse that. Generically throughout our society, racism and sexism and just people saying, “Well, I'm the powerful one, so I get my way”, like what the, we're not ready to go into space. Can you imagine how horrible that trip would be hanging out with Jeff Bezos all the time? Years and years and years with nowhere to hide from Jeff Bezos. Give me a break.

Erin: We wouldn’t make it out there.

Andray: And Elon Musk, yeah.

Ben: In one room, there's Jeff Bezos and another there’s Elon Musk, you know, you can choose between each of the room and you go back and forth between them. That sounds horrible. We're not ready.

Andray: I think I'm completely out of questions here. I don't know what else to ask about Neptune and deep space exploration and all that. But I will say that you have done nothing to assuage my fears. I'm probably three times as terrified as I was when we began this conversation.

Ben: Yeah, yeah, you don't want to imagine yourself falling into the middle of these horrible planets. But it's fun. It's it's interesting that we know so much based on how little information, like we started the whole conversation with a description of how little information that we've gleaned from it. How much, how little, it really is a triumph, the degree to which we understand what's happening under these layers of clouds, or why the clouds are doing the things that they're doing. On the other side of the solar system, with a small amount of data just in terms of like human ingenuity. Scientists, like Sabine have figured it out. It's amazing. I'm so impressed.

Andray: I think what probably would comfort me a little is if we found a way to load Jeff Bezos and Elon Musk into a an orbital probe and catapult them into atmosphere of Neptune.

Ben: Then we would need a radio telescope, "Hey did you see any of that super ion water?"

Well, that was wonderful. Thank you Erin. Thank you Sabine you please me your efforts have borne fruit and that fruit is sweet. Here is some fruit. Dr. Sabine Stanley, you get to eat a watermelon.

Sabine: Yummy! (Crunching sound.)

Ben: And Erin Wenckstern, you get to eat a durian.

Erin: What? What is a durian. Yum, yum yum. Thank you.

Andray: It's a, it's a fruit. No, it's a, it's a fruit that smells like dirty socks.

Ben: Doesn't it smell like, no, it's they taste good.

Erin: Hopefully that's not a reflection on my information.

Ben: They just smell like the clouds that you like so much on Neptune...

Erin: That's very fitting, I appreciate it.

Ben: ... on Neptune, yeah, right. Okay, I'd also like to thank our guest. Andray Domise. Thank you and Andray. If you'd like to know more about Andray visit, our website we'll have links to all of his stuff. Well, that was a really cool episode. Okay everybody, it's time for the announcements. So first announcement, please give us an iTunes review or tell other people about us online. Essentially, nobody wants to tell anybody else that they love physics and astronomy as much as they should, honestly. And so, they want to know that our show exists, but you have to tell them. So go ahead and tell them give us an iTunes review. Whatever. Mention us on Facebook. Let's have lots of fun. Next, we've been running a thing lately, where if I can't find the cool guest, or if our planned guest cancels at the last minute, I'll choose a listener of the show to sit in as the guest and chat with us about physics. So here's how it works, you need to do three things. The first is follow us on Twitter or Facebook because that's where I make the call. The second is that you need to have a fast internet connection and have a quiet room in your home or workplace. And the third is you need to be available when we want to record but that's it. Just follow us on Facebook or on Twitter and listen, and occasionally you'll hear me say, okay, you have 24 hours to get back to me if you want to be a guest. And then I choose from the people who reply, but you might get lucky. Finally, we're still humbly soliciting your donations, your donations go to paying our server fees, and our episode transcription project and to buy physicists are microphones. And finally, to help finance the travel costs of everybody going and recording a live episode at the AAAS conference in Seattle in 2020. If you'd like to help the show, you can send a one time donation through PayPal off of our website or you can go to our sweet Patreon site and give a recurring $2 or $5 donation. If you give more than $2 and supply your address, I'll send you a postcard. Now this particular episode of the Titanium Physicist Podcast has been sponsored by a collection of very generous people. I'd like to first thank the generosity of Heeda Cross. I'd also like to thank Christoph Beatty, Mr. MM, the wild Drew Hickox, the master Oscar Delgado, Colin Richardson and Joe Campbell, Sharon Bana Geary, JP Rodeo, Aaron Wheeler, Sander Boros, A badger, The Ceptid Baylor Fein, Luke Edwards, Mr. Astro Yuki, Shebang Patel, Mr. Martin Mihalka, Henry Rabum, Peter Scott, Russ Moodsy, Eyush Sing, Matthew Sullivan, a Daniel Lauzen. Patrick Eon, Kevin Forsyth, Yer Panay, Hoynem Duong, Stan Erickson, a TPR Jones, Pascal, a man named Ryan R, Michael Usher, Senior Canada, Adrian Shoning, Sarah Stradler, Louise Pantanella, a guy named Ben, a Mr. Matthew Lambert, a fellow named Aiosh Sing, a David Myrtle and Mr. Ryan Foster. Janeko Frafenburg, Mr. Steve Smethers, Magnus Christensen, Bart Gladys and Mr. Stewart Polluck. Our Emperor Courtney Brook Davis, Mr. David Lindels, Mr. Carl Lockhart, our Eternal Friend BS and Randy Dalzell. A Miss Tina Rodeo, the Enigmatic Ryan, a gentleman named Crux, and Gabe and Evan Weens, David Dee, Dan Vale, Mr. Alex, WTL, Mr. Per Proden, Andrew Waddington, Mr. Jordan Young, John Bleesy, a Brittany Crooks, James Crawford, Mr. Mark Simon, Two Songs Gang of One, Mr. Lawrence Lee, Sexton Listen, Mr. Simon, Keegan Eau and Andreas from Knoxville, Cadby, Joe Campbell. Alexandra Zani is great. Weena Brett, Eric Deutch, Atien. And a gentleman named Peter Fan, Gareth Eason, Joe Piston, David Johnson and Mr. Anthony Leon, as well as Doug B., Julia, Noah Robertson, Ian and Stu, Mr. Frank, Philip from Austria and Noisy Mime, Mr. Shlomo Delau, Melissa Burke, Yasee Yurasazi, Spider Rogue, Insanity Orbits, Robin Johnson, Madam Sandra Johnson. Mr. Jacob Wick, Mr. John Keys, a Mr. Victor C., Ryan Clause, Peter Clipsham, Mr. Robert Halpin, Elizabeth and Theresa and Paul Car. Mr. Ryan Newell, Mr. Adam K., Thomas Sharay and Mr. Jacob S. A gentleman named Brett Evans, a lady named Jill, a gentleman named Greg. Thanks, Steve. Mr. James Clawson, Mr. Devon North, a gentleman named Scott, Ed Lollington, Kelly Wienersmith. Jocelyn Read, a Mr. S Hatcher, Rob Abrosato, and Mr. Robert Stietka.

So that's it for the titanium physicists this time. Remember that if you like to listen to scientists talking about science in their own words, there are lots of other wonderful shows on the Brachiolope Media Network. The intro song to our show is *Tell Balgeary, Balguery is dead* by Ted Leo and the Pharmacists and the end song is *Russia* by Ramona Falls. Good day my friends and until next time, remember to keep science in your hearts.

Music

1:26:34

Andray: So I have a question then, because up until well literally up until you sent me an email about this show, I had no idea that there was such a thing as ice 1234 etc. You know what I thought, you know what I thought ice-four was when I saw it in your email. I don't know if you ever played the old Final Fantasy games. But in the...

Ben: Oh yeah, ice-four...

Andray: In the English translations there were like three different levels of ice spells, there was ice-one, ice-two, and ice-three. When I saw ice-four I was like sure is this Blizzard, like, how...

Ben: Yeah.

Andray: What on earth is ice-four?

Laughter

Andray: Is this, is this, is this a spell that's like, it, the planet was created by a mythological creature named Shiva, coalescing out of the mists and then like blasting the planet into existence. I have no idea what any of this is.

Ben: Well, honestly, I get the joke, and I think it's really funny. I don't know if anybody else will. But that's, yeah, no, actually I was wrong when I mentioned ice 1,2,3 and 4 in that email. Those guys don't show up in this particular, on Neptune...

Andray: Okay.

Ben: They show up on other planets and stuff, but it's gonna, there's a related idea is going to show up fairly soon in our explanation.

Andray: Okay.

Ben: So hold on, but it won't be ice-two or ice-thee, it will be something else.

Andray: Thanks for letting me down easy.

Ben: Wow.

Andray: Okay, and are there practical applications for doing these things? Or is it just, we're just going to like smush diamonds together and see what cool stuff happens? Is there a, like an Earthly application for these insane experiments?

Sabine: Sure. So I would say there are two. So the first one is more of a philosophical one. We're always trying to create new materials. New materials can have really cool properties that make them, like Kevlar or nano carbon fiber. You know, they don't occur naturally in nature, we make them by morphing some of the materials we have. So these types of high pressure experiments might create new materials that we could use for stuff. And secondly, these types of high pressure experiments are used a lot on hydrogen. And for someone like me, who's a planetary scientist, I'm like, great because hydrogen occurs inside giant planets and I want to know what it's doing at really high pressures and temperatures inside planets. But most of the hydrogen experiments done under high pressure are done because there's a theory that hydrogen at room temperature is a superconductor if you get it in a certain pressure state. We've never been able to make it, but if we could, we could solve most of our energy problems.

Andray: Well, okay, how would that, how would that, please break this down for me?

Sabine: So superconductors are materials that we know exist. And what happens is they can generate electrical currents without having any resistance or friction. The problem with our energy needs is that energy gets dissipated, right? Every time you've got current running in a wire, some of that current gets dissipated through friction, and you eventually lose the signal unless you keep putting energy into it. But superconductors can carry electromagnetic energy without friction. The problem is most of the superconductors we know about occur really, really, really low temperatures like really close to, like zero degrees Kelvin. The coldest temperature where everything stops moving. And a few of them at like 50 degrees Kelvin or something like that. It's been really hard to find them too and they're all in these really, really complicated materials.

1:30:02

But you can kind of do calculations to figure out what would have superconducting properties. And it turns out that hydrogen in certain situations could have these properties at room temperature. So everyone's looking for these room temperature superconductors, because we would make everything out of them. All of our transportation systems would be made out of them. It would just make our energy problems go away.

Andray: So if, okay, but how would, how would you turn hydrogen into solid matter for it to conduct things?

Sabine: So you'd have to take, so hydrogen is a gas when we experience it because of the pressure and temperature conditions that we experience on Earth. But if you keep squeezing it under higher and higher pressure, the atoms of hydrogen get closer and closer together. Eventually, things get so close together, that they become a solid rather than a gas. And so what you're trying to do is you're trying to squeeze them to high pressure to make them into a solid.

Andray: How then would you convert it into a solid that's able to maintain that pressure and not just dissipate?

Sabine: That's an excellent question. So, we don't know yet. No one knows.

Ben: Encase them in diamonds. I mean, you could, you'd be building them in these diamond anvils. But I've heard Okay, we mentioned earlier, I'm not, I’m going to scrub me saying this. But we mentioned earlier that there are different forms of ice, there's ice-two, ice-three ice-four, these different types of ice form in different temperature ranges, usually colder than 0 Celsius. So usually like -40 Celsius, but also in higher pressure ranges. And it's possible to get, like, ice-four, I think, really, really high pressure ice. You can't make it on the surface of the earth because the pressure isn't high enough, but you can make it inside the earth. And so sometimes water gets trapped inside a diamond in these really high pressure conditions. And the diamond solidifies around it. And you can get ice-four inside the diamond even though it couldn't exist out, because it can maintain that high pressure thing. You need to manufacture diamonds in such a way if you're going to put liquid hydrogen inside of it somehow. But I don't know, you can make a semi-permanent prison for high pressure situations using diamonds. It's fun.

Andray: It sounds like it's pretty far off from becoming a reality. So I think I'm just gonna that one. As far as like, the ways that we're going to save the planet. That seems, I hope I see it in my lifetime but I’m not going to hold out hope for that.

Erin: Release date 2020

Ben: Yeah.