Episode 15: Music From Before Time
Physicists: Michael Zemcov, Vicky Scowcroft

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 which 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!

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So, there's a kind of mystery that occurs when we look out into the universe at large scales. I've said it before and you'll hear me say it a lot, at very large scales the distribution of matter in the universe is fairly even and uniform. This is part of something called the Copernican principle which says there is no special place or center of the universe. Now, let me back up this truck. I'm going to take another shot at this explanation. I want you to imagine that your god and that you are in the process of building the initial conditions for the universe. So you've got this sheet in front of you, that's the spacetime, and you've got a big vat of cake icing that you're going to smear all over the sheet and you get to decide what the distribution of icing on the sheet is. And the deal is that after you've covered the sheet in icing the laws of physics will take over and evolve the universe from that initial set-up onwards further in time. Okay. The Copernican principle says that the universe has a distribution of icing which is perfectly uniform. So all the matter is super evenly distributed no matter where you look it has the same amount of icing, of matter. Anyway, we feel that the Copernican principle is true for two reasons. The first is that as the universe evolved it expands in a way described by a model which has complete uniformity. The second is the cosmic microwave background. We get into this a little bit more in the show but something like 13 billion years ago, the gas that filled the universe got cool enough and stopped absorbing photons and these photons have been cooling and kicking around the universe ever since and we see them as microwaves. Anyway, in any direction we look the cosmic microwave background is exactly the same in temperature, 2.725° K. That means that before it cooled, about 13.7 billion years ago, it was something like 3,000° K. But the important thing is everywhere you look it has exactly the same temperature. That means that 13.7 billion years ago the universe was super duper uniform. Anyway, that's not quite true anymore. I mean, look around you, there's a floor, there's a sky, there's a sun that we're orbiting around, it's orbiting a galaxy. Everywhere we look we see vast differences in mass concentrations. So, what, I mean, the dramatic differences in mass concentrations in the solar system and the galaxy are due to the effects of gravitational collapse. So, 10 billion years ago maybe our solar system was just a big cloud of evenly distributed uniform gas and since then all the matter collapsed down into the center to make the sun and stuff that didn't end up in the sun ended up in the planets, right? You say maybe that's the reason there's an earth and a sun and a galaxy and not just a big cloud of gas. Well, okay, you're right but there's two things wrong with that argument. First, there's the fact that for gravitational collapse to occur you need a seed of concentrated mass. You need a little region where the density is just a little bit higher than everywhere else. A perfectly uniform distribution without the seed won't have a special point to collapse down on. Now, secondly, if this were the only thing in play we'd expect a pretty even distribution of stars and galaxies in the sky. So, like every couple million light years in any direction you'd find one or two galaxies. In other words you'd expect galaxies to be distributed with a uniformity reflecting the Copernican principle. And that's not how galaxies are distributed in the universe. Actually they are distributed more like a sponge. There are big sheets of galaxies that are kind of stuck together and there are big gaping voids between them. So, there are two questions. What seeded the gravitational collapse of the universe and why aren't galaxies distributed in a uniform way? And the answer, it turns out, is pretty fun. It's sound waves. Sound waves in the early universe. Sound waves that precede the cosmic microwave background. Sound waves are the answer to both of these questions and today we're going to talk about acoustic waves in the early universe and how they seeded the large scale structure of the universe. It turns out that before there was anything there was music. You know, our show is a lot like the universe. It starts with music. Today my guest is the author of that music and thus, the god of our podcast, it's Ted Leo. Ted's a punk rocker and indy rocker and he's the front man and songwriter for his band Ted Leo and the Pharmisists. Hello Ted Leo.

Ted: Hello Ben, how are you?

Ben: I'm doing great.

Ted: I'm a little, I've, immediately been made to feel a little awkward it being suggested that I'm a god in this micro universe.

Ben: Everyone's the god to something. Like, even jerks have dogs. You know?

Ted: That's true. That's a good point. I'm going to have to reevaluate my entire, you know, cosmological hermeneutical idea of life.

Ben: So, Ted, for you today I have assembled two of my finest Titanium Physicists. Arise Dr. Michael Zemcov! Dr. Mike did his undergraduate with me at UBC and he did his PhD at Cardiff University in Wales. He's currently a senior post-doctorate fellow at Caltech working on experimental cosmology. Now arise Dr. Vicky Scowcroft! Dr. Vicky got her PhD from Liverpool John Moores in the UK. She's currently a post-doc at Carnegie Observatories where she works on the Carnegie Hubble program.

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So, why don't we start by talking about our Big Bang model for the expansion of the universe? Alright Ted Leo. Do you believe there was a Big Bang?

Ted: I do

Ben: Okay, good. Do you know anything about the Big Bang?

Ted: Ah, I know a little bit about it, yeah. In the introduction I actually was, I didn't know the origin of the Cosmic Microwave Background. I thought that that was kind of concurrent with the initial bang. I didn't realize it was, it had to do with the cooling of photons, you said? And I also didn't realize that the sound wave thing that we're going to be talking about preceded that because I thought that was a much later event. But, you know, beyond that I'm here to learn about the Big Bang.

Ben: Sweet. Well, alright, let's start talking about just general things in the Big Bang. So, the first thing you need to know about is something called the Hubble Law.

Vicky: So, the universe started off really, really small. Like tiny, the tiniest thing ever. And then there was the Big Bang and since the Big Bang it's been expanding, But it's not the stuff that's expanding, it's the space itself. Like, so, if you want to make a cake, like with raisins in it, and you pour the cake mix in the oven, the cake would expand and the raisins would all move apart from each other, and they're like the galaxies. So, that's what happens, everything is moving further away from everything else because the space itself is getting bigger.

Ben: So one question you might immediately ask is, if it's expanding then what's it expanding around. Like, are we at the center of the universe? Because when we look out we see all of these galaxies moving away from us. So it looks like we were at the center of a big explosion that shot out all these galaxies. And there's something very subtle about the way they're moving away from us. I mean, as Vicky said, technically they're not moving away from us. Technically what's happening is that the distance between us is increasing and the distance between us and far away galaxies increases at a rate that's linear with distance. So, I don't know, here's a hand wavy example. If it's a 100 million light years then it's moving 50 KM an hour, if it's 200 million light years then it's moving at 100 KM an hour, right. So, it just increases as, the size, sorry, the distance between us increases in a very simple and specific way depending only on the distance. And this very simple and specific way means that it has a mathematical trick in it which means that anywhere you look in the universe you will see all of the other galaxies moving away from you with exactly the same profile so that fits in with this Copernican idea.

Ted: Can I ask something here regarding the kind of, the cake analogy, I think that this is something that I never really thought about like this before. But, a cake, obviously, it exists in space for us as it is, it's actually got a center point from which the dough is expanding. But when you think about this in terms of the universe you almost have to think of it as just space between objects everywhere increasing.

Ben: Yeah.

Vicky: Yeah.

Ted: As opposed to the crust of the cake moving outward in some specific direction.

Ben: Yeah, so the bulk of the universe isn't expanding into anything, it's, the definition of distance is increasing almost.

Ted: Right, right.

Ben: So, if the speed of which of something that is moving away from us scales with distance then there's got to be some distance away from us that an object will be moving away from us at the speed of light. The problem with this is that in Einstein's theory of relativity the argument is that nothing can travel faster than the speed of light. And it sounds like a paradox but there's a trick and the trick is that objects in this case, it's like the raisins in the cake aren't moving in the pan, it's just that the cake itself the distances are expanding. So, it's the definition of distances that is increasing at the speed of light.

Ted: Yes.

Ben: Anyway, this is a feature of our model for an expanding universe there's always going to be a sphere around us at which objects at that sphere, they'll be moving at the speed of light, away from us. And what this means is that if anything is farther than that distance away from us, we are never going to be able to talk to them. Ah, because, there's no signal that moves faster than the speed of light and so if the distance between us and the far away objects is increasing faster than the speed of light there's no way a light signal if they shoot a laser back at us or something, there's no way that signal's going to be able to cover the distance and ever reach us again.

Ted: Right.

Ben: So, this sphere, this boundary, this distance at which things are moving away from us at the speed of light is called a horizon and it's the kind of division marker between the part of the universe we can see and interact with and the part of the universe that we can't see, can't interact with. And so the deal is that as the rate of expansion of the universe changes the radius of this ball will change. So, the faster the universe grows, the faster the rate at which this distance is increasing, the smaller this ball is going to be.

[11:52]

Ted: The faster the universe grows the smaller this what is going to be?

Ben: Oh, sorry, the smaller this horizon is going to be, the closer this horizon...

Ted: Oh, I see.

Ben: Will be to us.

Vicky: If things are moving away from you faster, the distance that you can see is going to be smaller because...

Ted: Oh, oh, oh, I understand.

Vicky: The other bits are going to be to far away for you to see anything.

Ted: Right, right. Okay. I got that. So, as like ah, as a tangible number of miles that might not change, though, theoretically, right?

Ben: So, if the rate at which the universe is increasing stays constant, so if the universe is evolving in a super steady way, then that radius of the horizon will stay the same.

Ted: Oh, ok, right.

Ben: But if the speed at which the universe is expanding changes then that horizon will shrink or grow appropriately.

Ted: Because...

Vicky: Compared to the size of the universe.

Ben: Right.

Ted: Because things beyond it will move away from you at a different pace. I got it. I'm set.

Ben: So, the horizon idea is one of the big important ideas for understanding what we're going to be telling you about how acoustic waves behave in the cosmic microwave background. So, let's take a time machine back and look at this cosmic microwave background.

Mike: Let's take the way back machine. So, we talked about energy densities and we know that the universe is filled with atoms which are certain nuclear material with electrons around them. And we have photons as well and a mix of a few other things, neutrinos and stuff but they don't matter for this picture as much. So, you're going to evolve backwards, you're getting denser and denser and hotter and hotter and we actually have experiments where we can measure this effect, we can look, you know, 6 billion years ago and say, ah, the universe was actually hotter according to the physical laws, we think it should be. Ah, which is pretty cool. It's telling us we understand that the universe is expanding in this pretty simple way. And if you keep cramming stuff together, pushing it together, what eventually happens is that as you're shrinking the universe the light that's in the universe is getting to higher and higher wavelengths and eventually it's going to start disassociating the atoms, probably mostly hydrogen because the universe is mostly made up of hydrogen. And you're going to get a situation that is not quite like the sun but is analogous to the sun where you have ions. So, that's nuclear material and electrons that are banging around, not stably bound to one another and lots of photons. Lots of light particles that are just bouncing around making sure that the electrons aren't binding to the nuclear matter and that situation is what we call plasma. You're probably familiar with that term. It's what's in fluorescent lights is a plasma, same kind of thing. The sun is made of plasma. So, once we get to the stage where the universe is a plasma we can start talking about, what were the original conditions that set-up all these patterns that we're talking about? That we can see how the early universe was.

Ben: I have this really stupid metaphor describing recombination. Mike pointed out, and rightly so, that what's going on, is actually, all of this cosmic microwave background radiation as you look back in time, so, as the universe expands, the cosmic microwave background, these photons are getting longer and longer and weaker and weaker. And so if you go back in time they get stronger and stronger and stronger until they get so strong that they can start knocking electrons off protons.

Ted: Right.

Ben: So, the metaphor is, okay, you have this early universe, pre-recombination, and the photons are all like little dogs and the electrons are like I don't know, like ladies and then the protons are like dudes and...

Laughter

Ben: And, you know, the dogs are playing with the men and women and they love barking and running around and they don't want the men and the women to get together because if the men and women get together then they get jealous and can't play.

Vicky: They have no one to play with anymore.

Ben: Right. So, it's in their best interest to keep, to be so energetic and keep those two distracted that they don't combine.

Ted: Right.

Vicky: But, eventually the dogs get stretched.

Ben: Right. Yeah, so...

Vicky: Into sausage dogs.

Ben: Eventually the dogs get old and weaker and they can't, you know, be as energetic and the two people combine and stop playing with the dogs.

Ted: Awwww.

Laughter.

Vicky: And then the dogs will die.

Ted: Poor dogs.

Ben: So the dogs that have been wondering around since the start of the universe getting older and older and weaker and weaker and no one will play with them.

Ted: Tragic.

Vicky: It's sad.

Ted: The universe is so tragic.

Ben: So, you're a musician. You know about acoustic waves right.

Ted: Yes.

Ben: Acoustic waves are pressure waves. So, as I speak they are bits of time where the air coming out of my mouth is rarified, has a slightly lower pressure and times when it has a slightly higher pressure. And that signal travels through the air like a wave and so all sound is it's a wave signal that propagates through the air where it's kind of really dense in some regions and really rarified in other regions.

Ted: I feel like most people in this day and age have seen, you know, on a computer screen, here or there, and actual depiction of a wave.

[16:49]

Ben: Yeah, I agree.

Mike: So, what happens is, in the early universe, let's just take it as given that the universe is mostly smooth but at very low levels it has density perturbations in it, it's a little more dense here, a little under dense here, and those density perturbations are sound waves. And in fact the early universe is just ringing with sound and it's ringing with sound in such a way that the dense parts and under dense parts are constantly interacting and it's going to be getting denser here and under dense here and that looks like a wave that's traveling through the plasma, basically. So, you can think of it, if you like, the matter is attracted to itself and not repulsed from itself, but it' spastically following the space. The space itself is kind of got a wave to it because of the densities and under densities. And in the early universe, as we talked about a horizon before, as the horizon is expanding, the waves, larger and larger sizes are basically coming in and you're starting to see them for the first time and it ends up that matter wants to fall into the over dense regions because it's attracting itself. And in the under dense regions it's going to go away from there because it's attracted to where there's more matter. So, I think the thing to take away here is that in the early universe there's these density perturbations and it's because of that it's analogous to sound and the whole universe is just ringing like a bell.

Ted: What's the, like, chicken and egg scenario in this, like, the sound waves are kind of following or leading in this.

Mike: Well, that's a very good question. So, it depends on how you look at it I think. So, the thing that sets it all up is that effectively where the matter lives is not distributed uniformly in the beginning.

Ted: Right.

Mike: Which is what Ben was saying in the introduction. So, that being the case, if you have a place where there is more mass, well space is actually curved there as well and so that effect basically looks like a wave and will propagate. So, I think the answer to the question is, the egg, so to speak, is that there are over densities but they are kind of coupled in this smeared geometric kind of way.

Ted: Can I ask you this, in regard to these waves that are created, then, you know, I mentioned that people, possibly familiar with what an actual, kind of, you know, drawn wave in any kind of sound editing program or whatever, might look like. It's possible to hand draw a wave and have, you know, have the sound of it reproduced, you know, whatever, through a bit of software, you know, etc. That's how you know, you carve grooves in a record and you know, sound is reproduced that way so, in regard to what we understand as human beings as sound, are these waves, the equivalent of a visual representation of the wave or is there a theoretical actual sound happening?

Mike: It's actually a sound. If we could put you in a bubble that was safe and dump you in the early universe you would hear noise and it would be, basically, white noise, maybe with a lot of base, it would be a kind of (makes sound) you know, kind of sound, right? And that's the sound of the universe. So, there's waves like you're talking about where there's a wave form, it's kind of like an ocean wave where it's going up and down and that's what we call an S wave. So that's equivalent to having somebody with a jump rope that's tied and they flick it and it just goes up and down and you can watch that wave kind of travel along and there wiggling around with, sound isn't actually like that. You can represent it that way graphically like you're talking about but physically sound is actually what we call a P wave. Think of a slinky. So, tie it to one end and stretch it out, right? And then push your arm back and forth and you get a sort of compression along the slinky and it travels along. That's what sound is. So, like Ben was saying, when I'm speaking to you my vocal cords are kind of compressing the air laterally to how it comes out of my mouth. You know what I mean?

Ted: Oh yeah.

Mike: And it's the same with an amp or you name it. That's why, a speaker, the speaker is this flat shaped thing because it's actually compressing the air, so it's a compressor of a sort. The early universe is exactly the same. It's just compression waves and they're traveling around and they're interacting with the matter. Well, they aren't interacting with the matter, in some sense they are the matter. The matter is creating them but that's all it is, it's the same as talking, it's just a different medium.

Vicky: It's like when the air presses on your ear drum and that's what you can hear. And that, it's the same thing it's just that it's pressing with photons instead.

Ted: Right, okay, I understand.

Ben: Yeah, all you need to get for this type of wave to happen is some kind of tension you know. If you imagine a box full of gas and then you make one region slightly over dense and another region slightly under dense, the gas surrounding the under dense region will want to fill in the under dense region so they'll become slightly under dense and the over dense region will want to spill it's particles out into the gas surrounding the over dense region and...

Ted: Right.

Ben: In combination because of this kind of, this effective tension, you'll end up with this waveform kind of propagating so it will end up moving forward.

Vicky: Yeah, it's, it kind of oscillates.

Ben: Yeah, yeah.

Vicky: Between the two.

[21:44]

Ben: And so, in the early universe there's a bunch of different features that effectively create this, right. There's like photon pressures, there is gravitational attraction versus the expansion of the universe. The expansion of the universe pulls things apart, gravitation attraction wants to focus things in. And so the net effect is if you have one of these waves, any wave will have a wavelength, right. If you have a wavelength that is smaller then the horizon radius, so we talked earlier about the horizon radius and the expanding universe...

Ted: Right

Ben: If your wavelength is smaller than that then your wave will just... Which one wiggles? Shoot.

Vicky: Yeah, they always will wiggle until recombination. At this point it will exist, the waves bigger than the horizon radius you won't know about.

Mike: And they don't wiggle because they have nothing... You can't...

Vicky: You can't wiggle something you don't know about.

Ted: Right.

Mike: Right. But let's say, let's say we're going to go... Exactly.

Ted: Yeah, sorry.

Mike: We're going to go back to the jump rope analogy... You're wiggling the jump rope but you're on a boat that itself is on the ocean and going up and down with very long period. If, from an outside point of view, I can see that the jump rope is, both, being flicked by both you and in addition it is moving on the ocean. But, when you're on the boat you don't know you're going on the ocean. So it's exactly that same thing but there's these large scale modes, but locally you don't know about that because that's outside where you can see.

Ben: Let's talk about what happens at recombination because that's the kicker right. So you have all these waves and if the waves are longer than this horizon they're just kind of frozen, they don't evolve. If they're smaller than it they wiggle around and so, but the early universe is full of waves and then all of the sudden all of the electrons decide to attach themselves to all of the hydrogen and helium nuclei. In effect, the thing stops being a plasma and it starts being a regular gas. And suddenly photons stop pressing against them.

Vicky: Yeah, so because the universe, all the time this has been happening the universe has been expanding, so it's been cooling at the same time. So while this has been going on, like, the protons and the electrons have so much energy they couldn't combine and they would just all be there. But right, after it's cooled they can like, stick together. But the photons could only interact with them while they're charged. So once they've stuck together the photons don't have anything to react with anymore...

Ted: Ah, okay.

Vicky: So they can just go on forever. Before you would like, the waves would propagate through the plasma. But once all the electrons and the photons recombine, it's like, there's nothing for the waves to propagate through anymore. It's like if you played a guitar in a vacuum.

Ted: Right.

Vicky: You could move the string but you wouldn't hear anything.

Ted: Right. Air is the medium that carries the pressure wave to our ears.

Vicky: Yeah, so there's no medium anymore.

Ted: Right.

Vicky: So, that means that like the wave forms formed in the matter are like frozen. So the position they were in before this happened is where they stayed.

Ted: Mmmmhmmmm

Vicky: So, yeah, that's what we call recombination.

Ben: So, you have all these waves and they're pressure waves. So you have these where there are lots of hydrogen atoms and there are regions where there are a few hydrogen atoms which were, moments ago this was a wave moving through space. All of the sudden the recombination happens and the wave stops moving and it freezes in space and suddenly, where before you had a fairly homogeneous background and nothing was going to collapse, suddenly you have these kind of these cores, these regions where it's slightly denser and these regions where it's slightly less dense. Because you have these regions where it's slightly more dense, these act as seeds for collapse and so the universe starts, all the gas in the universe starts collapsing down on these centers. And so the wavelengths of these waves determines how large the overall structures are. So, it turns out the largest wavelengths in the universe at recombination are the same length scale as...

Vicky: Superclusters.

Ben: Superclusters. So, it turns out that when we look out and we do surveys of the galaxies in the skies we see that they're groups, like the local group of galaxies, there's us and Andromeda and a couple others. So, they happen in little packets but we also see that these little packets of galaxies all kind of cling together. They're not evenly distributed out through space. And so the forms that they are all kind of grouped in together are effectively, those sound waves that...

Ted: Right.

Ben: Kind of, when the universe paused and we said, okay, sound waves stop evolving there, that slightly dense region was the core of a whole enormous area of gravitational collapse that then turned into these large scale structures.

Ted: And if the sound wave had not frozen at that point you would not have had that clustering of matter, correct?

Ben: That's right. Yeah.

Vicky: It would have been a different size, like, if you'd of...

Ted: Got it. Got it.

[26:39]

Ben: So, if the sound wave was bigger the groups of galaxies would have ended up larger if the sound waves had lower wavelengths then smaller regions would collapse down.

Ted: Mmmmhmmmm. And this might be a stupid question but what is it that holds them together now? Is that just gravity?

Ben: Yeah.

Vicky: Yeah. So, before you had like the pressure from all the photons, like, separating the particles but now that's gone all you have is gravity so it doesn't have to counteract anything anymore...

Ted: I see.

Vicky: It can just collapse.

Ted: Okay. Alright, alright, I get it!

Vicky: Yay!!

Ben: Why don't we talk about the limitations on the largest wavelength. We were saying that the largest wavelength is determined by the horizon size at recombination, right?

Mike: Well, it just has to do with the fact that in this plasma medium you have a damping effect where the sort of high frequency part of the spectrum gets damped out because on short scales you have frequent interactions and they kind of wipe out all that structure.

Ted: Right.

Mike: So, it ends up that the structure that's the biggest is the fundamental tone which is...

Ted: Literally fundamental.

Mike: Literally the fundamental, the, you know when you hit your guitar it's the first mode of that string, right?

Ted: Right.

Mike: It's so, I feel like we're at the stage now, we should maybe talk a little bit about the CMB which I'll tell real quick. As Vicky was just saying, there's a point where everything freezes out and you no longer have these acoustic oscillations anymore. What happens is, that happens approximately at the time when the energy of the photons drop below the point where they can keep, well, a proton which is the center of hydrogen and an electron apart, and what happens is that, photons, after that time can propagate freely. And, at that time, you know, 13.7 minus a little bit billion years ago, they're kind of like the wavelength of when you look at the sun. Because it's exactly the same physics of the surface of the sun. Why does the sun have a surface we can see? Well, it's because the light bangs around so much until there's a point where it can escape and go forever, right?

Ted: Mmmhmmm.

Mike: It's the same thing with the CMB but kind of reversed. So what happens is that since that time the universe has expanded by a factor of a thousand or so, at least the part we can see. So, the wavelength has gone from a micron to a millimeter. So now when we look in the basically the radio wavelengths, we can actually see the structure that's left over from the Big Bang. So, I don't know if you've every seen these, but there are images of this out there, from the, for example, the WMAP which is this thing which is this thing called the Wilkinson Anisotropy Probe that NASA put up. It's this beautiful all sky map of this sort of stippling in the microwave sky because of the Big Bang. Right, it's this sort of fingerprint. And basically the biggest, like, blobs, if you look at that image, the blobs have a sort of scale you can tell they're happening on a certain scale, it's about a degree, and that's that fundamental tone.

Ben: So, we're talking about the fundamental tone and why the fundamental tone freezes out and turns into these large scale structures we see, right? You might want to ask why a higher wavelength waves don't appear and also cause higher things. The idea here is that the only waves that propagate are the waves that are smaller than the horizon, right?

Ted: Right.

Ben: So the horizon had some radius at recombination, you know, the universe was expanding at such and such a rate at that time. And that determines that there's some largest wavelength possible wave at that time. And so that largest possible wave is the 1° wavelength that Mike was talking about seeing in the cosmic microwave background.

Ted: Mike mentioned before that some of the higher frequencies actually got damped out. Are you saying that they got damped out before the recombination?

Mike: That's right, they get damped out and you've got to think of it like you're horizon is expanding and expanding and expanding right, because light you can see can be coming further and further and further away at a given time, right?

Ted: Right.

Mike: So, what's kind of happening is as your bubble of light that you can see is getting bigger you're seeing more structure, like you're seeing more waves coming in, at that fundamental mode,
and the ones you saw before that are now small compared to you, they are getting damped away because they just kinda get messed up in in this bubble and trouble of the plasma.

Ted: Right.

Mike: So, there is this kind of constant generation of acoustic oscillations that are coming in just because that's how the initial conditions of the universe are set-up.

Ted: Right. Okay. Yeah, I do understand.

Vicky: They don't get, they don't get damped completely. They're still there but they have less power in them than the fundamental one.

Ted: Got it.

Ben: To review, there are little bits of lumps, little sound waves from the early, early universe before recombination. And the really fast ones kinda get damped out but the ones that are the length scale of the horizon kind of stick around at full strength and then the big daddy one that is the length of the horizon at the recombination is the one that seeds all of the large scale structure in the universe.

[31:54]

Alright. That's the show. Thank you Mike, thank you Vicky. You have pleased me. Your efforts have born fruit and that fruit is sweet. Here is some fruit. Vicky, here's an over ripe pear, the loudest of the fruits.

Vicky: (very loud munching sound)

Ben: Nice.

Vicky: Thank you.

Laughter.

Ben: Very good. And Mike, here's a potato for you.

Mike: Um, crunch?

Ben: Good work. Alright, I'd like to thank my guest, Ted Leo. Ted, thank you for coming on.

Ted: You're welcome. Do I not get a fruit?

Ben: No, you don't get... Your fruit is the...

Ted: What a ripoff man!

Ben: Here you go, it's a watermelon.

Ted: Oh, well, I'm going to have to put that aside so I can cut into it later.

Ben: Alright, thank you very much Ted, I hope you had fun.

Ted: You're welcome. I had a blast, thank you.

Ben: Alright. So, my fans, my Ti-Phyters, if you want to email us you can email us at barn@titaniumphysics.com or you can follow us on Twitter at @titaniumphysics. You can visit our website at www.titaniumphysics.com or you can look for us on Facebook. If you have a question you would like my Titanium Physicists to address email your questions to tiphyter@titatiumphysics.com and if you are a physicist and would like to become one of my Titanium Physicists email physics@titaniumphysics.com we're always recruiting. If you have an iPod or an iPad try subscribing to our show on the iTunes Store. If you've got a Zune or a Blackberry you can subscribe to our show on those doodads as well. If you like the show and would like other people to discover it please consider leaving an iTunes review. The more of us that give us good reviews the more people will see us because we'll be on the main page. If you'd rather listen to our show automatically through an app the Titanium Physicists Podcast is on Stitcher. So, download the Stitcher App and you can listen to us on the Android or the Kindle or the iPhone or whatever you want and you won't have to deal with iTunes. So, the Titanium Physicist podcast is a member of the BrachioMedia. If you've enjoyed our show you might also enjoy Science Sort Of or the Weekly Weinersmith, please 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.

[34:57]

Ted: Can I ask you a question. I think, you know, something that I don't quite have the best grasp on that I know is an aspect of the Big Bang and the expansion that I think is not, maybe general layman's knowledge, is the fact that because of gravity it actually started as a much slower expansion and is increasing in speed as things move farther away from each other and therefore, you know, gravity has less of an effect.

Ben: Are you asking about how the universe is accelerating in it's expansion?

Ted: Yes! Exactly.

Ben: Okay. So, the distance between all these objects in the universe is increasing at a rate that depends on the density of matter. So, it depends on the matter distribution and it also, it depends on what kind of matter it is because as the universe expands out it also kind of stretches the matter. And what this means is that as it expands the matter changes it's form a little bit. So, there was a time when the universe was a plasma so it was kind of hot like the sun and all the electrons weren't bound to protons and as it expands out the nature of the matter changes. As it gets cooler and cooler. And what we've noticed is in the kind of modern era of expansion is there seems to be another type of matter.

Ted: Right.

Ben: Nobody's sure what it is that's causing the universe to accelerate in it's expansion. And what this matter is kind of doing is, normal matter gets more diffuse as you stretch it. So if you imagine like a, bread dough, you stretch it out and it becomes thinner. Somehow this matter that we're dealing with, as you stretch it out it doesn't decrease in energy density. So, as you stretch out this particular matter that we're just discovering, somehow it gets more gravitationally potent.

Ted: You mean alongside the normal matter that we do understand which is getting stretched. So, that's what, kind of in a way, then explains the Copernican Principle of uniform distribution.

Ben: Oh, um... Well the

Ted: As well as the... I'm sorry, I'm jumping a little...

Ben: No, that's a good question. Um, so the uniform distribution Copernican thing is, uh is one specific issue. It kind of has to do with the really, really early state of the universe. And it's kind of a hypothesis that lots of people are working on and testing different ideas out on. But, independently of this accelerating expansion, the deal is that as the regular matter in the universe get's more and more stretched out, gets more and more diffuse, this other type of matter is becoming more and more gravitationally important.

Ted: I see.

Ben: So, it's becoming the more dominant in determining the dynamics of the universe's behavior.

Ted: And that change occurs in some sort of constant ratio between the two kinds of matter.

Ben: Yeah, right, so one type of matter is becoming more diffuse and the other type of matter isn't decreasing at all.

Ted: Oh, oh, okay, I see. I see. Got it!

Ben: Right. And so that other type of matter is what's causing the universe to accelerate and it turns out that that particular effect, the acceleration of the universe doesn't really have all that much to do with the cosmic microwave background. It affects the evolution in fairly subtle ways. Doesn't it Mike?

Mike: How this mostly effects the CMB is what we call flatness. So, that's saying that the energy density of the universe, that is, how much energy is there in a volume in the universe. And we're physicists, so we measure energy both by mass, right, by $E=MC^2$. And by the energy of that mass and other forms of energy, photons and things like that, stuff bouncing around. So, anyway, the point is that the energy in a volume is enough that the universe is flat. Which is to say that on large scales the metric doesn't have any curvature which is a way of saying that if you fire a laser, say, across the universe, it's going to go in a straight line. And it's not going to deviate in some funny way, that has to do with how space is actually curving.

Ben: Hold on, if you fire two lasers parallel to each other, right next to each other...

Mike: That's right.

Ben: They'll stay parallel. If it's curved in one way they'll end up getting skewed toward as each other. If it's curved in the other way they'll end up skewing apart.

Mike: Perfect. The ramification of that is that we're just talking about how the universe is expanding so one of the important implications of this is that at some infinite point in the future the universe is going to, what we call asymptotically stop, which means it's going to expand slower and slower and slower and slower and slower and eventually it's going to keep expanding forever but at such a small rate that it doesn't change.

Ted: Wow.

Mike: That's going to happen, you know, essentially far into the future but that's an important ramification of what is this flat and smooth. And so, ah, the cosmic microwave background is a way to measure what is the energy density of the universe just at the very beginning and that tells us that the universe is flat so it is a constraint on this dark energy that Ben was telling you about. It's saying that this dark energy has to make up a certain fraction of the budget of the energy of the universe.

Ted: Mmmhhmmm. That's like, derived, mathematically because, it's a variable that needs to be there to like complete the other equation?

Mike: So, it's not only mathematical, but more importantly, it's measured.

Ted: Ah, okay.

[40:30]

Ted: Can I ask a quick side question?

Ben: Go ahead.

Ted: Do we conceive that the components of atoms and the, you know, everything from like the neutrinos and positrons and electrons and all that, are they broken down at all any further in anybody's conception?

Mike: If you keep pushing this model back you're going to keep making things more compressed, more energetic, it's going to start banging together even harder and if you push it back a long way, say to 10 minutes, I forget what the number is off the top of my head, but very soon after the Big Bang, you can actually start breaking these nucleons apart.

Ted: Right.

Mike: And you start making really funky stuff which you've probably heard of, quarks, that sort of thing.

Ted: Yeah.

Mike: And if you push that back even further you might even get to a situation where, I don't know if you've heard of it, it's been this big thing, at higher and higher energies, physics theories start looking like one another and we have four forces in nature and it ends up that smarter people than me have figured out how to unify three of them. That is, you can basically start massaging them and pushing the math to start looking like the other theory and basically you come up that they can make three look the same at very high energies which makes us think at very high energies that there's really only one sort of overarching way that physics works. And then if you push it back to even higher energies that I don't think we'll talk about today, you can start putting the fourth one in which is gravity, which we don't know how to do yet. That's at the very forefront of what physics is about right now. But, yeah, if you keep pushing it back you're going to start banging stuff together even harder and it's like, what's the analogy I've heard, you know you can throw bowling balls at, you know, melons and smash the melon and you see what comes out but eventually you're going to get to energies where you start smashing bowling balls together to see what they're made of.

Ted: Is this the fabled Higgs Boson?

Ben: The argument is that there's this weird field, it's kind of like the electromagnetic field and it has this weird property that it's lowest energy is when it has mass for some reason. So the argument is that at some time in the universe, the universe gets cool enough and it's still a really hot temperature where suddenly it will go from not having any mass to having mass, effectively. And if it has mass it will give everything else in the universe mass so there's arguably a time in the early universe where this Higgs mechanism, where everything stops having mass... Essentially it's like the testing ground for theory. There's a big, there's a big dotted line in the Big Bang models and under that dotted line it says here be monsters because Einstein's theory of gravity breaks down at energies higher than that. There's a contradiction in the theory if you let things evolve to the singularity. The argument is that the theory of gravity must change at super, super high energies but nobody knows what's down there.

[43:20]

Mike: Ted, here's like a lame fact that always gets trotted out during these discussions of the CMB. Did you know if you tune your tv to static which you can't even do anymore because nobody has antennas.

Ben: I know, I had to cut that from the interview.

Mike: If you tune your tv to between channels, 1 in 400 of the dots you see is because of a CMB light particle.

Ted: Oh, that's a...

Mike: Is the statistic.

Ted: I didn't know that, I didn't know that it was only 1 in 400 because like I thought that the conventional wisdom was like yeah you know that's the Big Bang you're looking at right there.

Vicky: Well, some of it is.

Mike: Some of...

Ted: Yeah, 1 in 400 I guess.

Mike: But I always laugh at this because it's such like, a fuddyduddy thing, like who has a tv that can tune between channels anymore.

Ted: That's a really good point, yeah. I mean, I'm old enough to remember that but like, yeah, a lot of people aren't.

Ben: You have to go into the countryside where there aren't many tv broadcasting and you just go put it on channel 3.

Ted: Well, it's the same for radio too, right? I mean, the static, the sound of static between, you know, between stations would be also be a representation of that, no?

Mike: Exactly, you're picking up the same stuff. That's right. But I like radio too because you can hear thunderstorms that are far away but that's...

Ben: What do they sound like?

Mike: It's just bursts of static.

Ben: Oh.

Mike: But you can, it depends on where the ionosphere is but you can hear them all the way down in Ecuador and stuff like that.

Ben: Wow.

Ted: I didn't know that.

[44:52]

Mike: You have to do another one where you describe why anybody would care about any of this stuff.

Laughter

Vicky: Because it makes galaxies!!

Ben: Cool, it makes galaxies!! Do you want to talk about...

Mike: Well it does more than that, right? I mean, it lets you measure what's, in some sense, what's the mass of the universe. It let's you measure, what's the universe made of, it's a baby picture of, what's all the junk of the universe that's going to end up becoming, you know, galaxies and stars and us. And ah...

Ted: And let me ask, what does is it do in terms of projection. You know, for the future across spacetime with these waves?

Vicky: Well, it can tell us what the, what the universe is made up of. So if you look at, like this, the spectrum of these waves...

Ted: Mmmmhmmmm

Vicky: You can work out, like, how much is made up of normal matter and how much is made up of dark matter and dark energy. So then you can put that into a model to predict what's going to happen.

Ted: Right, right. Yeah.

Mike: So, that's another show..

Laughter.

Ben: What, another show on why the cosmic microwave background is interesting?

Mike: Yeah, I, I mean we, we've kind of discussed the, you know, what the wave's mean and everything but I feel like Ted's like okay great but so, what? Is there...

Ted: No, no, no...

Mike: Actual physics you can get out of this, right.

Ted: I mean, I, I find it interesting, you know, just kind of without, without immediate tangible benefits. To be honest with you.

Laughter.

Ted: But that could just be me.

Ben: Listen, Mike, okay, so there were sound waves at the start of the universe and those turned into galaxies.

Vicky: Yeah, that's the...

Ben: That's insane!!!

Ted: I guess that's why it's important.

Vicky: ... The point we need to take away.

Ben: ... So interesting!!

Mike: Yeah, I, I've done this for awhile so I think that the cooler part is we can measure, um, sorry Ted this might go over...

Ted: No, no.

Mike: This might be jargony but we can measure, we can measure in principle the parameters of inflation. I mean, if you want to get into god's head that's the closest thing you can do. I'm not a religious person but you know what I mean, like...

Ted: Right.

Mike: It's, it's it's, the very first stuff. So forget galaxies. To me galaxies are a solved problem, like you know, they're just a mess of hydrogen that you can smash together.

Vicky: But galaxies contain interesting things. But, they, like...

Mike: Sure. But cosmology is the study of the universe on the largest scales, I mean...

Ted: Right.

Mike: Among other things but, so, so we're you know, the CMB is a way to get the big picture.

Vicky: But without the large scale structure there wouldn't be any galaxies so there wouldn't be any people so we wouldn't be able to think about inflation.

Ben: That's right.

Mike: I, I, I'm not trying to say it's not important. I'm trying to say that we can ask questions we can't get at with any other tool, right now.

Ted: It is the big cosmological aspect of it that is the most interesting to me and um, you know, I mean...

Laughter.

Ted: As somebody who spends his life, you know, deeply involved with music and being constantly, you know, moved by it, it's just really, really interesting to think of sound, you know, it being such a fundamental factor in the literal makeup of the galaxies in the universe.

Ben: Yeah Mike.