Episode 22: Falling Down the Stepped Leader
Physicists: Amanda Bauer, Zach Weinersmith

Transcribed by Denny Henke

Ben: Over the course of my studies in theoretical physics I've traveled across the continent and around the world sampling new ideas and tasting different answers to the questions of how and why. And still I find there remains a deep hunger that lives within me, a burning desire to share these great ideas with the people around me. And so, I have assembled a team of some of the greatest, most lucid, most creative minds, I have 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!

[1:49]

Today's show is about thunder and lightning. The physics aren't breaking but it's fundamental it puts mental back in fundamental if you will. So the deal with thunder and lightning is that as a child I at heard many descriptions for how and why they work. Some people said thunder was the sound that clouds made as they rub together other people so that lightning never struck the same place twice, Angels bowling, angry hammer gods, Thunderbirds… people say all sorts of things. So back when I was working on my masters degree I was thinking of starting some kind of physics outreach. Anyway the first topic I decided to look into was thunder and lightning because hey nobody has a good understanding of it anyway and what I read blew my mind. Thunder and lightning are pretty well understood, they are simple and they are fascinating. So I have honestly been waiting eight years to do this show. Anyway, in preparation for my intro I decided to look on to Yahoo answers otherwise known as the best place on the Internet to find out how uninformed everybody is on a subject. And it looks like everybody already knows where thunder and lightning comes from, at least everyone on Yahoo answers knows. But, I don't care I've been waiting for this show for eight years I now you'll just have to endure it and act all smug and nod smilingly at your earphones when you hear me explain things you already know. You'll have to endure it because you love me and sometimes you humor the people you love to make them happy. So that's it thunder and lightning. So the thing about lightning, it lights up everything around you but you only get a glimpse that's why I like lightning and that's why I like short stories too.

Today I have invited on Elizabeth Bear, the speculative Fiction author. In 2005 she was the winner of the John W Campbell award for best new rider and since then she's want to Hugo awards for her stories. She writes novels and short stories and she first you're my attention with the Hugo award winning novelette Shoggoths in bloom we're she accurately captures the nature people in down east Maine. I also like the story Boojum and Mongoose which she wrote with her collaborator Sarah Monette. So some of these stories have been recorded on podcasts and on the webpage I'll link to all the different podcasts episodes that feature her story so that you can have a listen too. Also the SF Squeecast just one the 2012 Hugo award for best fan cast. Hello Elizabeth Bear and welcome to the show and congratulations.

Elizabeth: Thank you, I am absolutely thrilled to be here and I feel like I can bring you some good news because Sarah and I just published a third story in the Boojum mongoose continuity, exclusively as a podcast. It's up on the Drabblecast site.

Ben: Amazing!

Elizabeth: I brought you a present!

Ben: I love those giant flying space fish monsters so much! So, Bear, for you today I have assembled two of my finest titanium physicists. Arise Dr. Amanda Bauer! Dr. Amanda did her PhD in Austin Texas and she is currently a super Science fellow at the Australian Astronomical Observatory in Sydney where she studies galaxy formation and she also blogs under the name of Astropixie. We will also link to your website on our website Amanda. So, Elizabeth, I tried to find real fulminologist for you for the show, that’s somebody who studies lightning. But I didn't know anybody so instead I've got a really exciting guy and people call him the lightning kid. Arise Zach Weinersmith. So you might know Zach from his multiple award winning web comic series Saturday Morning Breakfast Cereal or from his fantastic podcast, the Weekly Wienersmith. You might even know him from Episode 9 where Jocelyn and Dave and I tried to explain warp drives to him. But he’s got half a physics degree and I'm happy to have him in my corner today.

Alright let's talk about lightning. So the story of lightning starts with cumulonimbus clouds and there's something crazy going on inside cumulonimbus clouds. All of this graupel, all of the water particles, all of the snow inside of it, all of the ice crystals end up bouncing against each other as they pass each other really really violently and this causes the particles to get electrically charged.

Amanda: You can think of lightning as a form of static electricity in the same way that you shuffle your feet across carpet or occasionally you touch your car door and you get sparked. The cause of that is that as you’re shuffling your feet you're picking up extra electrons and so you're getting a negative charge even though you don't know. Until that doorknob kind of feels that negative charge and it produces its own positive charge and then when you get nearby you have a spark. So lightning is essentially that spark and the reason it can happen is inside of the cloud you've got all of these water droplets forming, a kind of natural process of evaporation and condensation, these particles are kind of shuffling against each other and they're freeing electrons and their building a negative charge because of that. So it's just sort of a natural process, you build up this electric charge, you get a separation so that the negative charge sinks down to the bottom of the cloud and then the ground or the planet feels that, forms its own positive charge and the spark between them is what we see as lightning.

[7:09]

Ben: So, you want to imagine a cloud and in essence there are different parts of the cloud. Some of the cloud has gone up from high in the atmosphere, down to mid-level, some of the cloud is moving upwards, some of the cloud has been sitting there for a while, so what's full of all of these different constituents. There's parts of the cloud where there's lots of this graupel. There parts of this cloud where there are a lots of ice crystals, in essence these bits have rubbed against each other because sometimes, you know the graupel is going down, the ice crystals are being swept up in an up draft and they rub against each other and then the graupel ends up with a negative charge, it steals an electron from the ice crystal. It’s kind of like rubbing your head on a balloon and your hair steals electrons from the balloon and the balloon ends up with a static charge, your hair into up with a static charge, right?

Elizabeth: Right.

Ben: So if you have imagined a cross-sectional diagram of one of one of these cumulonimbus clouds what you would see is, there will be large concentrations of charge based around, you know, the parts that had stolen the electrons and the parts that hadn't. Near the top there'd be whole huge concentration of positive electrical charge. So something had stolen electrons from that region and then near the bottom there will be a whole bunch of areas that are just full of negative electric charge.

Elizabeth: You've polarized your cloud.

Ben: You have polarized your cloud. The thing is, that it's not that bipolar, quite. When physicists go in to study these clouds there are often multiple poles. So there sometimes there are multiple regions where there is negative charge, and multiple reasons where there's positive charge. And the reason for that is, in essence, different regions have different stuff in them and different stuff steals or gives away electrons depending on what it's hit and what temperature it's hit. But, in essence, you end up with a big of clusters of charge. Over here you end up with a cluster of negative charge, over here there is a cluster of ice crystals with positive charge.

Elizabeth: Okay, and you can get cloud to cloud lightning because of that?

Ben: You can get cloud to cloud lightning because of that. 75% of lightning that happens is cloud to cloud lightning. Essentially, it's just the electrons on one side of the cloud want to be over where there's a positive charge on the other side of the cloud and then make a lightning happened between them and travel along along that lightning. Up until now I have been kind of waving my hands talking about positive charges and negative charges in a cloud but one in four times lightning comes from the cloud it hits the ground where there are positive charges in the ground. In essence, what happens is you have this big negative charge you have all of these electrons in a big cloud sitting right above the earth. It's 2 km away but that's pretty close. Electrons repel each other, right, they push each other apart right. In essence, this big cloud of electrons pushes all of the electrons on the ground beneath it away so you end up with a local region right under the cloud right under this concentration of negative charge that's positively charged.

Elizabeth: Alright.

Ben: And in essence, when you get lightning that goes from the cloud to the ground, what's happening is this negative electric charge is saying, well, the ground in general isn't positively charged, in general the ground is neutrally charged but there's a patch right under me that has a positive charge these negative electrons I'm going to try to get to that positive induced patch right under the thundercloud. So, essentially what happens is all of this electrical charge, it sets up a bunch of electric fields that are really, really strong. Now, they're not quite strong enough to break down air. So air is an insulator, it's a thermal insulator, but it's also an electrical insulator. And what that means is if you take a battery, imagine one of those 5 V batteries, it's got two terminals right next to each other right. There is the knobby one and the sucky one.

Laughter.

Ben: And somehow even though those terminals are right next to each other, there's less than a centimeter between the two, the battery is not discharging. There isn't current passing between the two.

Elizabeth: Not unless you stick it against your tongue.

Ben: Not unless you stick it against your tongue or keys in your pocket. Right. So air is an insulator and what this means is usually air doesn't let charge move through it. So these positive regions and these negative regions are stuck. The electrons are stuck over in the negative regions even though they want to go to the positive regions. So, the electric fields in the system have, kind of have a trick, that let them tunnel through the air. In essence, they're building a tunnel between the negative charge and the positive charge. Air is neutrally charged it's like, so imagine that it's all made of neutral hydrogen because that’s nice and easy to talk about. You got the positive charge in nucleus and then an electron. The positive charge in the nucleus, when it faces this big cloud of electrons, the positive charge it's going to be attracted to the negative charges. The electron on the other hand is going to be repelled by this big cloud of electrons. It will want to move away from it and so what you end up doing it's kind of pulling the electron and proton apart. The positive nucleus will want to go one way, towards the cloud, the electron will want to go the other way away from the cloud. The amount of electric field required to do that is called the breakdown voltage of the gas. So, air has a breakdown voltage, it’s 2 to 3 million volts per meter. Okay so if you take a meter span of air and you put 2 to 3,000,000 V across it then the air molecules between these two big plates will get pulled apart and will become free electrons and free nuclei.

[12:52]

Ben: So, in essence, there are these big clouds of charged particles inside these thunderclouds and they want to get to the ground but the problem is there isn't enough electric field to rip the electrons off these atoms to make a good conductor. So, there's a trick to doing this, it's a kind of devil in the details kind of thing, and the answer is lightning. Alright so let's talk about lightning. You can describe lightning happening in two steps. The first step is you know if you were to draw lightning onto a page, you would get this kind of jig jaggy shape, right? So the first step in lightening formation is the formation of that jaggity shape, it’s called the stepped leader. So, it comes down out of the cloud, and it forms one segment, one line at a time and it takes about 20 milliseconds to reach the ground and each segment is about 50 meters long and so, one forms and then the next one along branches off of it and then another one forms after that and it forms lined by line like your building things out of sticks that's you're sticking together end to end, right? So one will form and then there is a 50 microsecond pause and then another will form and then there is a 50 microsecond pause and then another will form and you can see this on really, really fast photography and in essence you see the lightning growing down from the cloud. Jag, jag, jag, jag, jag… sometimes it splits into different branches each time another segment is added the whole stepped leader flashes.

Elizabeth: So that's why if you see like ultra high speed photography of a lightning bolt before the actual bolt you see this sort of dimly lit fingers coming down from the clouds and then you get one big bridging spark and the other one sort of fades out.

Ben: So when this stepped leader touches the ground…

Elizabeth: As I understand it there is a thing that happens where leaders, both descending from the cloud and ascending from the ground and where they touch is where you get an actual ground strike, is that… ?

Amanda: Exactly.

Elizabeth: That's a correct interpretation?

Amanda: So, you've got this the electric field that's occurring in the cloud, you have this negative charge coming down. The ground kind of feels this negative charge and so everything like the top of your head or the top of a tree, or the ground, pushes up these little positively charged leaders as a result of that. But it's those negative things and those positive things that are reaching for each other, there's a lot of different potential connections that they can make and they're all searching for each other but as soon as one actually connects that's when you get this shuffling of charge and a big lightning bolt.

Ben: Once it gets to within 50 m of the ground another branch will start at the ground and move up and connect and once these two are connected, once there is a continuous path from the charged concentration in the clouds down to the ground you get something called the return stroke. And, the return stroke is the time when all of the charges, all of these electrons inside the cloud rush down this tube and into the ground and that's the flash you see as lightning. In fact it tends to happen more than once it will flash once and then this charged concentration up high in the clouds will send off a little filament, a little lightning tube to another nearby charged concentration and that will drain out and then it will send a tube to another one and then that one will drain out and so you get several of these pockets draining one after another, three or more times usually, those are called the return strokes. And, so, that's essentially what you see when you see lightning flickering. You can vaguely perceive because it takes 50 milliseconds between each return struck but in essence that's what you were saying when you see lightning.

Elizabeth: Because it's already got this fully ionized pathway that it may as well use…

Ben: Right.

Elizabeth: Instead of making a whole new one.

Ben: That's right. Once they have the escape route the other nearby ones follow that escape route. So it turns out the physics of the stepped leader and the way it works is completely understandable. So I mentioned that before that this ball of charge up in the cloud doesn't emit a high enough electric field to cause the breakdown voltage of air but it turns out the little tube of lightning, the charged leader itself does, okay? So nobody knows how the charged leader starts, nobody knows where the first little tube of ionized gas comes from outside the cloud, but there are probably lots of theories on it. But what happens is once that little tube is formed, once there is one little tube, there are regions of that tube that can cause enough concentrated electric field for the breakdown voltage to occur. So, I want you to imagine, like, imagine you've got a 2 x 4. You've drilled holes in the 2 x 4 and you stuck lightbulbs, clear light bulbs, down in this so they're not glazed they're just regular shiny lightbulbs that you can see through. And you turn them on so that's all the lights are shining. So imagine that you're holding this 2 x 4 maybe it's a foot-long, and you're looking at it from different angles. What orientation will the light be brightest on that 2 x 4?

Elizabeth: So, you have a bunch of lightbulbs all in a line?

Ben: Yeah.

Elizabeth: Which way will it cast the most light, is that the question?

Ben: Yeah.

Elizabeth: If you face it directly toward the observer.

Ben: Beautiful! Oh Bear, that was wonderful!

Elizabeth: What's behind door number two?

[18:13]

Ben: No, that's absolutely right, you got it right. The reason is, essentially, because if you look at it straight down you'll see every lightbulb in a row. So, it's super extra bright. So, imagine that you have your stepped leader, essentially you have a big tube you start with a tube and it's full of electrons. Now, these electrons will be pulling nearby protons towards them and pulling nearby electrons away from them. Turns out that even though all of the electrons generally in the system don't have enough oomph to rip the electrons from their protons, if you look at the system from the very edge, if you stare straight down the tube and together if they are all aligned like that, there is enough force there to rip the electrons from the protons. So it turns out that the very tip of that tube is where the breakdown voltage will occur. So it turns out that what's going to happen is, you have this big tube of electrons, there're so many electrons packed into that tube that at the very tip of the tube it's going to ionize another trail, it's going to make a new tube of ionized gas that comes off the very tip of it. Do you see what I'm getting at?

Elizabeth: I think so, yeah.

Ben: Yeah, so how can that happen? It turns out that there's lots and lots of electrons in there and they're pushing all of the electrons nearby that are stuck to protons away from them. They're pulling all of the protons towards them. All you need is one electron. You just knock one electrons of that gas out and it will rocket away from your tube of electrons because it's being pushed so hard. All you need to do this split them apart a little bit and that electron will start to accelerate and as it accelerates it bumps into other atoms of gas and as it bumps into these other atoms of gas it knocks their electrons off.

Elizabeth: This sounds very much like the famous mouse trap and ping-pong ball demonstration of nuclear fission. Apparently this was early on, I think in the Manhattan Project. They filled up a gymnasium full of mouse traps with ping-pong balls on them to demonstrate this to a bunch of visiting politicians and had some guy toss one ping-pong ball into the middle of the gymnasium.

Ben: Right.

Elizabeth: And you can imagine what happened next.

Ben: That’s brilliant. Oh that's brilliant can you imagine being like the grad student who has to set those up and then you miss place one…

Laughter

Elizabeth: … four fingers for the rest of eternity.

Ben: Jeeze. Thankless. That's amazing. Yes. You knock one of these electrons off and it just cascades a whole bunch of electrons along its path off and so as a result you end up with a line of new ionized gas and that new line of ionized gas is the next step in the stepped leader.

Elizabeth: Ahhh. Ok.

Ben: And so what happens is as soon the gas is ionized all of the electrons in the previous line and all of the electrons in the cloud, they're all packed together, they are unhappy, they say hey we can move down into that new space. And so they all rush down the tube into the new segment of ionized gas and that's this flash you see as it builds up. Because when electrons move through gas they bump into things and that produces light. So in essence that's why whole stepped leader flashes, flashes, flashes, flashes as these lines get made on the way down.

Elizabeth: And that's the same process that produces a fat blue spark when you touch your cat, only in macrocosm.

Ben: So, in essence, what happens is you have this stepped leader, step, step, step all of the way down, it's just full up, the same say the electrons density as up in the cloud. All of the electrons that possibly can file into each of the tubes as this forked pathway gets forged down towards the ground. As you mentioned before, sometimes what can happen is near the ground, because this thing as it gets closer closer to the ground it will induce a positive charge on the ground, it will chase away the electrons on the ground and make the ground more and more positively charged. Sometimes what you can get on the ground is called a positive streamer. You can get one of these little arcs of ionized gas moving up from the ground which will then try to reconnect with the tube and in essence that's exactly this a process but instead of negative charge its positive charge instead of electrons being pushed away it's electrons sucked towards it. But essentially you get these two arcs and then if they touch then there is an an uninhibited pathway as I said before from the cloud into the ground and all of the electrons move at once. So now we are talking about something called return stroke and this is when the lightning flashes, this is when you see it this is when it gets really big. What happens is, this stepped leader is packed full of electrons it is full, full, full to the brim of electrons, you let some of them out at the bottom, the ones at the bottom will start moving first. The ones at the bottom start moving out, down into the ground, the ones above then get the message and they start moving down, the one's higher up, they start moving down. And so if you watch a lightning, if you watch a lightning, (chuckle) oh god…

Laughter

[23:31]

Elizabeth: A stroke of lightning…

Laughter

Ben: If you watch one of these strokes of lightning you'll see it the luminescent part will start from the ground and then move up to the cloud and in essence that's what’s happening it's like a traffic jam. All of these electrons are saying oh hey I can move and as they start to move they bump into things and that's what causes it to be bright.

Elizabeth: So is that you were saying earlier, something about experiment relating to this?

Zach: Yeah, so you see in essence what you need to get the electrons to come from the clouds of the earth is one of these pathways of ionized gas so in theory you could just ionize the gas yourself. And so apparently this was actually done with some limited success where they thought well if we just shoot a laser at the clouds it will heat up, I believe the idea was just to heat up the air enough that would ionize the gas. And so the idea is you would artificially create the tube Ben was describing and then what should happen then it is the lightning should come right at you.

Elizabeth: Yeah there's no way that could possibly go wrong.

Zach: No it’s mad science, nothing ever goes wrong.

Laughter

Zach: Presumably you have a Frankenstein set aside to absorb the lightning and then wreak havoc. I assume that you could probably set up a lightning rod that would gather lightning but what's cool I think theoretically you could justify it by saying well there are situations where lightning might be dangerous so we could just suck off a bunch of these excess electrons created by the graupel and ice and everything rubbing against each other and maybe we could protect some area from getting struck, we could get this lightning into a lightning rod and dump it into the earth or whatever.

Elizabeth: Divert it off to someplace safe as opposed to in the middle of your outdoor concert or whatever.

Zach: Yeah, exactly. I guess it would be really hard to use as a weapon because it has to shoot right at you.

Elizabeth: You have to have some guy standing right there with a laser.

Ben: There are lightning guns. There was a pop press article on it a few months ago. In essence, they take two lasers that can ionize gas and then they take a Van de Graaff generator and then they just shoot the two ionizing lasers at something connected to this charge difference, and the charges moving down one channel of ionized laser through the person they want to fry and then back up the other one. So yeah, no, lightning guns exist I think the Navy was building them if I remember correctly. So do you want to talk about thunder?

Elizabeth: Sure.

Ben: Nah, nah, nah, nah, nah, nah, nah, THUNDER! Nah, nah, nah, nah… anyway. Okay, so, thunder. When you were kid did you ever hear that thunder was two clouds rubbing together?

Elizabeth: No

Ben: Okay, just me, that's okay.

Amanda: I heard that too, don't worry.

Ben: So I'd heard multiple things but consensus said that it was two clouds rubbing together whatever that means but it turns out that thunder is literally the sound that lightning makes. The light in lightning comes from the electrons bumping into gas as they move down this tube and that causes the gas to heat up really, really fast 30,000°C

Amanda: It is actually five times as hot as the sun's surface so it gets very hot.

Elizabeth: Wow.

Ben: So, this tube gets five times the temperature of the surface of the sun all at once like in milliseconds and it doesn't have enough time to expand out and so what happens is it explodes out it makes a shockwave. And the shockwave lasts about a meter until it turns and the sound but in essence that whole tube of lightning exploding is the sound we hear as thunder. And here's the neat bit, the sound you hear of thunder reflects the shape of the lightning. So depending on where you're standing and depending on the shape of the lightning you're going to hear thunder sounding in different ways.

Elizabeth: So that's why a big, elaborate forking flash of lightning seems to come with a longer and louder crack of thunder.

Ben: Right.

Elizabeth: I never knew that.

Ben: Yeah. And what more, okay yeah, so you know how lightning, the path that lightning takes is made up of these 50 m tubes connected end to end?

Elizabeth: Yeah.

Ben: The orientation of that tube will determine how the thunder sounds to you so if that tube is oriented perpendicularly to you, all of the sound coming from that tube will come at you and hit you at the same time. And so you hear, like a snap. If the tube is pointed straight away from you then it's going to take a little bit of time for the sound from the back of the tube to reach you so the sound at the front of the tube we'll reach you before the sound the sound from the back of the tube will. So, then you will hear a more elongated boom. And so what happens is because lightning jags on its way up because they're all these different orientations you're going to hear sound that comes from the nearest part of the lightning first and then the shape of the lightning is going to determine the sound of the thunder as it reaches your ears so it will go (indescribable crazy sound from a heavy metal song) depending on exactly what the shape is. And each different orientation of each different jag will determine what the next sound you hear sounds like.

[28:36]

Elizabeth: So thunder is just kind of a sound sculpture.

Ben: Yeah, it's a sound sculpture.

Elizabeth: That's very cool.

Ben: Incidentally, there is that old trick you learned as a kid where you, you know sound travels much slower than light. You can see lightning, count the number of seconds divide by three and that tells you how many kilometers away the lightning was, right?

Elizabeth: Yeah, or divide by 5 for miles. Being a backwards American that's the version I learned.

Ben: Right! Lightning trivia! Did you know that at anytime on earth there is about 100 lightning strikes per second.

Elizabeth: I did not know that.

Ben: Okay, Amanda tell us about lightning on other planets.

Amanda: So, one of the fascinating things about lightning I think is when you look at it on a global scale, so the whole planetary scale. So there are about 2,000 thunderstorms that are occurring on earth at any given time which is producing these hundred lightning bolts at any given time and since we are encompassed in this ionosphere we have this big cavity around us that actually allows electricity to flow through it. That sort of traps in all of the energy from the lightning. So all of these bolts are causing this resonance to happen we have an electromagnetic heart beat around the earth and it works at a really low frequency so it's something like 8 Hz but because of that we can understand the different compositions of the chemicals in our atmosphere and you can use this technique to go to other planets to understand the chemical makeup of their atmospheres. But in order for that to work you need lightning on other planets so we have searched for lightning on quite a few other planets. The candidates would be Venus and Mars and Saturn, Jupiter and Saturn's largest moon Titan. We have seen lots of evidence actual images of lightning on Jupiter which is pretty exciting you can imagine that they are super lightning bolts because while you have the top of the storm at about the same pressure as the earth the storm goes a lot deeper into the atmosphere of the planet so you get a lot more length of the bolts that can go through. So on Jupiter you see lightning bolts all over the planet, there is not a specialized location in the same way that you see it in most places on earth. But on Saturn, interestingly, you only see it in this one region in the southern part of the planet that they call Storm Alley. So it's this massive storm that's been raging for a long time.You can actually see it with small telescopes from the earth. You can see it picking up and getting really strong for months at a time and then it goes away. We have been able to detect lightning through magnetic pulses and radio waves and only recently have we actually been able to take photos from Cassini and the other spacecraft that have been traveling around. Take actual photos of the lightning on the planet and you know how hard it is just to get a photo of a crack of lightning on earth so imagine the spacecraft up there trying to capture the lightning there. So you would think that in principle the lightning there is going to work based on the same physics as lightening here, so the presence of lightning there would infer that there's going to be some sort of water in the liquid and ice form. So that's pretty exciting. But, it's possible that the same physics, the same separation of charge could occur from rain that's not made of water. So, what if you've got methane or ammonia or something like that, as in on the moon Titan. You've got methane rain instead of regular water rain. But the physics should, ideally I'll be the same, and a nice well behaved universe. So lots and lots of different teams have been looking at Titan for many years now trying to find evidence of lightning through the radio and magnetic pulsations and visually and even though we expected it to be there, we have not seen any evidence, quite frustratingly no evidence whatsoever of lightning on Titan. So this is a big mystery actually. We have no idea why there isn't lightning when it seems to be that it should have lightning. Let's see so Venus also has a very thick atmosphere and we didn't see lightning for a long time but recently there have been evidence based on the radio frequencies so radio pulses we've seen evidence for lightning there. No actual photographs though, no images. And the other one that I find fascinating is Mars. So Mars doesn't have clouds in it's atmosphere in the way that the earth does but it has these huge dust storms that go around which is good for the rovers that are living up there. But with these dust storms, the particles kind of rubbing up against each other, cause enough of this charge separation that it's believed that they can create lightening inside of them as opposed to the clouds where we get on earth. So that has been kind of loosely detected it's not a solid yes we have found lightning there, but that is one possibility. So, the fact that some of these planets have lightning and it has been pretty great and producing great pictures, when we try to use this resonance that I talked about before, to get an idea of the composition of the atmosphere of these planets, so we look for how much water there might be, how much ammonium, how much methane and ultimately this can help us understand how our entire Solar System formed or what the base cloud was that our solar system formed from. The amount of methane and ammonium that's in Jupiter's atmosphere is a bit different that what we've seen in Uranus and Neptune and there's really no good explanation for why that should be different. So if we can get some of this, the actual amount of those in the planets at different distances from the sun then we can really start to understand and test our theories for how our entire solar system started, all thanks to lightning.

[34:12]

Elizabeth: That's insanely cool.

Ben: Well, that was fun. So thanks Zach, thanks Amanda you have pleased me. Your efforts have born fruit and that fruit is sweet, here's some fruit. Okay Zach, you get a banana. Yeah, it's the lightning of the fruit. And Amanda, you get the thunder of the fruit, the mighty coconut. Awesome! Okay I would like to thank my guest Elizabeth Bear! Elizabeth Bear thank you for coming on so much.

Elizabeth: Thank you, I've had the time of my life with you guys.

Ben: Oh, we've had so much fun with you. We hope that we answered any questions that you have.

Elizabeth: I feel thoroughly edified.

Ben: Yay!!

Ben: Okay, fans. Let’s suppose you want to interact with the titanium physicists a little bit more. If you would like to keep track of us why not follow us on Twitter at @titaniumphysics or join our Facebook group. If you would like to hang out with us and socialize why not join our online forum. Or if you would like to send me an email directly or to ask a question or propose a topic you can email me at barn@titaniumphysics.com. So let's suppose you want to listen to us more conveniently if you've got and iPod or an iPad you can try subscribing to our show using the iTunes store. While you're there write us a review. Your reviews determine our ranking within the podcast app in the iTunes Store which in turn determines how many new listeners discover our show. If you have a Zune or a BlackBerry you can subscribe to our show on those doodads as well or you can download the Stitcher radio app which will lets you subscribe to listen to all of your favorite podcasts. You can download the Stitcher app for free onto your iPhone and android phone Kindle fire or other devices. Stitcher is convenient because it lets you subscribe to your favorite podcast and listen to them easily. Okay, for all of this and more information visit hour website at www.titaniumphysics.com. The titanium physicist podcasts is a member of the BrachioMedia if you enjoyed our show you might also enjoy Science Sort Of or the Weekly Weinersmith, check them out! The intro music is by Ted Leo and the Pharmacists and the end music is by John Vanderslice. Good day my friends and remember to keep science in your hearts.

[37:34]

Ben: As a physicist I have absolutely no training in the physics of the atmosphere. For some reason, studying clouds is completely off topic for any class I have ever taken so it was really interesting to me to look up into the sky and try to guess the physics involved in it. So one obvious thing with the atmosphere is that it is warm down on the surface and cold way up high right. So you might ask yourself you know hot air balloons rise why doesn't this warm air just bubble up into the higher atmosphere? Why isn't it warm up top instead of down at the bottom? The interesting answer is that it kind of has to do with the thermal dynamics of the gas. As you go up higher in the atmosphere of the pressure decreases and so if you took a bubble of gas and you brought it up into the upper atmosphere the gas would expand because of its higher pressure and as it expanded it would cool and it would end up colder, in fact, if you took a bubble of gas and took it way up high into the atmosphere. The story changes a little bit if you have really wet gas full of vapor. So if it is a really, really humid day if you take a block of really humid gas and you let it rise up into the atmosphere, what happens is the latent heat and the heat capacity of the vapor in this block of gas, as it rises up, will keep it warm. In essence it's kind of like if you take a water bottle out of the fridge you know it's stays cold for a long time. Is you take this block of damp gas up into the atmosphere, it stays warmer than it should for much longer as it goes up. Essentially, to form a cumulonimbus cloud, you have a bunch of really hot gas near the surface of the earth. It's not really hot you know it's hot summer afternoon temperature, but it's really damp. So in the end it can rise a lot longer and cumulonimbus clouds as a result and much taller than any other cloud formation. They are those thunderhead clouds. In essence this system is unstable at the very start like drawing back a slingshot this big column of air rises up high into the atmosphere and you get a cumulonimbus cloud. If the cumulonimbus cloud was above you it would be about 2 km above you so that's about an mile and a half. But then it goes about 16 km up to the top so it's really, really, really tall, it's about 14 km tall depending on where you are.

Elizabeth: Now, I have noticed that they tend to shear off at the top, is that generally because of air mass or wind moving in a different direction from the cloud?

Ben: Yeah.

Elizabeth: Is that what sets the limit on their height?

Ben: Actually, so if you took a marble and you put it in a slingshot and you shot straight up it would go up, reach a certain height and then fall back down, essentially. Essentially something very similar is happening to this water vapor it starts out really really hot it starts to rise like a hot air balloon and as it rises it gets colder, it starts to expand, and as it cools it's going to keep climbing until the temperature of the ball of gas is as cool as the ambient temperature at that altitude. So as it cools it gets colder and colder and a colder and what happens is the water vapor in it starts to condense.

Amanda: So the height of the top of the thundercloud, it's also very dependent on the pressure so you get lower and lower pressure as you get higher and higher up. An interesting comparison between the Earth's thunderstorms and thunderstorms on other planets is that the top of them is all defined by this one standard pressure it's .1 bar if that unit means anything. But it's the same pressure that defines the top of these storms and then the bottom is completely dependent on whatever temperature your planet happens to be.

Elizabeth: So, if you were talking about a mega storm on Saturn or something it's still tops out at one bar.

Amanda: Yeah.

Elizabeth: Cool

Amanda: I thought so too.

Ben: Okay, so cumulonimbus clouds are fairly violent on the inside. Essentially you have this big mass of hot dense air it rises up and then the vapor in it condenses. And because it condenses in fairly cold regions and because it moves upwards so quickly, it ends up supercooling the water vapor in it. The way supercooling water works is that if you take water like a cup of water at sea level, it starts to freeze at zero degrees Celsius, right? So, at 0 Celsius if starts to turn into a block of ice but it turns out you can keep it from turning into a block of ice if you can keep the crystal from forming. So if you stir it you can keep these crystals from forming and essentially the water will be cold enough to freeze but it just won't have a chance to crystallize and the crystallization happens really suddenly as soon as it gets a chance and so water in that state is called supercooled and essentially that's what happens to these droplets of water up way high in the atmosphere at the top of these cumulonimbus clouds. And so when some snow particles or some ice particles come in the water it makes a little ball of ice around each snowflake and this is called graupel. Have you ever heard graupel before?

Elizabeth: I have not.

Ben: It’s called soft hail, but in essence, what happens is you get this graupel ice up high in the atmosphere that is then too heavy, the air supporting it is no longer buoyant and then it falls down. All of this graupel, all of this ice, all of the snow falls down in a rush straight down. That's called downdraft and it brings a column of air down with it. You think about when you've been outside in a thunderstorm the temperature drops really suddenly. It goes from a nice hot day to pretty cold all of a sudden, that's that mass of cold air from the top of the cloud rushing down and hitting you and then it immediately after it starts to pour rain. Instead of a nice happy half hour rain shower it all comes down in a rush and so you end up with a fairly short, they only last about 10 minutes, but really really intense rain, right?

Elizabeth: Right.

Ben: Right. Okay, so, in essence that's how cumulonimbus clouds work.

[43:45]

Ben: Um, okay, ah, so, right. Hold on. I've got so, the moral of the story is that… Yeah, yeah… I've got a great explanation.

Amanda: … put it laymen's terms, kind of like what I would say to my niece or nephew…

Zach: Can we talk about ionizing air, I feel like that's the concept that elucidates everything at least for me.

Amanda: Okay.

Ben: Yeah. Let's start…

Zach: I think Ben to do a better job than me.

Elizabeth: I should say that this podcast is incredibly fortuitous for me because I am actually working on a story right now for the online serial I work on, Shadow Unit, which involves controlling where lightning strikes.

Zach: Oh, awesome. Actually, we, there is a scientific experiment where they basically did that we can get into that once we do a little more.

Elizabeth: So, you guys are doing my research for me, this is fabulous.

Ben: No, this is awesome. Okay, so…

[44:46]

Elizabeth: I think it's, really fascinating that it, did you say it was 50 microseconds…is that…

Ben: Yeah.

Elizabeth: It's always exactly the same interval. I find that kind of fascinating.

Ben: Well, it's, I probably, 50 microseconds is a Wikipedia number. I mean, it probably takes a around that, there is probably some variation, I would bet my hat.

Zach: It’s hard to imagine a situation when there wouldn't be some variation.

Ben: Yeah, in essence it's probably due to the, the amount of time it takes to ionize the gas and for the electrons to move from the big dense mass of electrons down to the new extended tube.

Elizabeth: So, it's not cloud spirits playing some advanced version of Ticket to Ride. Okay that was an obscure joke I'm sorry.

Laughter

Amanda: I liked it.

[46:04]

Elizabeth: Can I talk about this cool thing I found at World Con…

Ben: Please do.

Elizabeth: So, I am sitting at a signing table in the dealers room at World Con, and as I'm sitting there signing books, I am realizing that the dealer across from me has these blocks of acrylic that have fractal branching patterns in them. And after I've been staring at them for about 15 minutes I realize that they are Lichtenberg figures which are the patterns that lightning makes when it strikes something, a human being, a golf course, a tree, they look like roots. So after I was done signing I went over to these guys and I had a fascinating conversation with this guy, Todd Johnson, it’s capturedlightening.com is their website. He explained to me what they do, in a conversation that began, first you rent a particle accelerator which I think is my new favorite sentence in the English language. So they take these blocks of acrylic, they run them through a particle accelerator, they basically put an immense static charge on them and then when they get them out the other side they take a metal rod of some sort and discharge them from a point and you get, I guess vaporization trails through the acrylic.

Ben: Sweet.

Elizabeth: How cool is that?

Ben: That’s so cool.

Elizabeth: and they have all kinds of they can make them three-dimensional by shielding different parts of the acrylic. And apparently what they will do is shield part of it, charge it turn it over. I asked him how to turn it over he's a very carefully. Shield another part, charge it again, and then discharge it and they get these swirly patterns. It's really neat stuff. I may have embarrassed myself squealing about the coolness of it.

Ben: What are they pronounced again: Lichtberg…

Zach: Lichtenberg was it?

Elizabeth: Lichtenberg figures, I think it’s Lichtenberg. Lichtenberg.

Ben: Yeah, we looked at them up and sure enough they are, essentially it's the wounds that are left behind on the material as the stream of electrons tries to escape as best as possible. And they kind of, they form kind of arteries as they follow the paths of the previous electrons have traveled down and then they tried to optimize areas so they branch out. Essentially like a root structure and so when people get hit by lightning this is kind of what it looks like on their skin afterwords. There are some horrific photographs on Wikipedia.

Elizabeth: Yeah, the effects of lightning on human beings is actually something that I've been researching again for the story.

Ben: It’s horrible.

Elizabeth: They call them lightning flowers when they are on a human being.

Amanda: That’s a lovely euphemism isn't it.

Elizabeth: Yeah, it's a lovely euphemism for burn scars. Lightning also has profound neurological effects on people which is really fascinating. There is this guy who, I think he was a mathematician or a physicist, who was struck by lightning and suddenly decided he wanted to be a concert pianist and so he became one. And had never had any urges in that direction before but it just became obsessed with this, I guess music and mathematics are related fields. If you go to YouTube and look up lightning sonata you can hear one of his compositions.

Ben: Oh, fun.

Zach: Yeah, I’ve read, Oliver Sacks wrote about him a bit I think. That's interesting too because you know when electroshock therapy, worked, I think, on a similar principle. You basically give the brain a really hard dose of electricity, you get really interesting results, for example it still used for depression.

[49:37]

Ben: So turns out that how the stepped ladder works and why the lightning flashes the way it does…

Zach: Stepped leader, I think you said stepped ladder…

Ben: Oooooh Okay, for that, ah, oh, that’s alright, okay.

[49:57]

Ben: That’s right, in fact florescent lights, so with florescent lights, essentially it's something similar is happening you've got these two leads inside this tube and the tube is full of gas and these leads are above the breakdown voltage of the gas and so you get one electron and it cascades down the tube knocking off other electrons and shining light. And so you know what a ballast is in like a florescent light, right, it's this big block.

Elizabeth: I know that they exist, I…

Ben: Who knows what they do, right?

Laughter

Elizabeth: I could not claim to know what their engineering purpose is.

Ben: Yeah, well right you don't want to throw them in landfills that's all I really knew about them. But in essence what those are for is that they are there to keep the cascading ionizing electrons from going out-of-control. Because as these electrons cascade down they knock down other electrons and the more free electrons there are in this gas the more conductive it is, the resistance of the thing goes down. You've heard of a short circuit before right where you take to leads and put them together there needs to be some kind of resistance push through it or or all of the electrons move from one to the other and a whole bunch of heat is generated and the system blows up. In essence inside one of these florescent tubes if they let this electron cascading get out of control. The electric tube can short circuit. The resistivity can go to zero if you let it go on too long that's why they flicker and that's what the ballast is for. It is, in essence, in florescent lights, they turn it on, the gas gets hit by electrons, the gas becomes more and more conductive and then they shut it off before it gets too conductive. And then let it cool for half a second and then they restart so it goes on and on and on and on and on. So in essence florescent lights are just lightning in a tube.

Elizabeth: Neat.

[52:07]

Ben: Let’s talk briefly about lightning rods, do you know how lightning rods work, can you guess?

Elizabeth: Well, I am guessing that in general one tries to make the lightning rod the highest point in the surrounding area and I would assume that the stepped leader hits that first the channels into it.

Ben: Right. Actually you want the positive streamer to kind of come off of it. What will happen is, it's a rod of metal so it’s a good conductor first off. When you have this great big concentrated electric field coming off your negative charges, coming towards the earth nearby, what will happen is they will push all of the electrons out of it. And so you'll have a really strong positive charge on this rod and then, just like how the stepped leader how it can cause a breakdown of the gas, only at the very tip of it. You can take a similar advantage of that on a lightning rod essentially it's a rod shaped because what will happen is off the very tip of that, is where you'll see the air breaking down. So you'll end up with tubes of ionized gas, essentially, coming off and connecting to the very tip of this metal rod. And that way when the lightning comes through that positive streamer will be moving up, connect to it and then maybe it won't have to hit your house or something like that so incidentally that's why things like golfers get hit.

Laughter.

Elizabeth: And why you were not supposed to stand under the only tree in the field.

Ben: Yeah, it's because these pointy things have really strong electric fields off the very tip of them and so they're more likely to get struck by lightning.

Elizabeth: Ahhh ha. Which would also be why things like church steeples and tall pine trees tend to get hit.

Ben: That’s right. Incidentally it's like you're starting your own stepped leader. I was telling you before how we don't know exactly how these stepped leaders get started, we don't know where the first tube of charged gas comes from. It’s, in essence what you're doing is you were starting one your self that's coming out of the ground. That one's going to go up into the sky and channel the lightning down through metal instead of through your precious belongings. But incidentally what happens is lightning sometimes hits trees as you mentioned, you can actually identify trees that have been hit by lightning. It happens a lot. What happens is sometimes the lightning will hit a tree and all of the electrons will pass through the sap of the tree. When electrons move through things they bounce off of them. There is essentially a lot of friction, what it comes down to it heats things up. It heats them up so fast that the sap in the tree can turn into gas and explode so what you see in the tree is part of the bark is exploded.

Elizabeth: I’ve seen this in my own backyard, it's a reasonably impressive.

Ben: You see these, essentially it’s little scar marks, these little holes in the bark and that's where the bark has exploded because it was hit by lightning.