Episode 31: Pushing Mirrors
Physicists: Tia Miceli, Mike Zemcov

Transcribed by Denny Henke

Ben: Oh. Hello old friend, it's good to see you. Let's talk about this word fascination. It describes an unquenchable urge which compels our hearts to quest and be captivated. As long as there are elegant explanations to complicated phenomena science will never lose its romance. Over the years I've traveled the world indulging in my fascination with physics and now I find that a new hunger has woken within me a fiery need to share these great ideas with the people around me so I have assembled a team of some of the greatest most lucid most creative minds I 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]

Ben: I'm going to start this show by presenting you with a mystery. So, if you take two mirrors and you push them close together they'll feel a force pulling them together. It's not gravity, it's something else. And you can do it in an isolated vacuum so you can put it in a vacuum chamber and suck out all the air so there isn't anything, no wind, no sound waves, even in a vacuum these two mirrors will still get sucked together. It's called the Casimir Effect. It's named after the physicist Hendrick Casimir in 1948 who predicted it would happen. Oh, yeah, so what's happening? It's kind of like if you have two ships, big ocean liners, side by side at sea, so there's going to be waves bumping into the ships from all sides except for the side that's facing the other ship. So, there won't be as many waves between the two ships and as a result the waves hitting the opposite sides will end up pushing the two ships together. It's kind of like that in our mirror sandwich except that there isn't any water and there isn't any waves. It's just a vacuum. So, somehow, there's more vacuum, more nothing, outside this mirror sandwich than there is inside it. And it's this difference in the vacuum that's pushing the mirrors together. So, today, we're going to talk about vacuum energy and the Casimir Effect. So, the fundamental thing about pushing these mirrors involves, kind of, that we put them in. Who can sort out all the details? Megan Harns works for UC Davis as an environmental education programs coordinator. She teaches kids about the environment. She's a friend of Tia's and she's been wrangling physicists since she was a freshman. I know of no better person who can help us sort out all the details, Megan, welcome to our show.

Megan: Great, thank you very much for having me Ben.

Ben: Alright, so for you today I've assembled two wonderful Titanium Physicists. Arise Dr. Michael Zemcov! Dr. Mike did his undergraduate degree at UBC with me, he did his PHD at Cardiff University in Wales and he's currently a senior post doctoral fellow at Caltech working on experimental Cosmology. Now, arise Tia Miceli, Tia is a graduate student at the University of California at Davis where she studies high energy experimental particle physics and she's writing her thesis on extra dimensions. Alright, so, let's start talking about the vacuum.

Tia: You know what, actually it was sort of strange because I was at my storage unit a couple of days ago and had a close encounter of the Bernoulli's principle kind and just sort of struck me as maybe analogous, kinda got my brain thinking in the same way.

Megan: Wait, which one is Bernoulli's principle?

Tia: Yeah, so the classic experiment that was used to introduce me to Bernoulli's principle was, you have two ping pong balls taped from a thread or string, the same distance apart but you use a straw to blow a stream of air in between the two balls and you see them actually drawn towards each other because the air going in between the two balls is faster than the airspeed on the outside of the two balls and the difference in pressure sort of sucks them together a little bit.

Ben: Yeah, actually, it's fairly insightful because what's going on is in the Bernoulli Principle you have your two ping pong balls and you're blowing air between them. Let's describe it in terms of a ping pong ball sandwich, ok? So, the jam area is the part in between the ping pong balls and then the bread area is the part on the outside, ok? Just to help us imagine.

Megan: Sounds good.

Ben: So, there's pressure in both parts there's a pressure coming from the air one atmosphere of pressure pushing on this bread side of the ping pong balls and then in the jammy part of the ping pong balls there's also some air pressure. Now, because the air is moving when you're blowing through your straw the air pressure between the ping pong balls is going to be lower than the atmospheric pressure and so essentially the ping pong balls end up comparing the pressure in the middle of the sandwich to the pressure on the outside, on the bread part of the sandwich and the fact that there's a difference between the two pressures pushes them towards each other. Your insight is absolutely correct. So, what happens in the Casimir effect is, there is a vacuum and the vacuum has an energy and the energy exerts kind of a pressure, there's a pressure between the mirrors exerted by the vacuum and there's a pressure on the outside on the bread side of the mirrors except that the pressure on the bread side of the mirrors is larger than the pressure in between the mirrors and this effectively sets up the net force pushing the two mirrors together. It's analogously the same, the only difference is where the pressure's coming from and the reason why there's lower pressure on the sandwhichy bit than there is on the bready bit.

Megan: Yeah, because in the Casimir mirror example we're missing an agent that's sort of lowering the pressure in between the mirrors in the same way that the stream of air lowers the pressure in between the ping pong balls so I guess my question is why is the vacuum pressure lower in between the two mirrors in the Casimir mirror example than on the outside.

[6:49]

Ben: That's a wonderful question and to answer that we need to start talking about what the vacuum is. So, when we say vacuum we usually mean nothing, right?

Megan: You sort of get that impression so you wonder how can energy you know, exist in a vacuum or how can a vacuum have a force.

Ben: And the answer actually involves a set of arguments that come from quantum mechanics so to start talking about vacuum we have to start talking about particles. How particles behave was the historical origin for all quantum mechanics.

Tia: We're going to build up to the explanation of what constitutes a vacuum. It's not actually nothing with a capital N, but there's actually exciting stuff going on in there. So, to start out, if you imagine a particle in a box, and you lower that temperature and you try to get as close absolute zero as you possibly can that particle will still have motion because Heisenberg's uncertainty principle you can't know its position and its momentum at the same time so if the particle were to stop moving you would know that its momentum is zero and you would know both.

Megan: You would know both and the world would explode.

Tia: So, we can't have that. So, in actuality this particle is still moving in the box, so the probability of finding this particle anywhere in the box is represented as the particle's wave function. This wave function is a mathematical expression of the field of the particle. So, all particles are just perturbations of this field. If I look in the box and I see it at one place I collapsed that probability wave to one little spike and that's the particle. So particles behave like particles and they behave like waves.

[8:47]

Ben: So, we call this the wave particle duality. So, the deal is that in classical physics, you know, back, powdered wig days when everybody was holding candelabras and looking at experiments with billiard balls they'd say that well, you can have energy and motion as a wave, so like, waves on a pond or in a tank of water or something, or sound waves, or you can have these particle things which look like billiard balls and they fly around and they bounce off each other and what quantum mechanics discovered in the early twentieth century, is that if you're going to describe the physics of these objects neither and both mathematical models describe how actual particles or actual waves end up evolving. What quantum mechanics eventually becomes is it becomes a mathematical way to describe the motion of these particles, the evolution of these particles as they move through space, in terms of the evolution of one of these probability cloud distributions. So, the probability cloud distribution thing doesn't really matter all that much for our explanation of the Casimir effect but one interesting aspect of it is, the deal is that we can talk about the energy of the particle either in terms of the particle moving around, but we can also describe its energy in terms of the energy we can extract from the system. So every time it bounces off near the end of one of the boxes we steal a little bit of energy. According to this picture, there's a point past which you can't steal any more energy from the particle, okay, once we extract all the possible kinetic energy from it, it's till moving around in the box. We call that energy the ground state of the particle. Ground because it's on the ground, so it's like a ball, right, if I hold a ball in the air it will have some potential energy from gravity and if it's on the ground it's got no potential energy left. I've extracted all the possible energy I can once the ball weight is on the ground. So, the particle in the box, it will have a ground state, it will have a state past which we can't extract anymore energy from it but it will still be moving, it'll still have a little bit of energy to call its own. It's kind of like a bank account I guess, you know how some banks won't let you extract all the money from a bank account, you need to keep you know, a hundred dollars in the bank account or they get really mad and start fining you

Megan: I know that all too well.

Ben: A particle in a box will have some basic amount of money in it, just like the money in the bank account that you can't extract money past it, it will always have a little bit of energy set aside that you won't be able to withdraw.

Mike: So, the place we're trying to go next, Megan, so, there's this complicated term which is a quantum field which is kind of the underlying structure of how these quantumy things exist and get to propagate around. So, one of the things to keep in your mind is that when Ben's talking about zero point energy and particles and all this other stuff that kind of lives on a background and the background it lives on you can think about as a sheet of balls connected with springs and basically what happens is that individual particles are little waves in this sheet of these oscillators which are just these balls connected by springs so if you think like, a table sized one, I could flick it in the corner and that would propagate across the thing. So, the different particles are different excitations of that sheet and then the thing that maps a quantum field to what Ben was just talking about, which is the zero point energy of something, is that this background, it's never still, because of the zero point oscillations, each of these little balls is kind of wiggling around and so the whole sheet has kind of got this like energy to it that it's just kind of bouncing around all the time and that wiggling that the sheet of balls and springs is doing is an energy, you can calculate how much energy would be associated with that system so that's what we're going, thats where we're trying to go with this whole thing, is that there's this background that all these things live on that has an energy to it.

Tia: That sheet is just one of the quantum fields, I mean, there's a quantum field for the electron, for the muon, there's a photonic field, there's one for up quark…

Megan: So, my understanding is that the background for quantum particles is sort of in a sheet and the sheet is not composed of things that are necessarily woven together but these balls, or particles, that are connected in a flexible way to each other and their state or their position is going to be relative to how much energy in a wave has been put through that background sheet, but that the background sheet itself is never entirely still because there's always that ground state of energy and that can be measured but that it can also be, I think as Mike said, perturbed, or changed with energy inputs into the system and the spikes are the resulting position or momentum of the particle that you're looking at in particular in that area of the sheet. Am I on the right track?

Mike: perfect.

[14:02]

Ben: Um, okay. Let's talk about electromagnetic fields. You know what light is right? It's a wave in the electromagnetic field.

Megan: Oh, I don't know, we've had plenty of discussions and arguments about what is light. But, for the sake of argument, yes.

Ben: No no, what have you taken away from… can you summarize what you know?

Megan: My understanding is pretty simplistic but, while visible light is in a certain spectrum wavelengths of energy between such and such a frequency that we can see but that there's plenty of other kinds of energy that we can't see without the aid of technology. We can have infrared light, ultraviolet light, microwave light, light is just sort of a term that we use colloquially to refer to this kind of range of different frequencies that can be picked up by different kind of technologies or the human eye so when you're talking about the electromagnetic spectrum you're talking not just about visible light but the other ranges of light or energy that we just can't see with the human eye.

Ben: Correct

Megan: And I've got to put in my plug for environmental science here. Plants of course are very interested in certain wavelengths of light so that they can prefer photosynthesis, they need a snack, so I get to talk a little but not in as much detail as I think we're going to be getting into in just a minute.

Ben: Right, well, okay, so energy is a really crazy thing in this Universe. We were talking about packets of energy here and there and extractable energy and the deal is that energy can live in a variety of forms so you could have it in terms of mass like a weight that has some mass and you can also have it in terms of a wave. Imagine you have a balloon, you rub it on your head, you charge it with electric charge, right? That electric charge interacts with other electric charges through something we call the electric field. So, if I have a positive charge it will push against another positive charge and if I have a negative charge nearby it will be attracted to those positive charges and then there's a related field called the magnetic field. I'm sure you remember from when you were a kid and you do these fun science experiments, you take a magnet and you put it down under a piece of glass or paper and you scatter wire and filings around, they rearrange themselves on the page in loopy, magnetic field…

Megan: Interestingly enough I read an article that cows seem to orient themselves along the electromagnetic field lines of the Earth which can be perturbed if they are next to high energy power lines.

Ben: Oh really

Megan: So, evidently cows are analogous to iron shavings.

Ben: That's great! So, the deal is, if I take a charged up balloon, so, my balloon is covered in positive charge and then I wave the balloon around in the air I end up distorting the electric field the same way as if I stood in the water and moved my hands around I'd be distorting the surface of the water and waves in the electromagnetic field will carry energy away from me waving me around, so anytime I make some motion with my charged balloon it's going to generate waves in the electromagnetic field just like ripples of water on the surface of the lake. And these waves, in the electromagnetic field are, what we colloquially call light. So, all light, classically, is just this information about a disturbance in the electromagnetic field and here's the really crazy part. So, you've heard of a photon. Photons are just particles of light, have you heard that?

Megan: Yeah

Ben: So, the deal with quantum mechanics is we had a very good understanding of what light was in terms of waves, quantum mechanics said, oh, well, you know what? These waves are actually just little particles of light so, instead of imagining a great big sheet flapping around in the wind you imagine little particles running across the sheet and somehow the wave particle duality of the system allows for electromagnetic waves to act both as photons, little particles, and as wavy disturbances.

Tia: No no, I take issue. The particles are not like little marbles going around on the sheet, what the particle is is actually if you were to shake that sheet really hard, fast like up and down and you create a very short, kind of pulse, that pulse in the sheet would be your particle.

Megan: Is your particle independent of the fabric of the sheet or no?

[18:33]

Tia: It's made up of it.

Mike: It's a coherent disturbance in the sheet. Sorry, that sounded really physicsy, sorry.

Ben: Yeah

Tia: That did sound really physicsy.

Laughter.

Megan: I guess something it sorta reminds me of is my understanding about how waves happen in the ocean and that you know you've got this disturbance in the force, but that a wave actually isn't taking ah one collection of ocean water molecules and crashing it out on the beach until the very, very end, but actually they just sort of oscillate up and down, more or less in place and it's the energy of the wave that is carried through and sort of bumps these ocean molecules up or down but that until the wave breaks up on the shore the particles themselves aren't actually moving all that much. The molecules stay, more or less, in the same space.

Tia: Yeah, so, with the ocean wave example, the particle isn't actually the molecules of water, the particle would be the wave, the actual wave that's traveling. And, the medium that it's traveling in, the water, that's the field. So, the particle is actually that disturbance traveling.

Megan: So, when we're talking about the mirror example that it exists in a vacuum, you know, as Tia pointed out, a vacuum doesn't mean that there's nothing with a Capital N inside, so the waves or the energy they're pushing against, the outside edges of the mirrors, or the bread of the mirror sandwich if you will, what sort of particle or background sheet, what's the label we're talking about, are we talking about electromagnetic energy, what kind of sheet are we looking at?

Tia: Yeah, so that's a good question. So, it's all particle fields. Electromagnetic, electron, up quarks, down quarks, muons, tauons, there's a field for each of those and so on the outsides of the two mirrors, on the bread side, each one of these fields can have any range of wavelengths. Like you were talking about how electromagnetic light can be in the visible spectrum or the microwave spectrum or the x-ray or all them can be present and contributing to the push that the mirrors are feeling on the outside, on the bread side of the sandwich.

Megan: Yeah, so these waves are existing and can go through and effect things in a vacuum. What the heck is a vacuum? What's missing?

Ben: So, it's like this. Imagine yourself with a guitar string, ok, out in front of you you've got your guitar. Different wavelengths are possible on the guitar string, right, depending on how long your string is. So, each guitar string is about a meter long, so you can get one wave on it, one sound wave where its wavelength is two meters long. And then there's another wave where the wavelength is one meter long and then there's another wavelength where the wavelength is a half a meter long and it goes up and down twice over the course of the guitar string, ok?

Megan: Okay.

Tia: That gives you different musical overtones.

Ben: Yeah. So, higher and higher notes correspond to shorter and shorter wavelength. So, if this is a quantum mechanical guitar string, something fantastic happens. I mentioned before the wave particle duality to this, the idea here is that every possible wavelength on the guitar string acts like a particle. Talk about all the different possible waves that are excitable, all the different possible modes that are possible on the guitar string and then each mode is going to have its own ground state component and then if all the different modes are in their ground state, we call that the vacuum and that's the definition for the vacuum that we're going to use.

Megan: hmmmmm. So, if I haven't actually plucked any of the guitar strings but they're just sitting there kind of at their natural energy state that's a vacuum.

Ben: Yeah, that's right. If it's a quantum mechanical guitar string each of the modes are vibrating, they're just vibrating in their lowest energy state. So, the deal is by plucking the guitar I increase some particular mode's energy state and I give that mode a little bit more energy but at it's heart I haven't plucked the guitar string in a long time and so the guitar string is in its lowest possible energy state. If it's a quantum mechanical guitar string every possible mode is then in its ground state so every possible mode has a little bit of energy belonging to it, okay?

Megan: Sounds good.

[22:55]

Ben: So, the deal is that, of course, a quantum mechanical field isn't a guitar string like a great big cube of jello, ok, you can still make it wiggle, you can still put waves through it, so every possible quantum mechanical field, so electromagnetic waves, electron waves, you can break down the number of different waves moving through your block of jello in terms of individual, excited modes and then if you do, if you cool down your cube of jello, each of those possible wavelengths will still have a bit of motion to it. And that motion is, it's called the vacuum energy, but the state it's in is called the vacuum.

Megan: Basically what I got is that, you know if reality is a block of jello, that you know, if you're adding energy to it and waves are moving through it, you can describe the waves as kind of, you know, the relative strength of maybe, the component parts. So, whether it's got a high energy component in the electromagnetic spectrum or a high energy component from, you know, a gravity wave, whatever kind of waves are going through its either, it can all be described… the block of jello is cooled down enough and doesn't appear to be moving very much, that you would describe all the different kinds of waves that could be going through it as being at their ground state. They're not zero because as talked about earlier, if they were all at zero we would know their position and momentum of the different particles and again, we can't know that, so, ah, if its cooled down enough that block of jello will be at it's most minimum disturbance because the waves passing through it will be at the smallest amount of energy they can possibly have.

Ben: Wonderful. Okay, so, now lets talk about what happens if you have two mirrors that get smushed together. Okay, so mirrors are reflecty, right, light can't pass through a mirror, it always gets reflected by one, okay. So, if you have two mirrors and you put them together it reduces the number of possible different wavelengths of light you can have between the mirrors so if your mirrors are a foot apart you can't an electromagnetic wave going between the two mirrors that's longer than that one foot apart.

Mike: It's like Ben's guitar string where you can't play a note that's deeper than the length of the string.

Megan: So the amount of energy that can be passed back and forth between the mirrors is constrained by the distance between them, similar to the length of the string in the guitar example is the constraint on what the maximum and minimum energy of the, of what the wavelength is going to be.

Ben: It's an interesting point that you're making here. We're talking about energy so, you can actually pack as much energy between the two mirrors as you want, you just refine to what colors the light can be in.

Mike: Remember how you were talking about how there's optical light like green that plants can see, and there's red light you know and there's blue light and if you go to longer and longer or shorter and shorter wavelengths you go into the ultraviolet and the x-ray in one direction and] the other direction you go in to the infrared and radio, right? So…

Megan: Right

Mike: The point is that with the mirrors is that there's no maximum, right? Cause you can have an arbitrarily high frequency between some space things right, what you can't have is the long wavelength like we're talking about with the guitar string. So, as you bring these things closer together, you know, you start excluding wavelengths that are in the radio and then you come through the microwave and then the infrared and so on and so forth, closer and closer together, So, you basically start at the very lowest energies and as you bring the mirrors closer together you're excluding higher and higher energies which means bluer and bluer colors.

[26:42]

Ben: In terms of energy there are now two different things we can talk about, we can talk about say, how bright the light is between them and we can still make the light as bright as we want but we're stuck. We're confined to waves that have a shorter wavelength than the distance between the mirrors. So, this makes a really big difference when we cool down the electromagnetic field between the mirrors, down to it's vacuum state. So, the deal is that, between the plates, I'm still not allowed to have red excited light you know, long wavelength light, but beyond the mirrors I'm allowed to have as long wavelength as I want and so the region between the two fields, because it doesn't have all those ground states, for the deep, long wavelength light in between the mirrors, there's going to be less vacuum energy between the two mirrors than there will be outside it. And so, in essence, that's what's causing the difference in pressure even though the system is in a vacuum, even though there aren't any photons wandering around in this system, the fact that I've excluded the possibility of having deep, long wavelength photons between the two mirrors, causes the vacuum energy outside the mirrors to be much greater than between the mirrors and that's what pushes them together.

Megan: You know, we've been talking about getting the mirrors closer and closer together in a vacuum to exclude the long wavelength energy from being bounced back and forth in between the mirrors. So, at what point can you distance the mirrors, or spread them apart enough, can you have that effect be equalized so that they aren't being drawn closer to each other or is the nature of the vacuum such that no matter how far apart the mirrors go they will still always have less energy in between them than on the outside and will always, consequently, be pushed together.

Tia: Well I've read that it starts to turn on around 10 nanometers but I'm sure it depends on what the material is made out of and how smooth the surface is.

Mike: But that's an experimental thing. Theoretically, anytime you have mirrors that are facing each other you're going to be excluding some of the modes and you know, get this effect. So, maybe the thing to think about is Ben's initial example of the two ships on the ocean and if the ships are really long then you've got really quiet water in between. If the ships very short then you're letting more, just of the random stuff in and the mirror isn't working nearly as well anymore. So, the problem that Tia is talking about is that, basically, our ships are very short in the lab and so, you have to get really close together before you can actually start seeing these effects because if you pull them apart further things start getting swamped by just other stuff.

Ben: To put it in a different way, we're excluding wavelengths as we get the mirrors closer and closer together but the really long wavelengths don't have much energy to the so if the mirrors are fairly far apart the force pushing them together is going to be really, really small because the wavelengths that you're excluding don't have much energy. So, the deal is, the closer the mirrors get to each other the more wavelengths we'll be excluding and the larger the difference between the vacuum between the mirrors and the vacuum outside the sandwich will be, to the point where I think you can start really feeling it around 100 nanometers when they're close together, but then if you get the two mirrors really, really, really, really close together what happens is, essentially, any mirror that we deal with is going to be made of atoms so if you put these two mirrors close enough together the little bumps and the fact that it's made up of atoms will start to dominate the overall effect and the Casimir force will kind of switch off. Well, it will actually cause them to stick together sometimes but the moral of the story is there's kind of range where you can really get a good measurement of the Casimir effect and when they do experiments they find that the pressure exerted by the vacuum is exactly the force that you calculated using this picture of different vacuum states outside and between the mirrors.

Mike: So, there's also an interesting thing which is that you can imagine other geometries where actually you're kind of enhancing the modes in between and it actually makes the two things be repulsed from each other. The point is that you're gauging the energy density between the two mirrors and so that is just a pressure like you were talking about the Bernoulli effect at the beginning. It's very analogous to that.

[31:18]

Ben: The Casimir effect has some ridiculous consequences. So, for one, this picture that we've painted is fairly straight forward, right? Any possible wave that I could excite has a ground state and all of those ground states contribute to the overall energy of the system. Now in quantum mechanics we don't care about that all we really care about is the energy that is accessible from the system so we care about how much energy I can put in and how much I can take out and once the system is in it's vacuum state I can't take anymore energy out so even though there's an infinite number of possible ways I could excite so there's an infinite possible vacuum energy, but here's the thing: gravity. So, gravity works in a fairly straight forward way. If something has mass it causes gravity, right?

Megan: Right

Ben: So, question. Shouldn't the universe have an infinite mass if I can excite an infinite different possible number of waves, why isn't the universe really, really heavy? They did this calculation, so they said, well maybe all possible wavelengths aren't possible, maybe wavelengths can only get so small but even in that case they ended up with a ridiculous number. They said that the universe on average should weigh something like 10^{60} grams/cm^3 so, 10^{60} that's a ridiculous number, that's like, have you heard of a google?

Megan: Yes and besides the search engine. A million millions if I'm not mistaken.

Ben: A million millions, right. Theoretically, using this calculation, there's a number describing how much the Universe should weigh and we've tested it astronomically. We've looked using telescopes and our theory for gravity and we know how much the Universe does weigh. How much this effect should have. The vacuum energy that you calculate ends up being 10^{120} times larger than the number we actually see. So, it's like ridiculous, it's more than a google, more than 1 with a hundred zeros after it times larger than it should be. Nobody knows why they don't match up and that's the current problem in physics, it's called the cosmological constant problem, and nobody knows what the answer is but it's fun. So that's one of the ridiculous consequences. There's another ridiculous consequence which is that in quantum mechanics when we talk about energy, it's like I said, all we care about is the ground state. That's like zero degrees Celsius, I guess zero degrees Fahrenheit works as just as well, zero degrees on a scale, so we're saying okay, any temperature above that has a positive energy. Now, you've got your two mirrors, the energy density between the mirrors is less than the energy density outside the mirrors because of this vacuum energy so technically speaking in these terms there should be negative energy density. There's a negative mass between the two mirrors. Of course there's an accounting trick involved which is that we say that the Universe in general, you know, has zero mass and so, as a result, the energy between them has negative mass but if you can have negative mass you can build all sorts of crazy things with gravity. You can make warp drives, you can make time machines, you can make wormholes, you can make pretty much anything Star Trekky or science fictiony that you can imagine and so there's some question as to whether or not you can make a warp drive using this Casimir effect.

Megan: How do you make a warp drive?

Tia: That would be pretty awesome.

Ben: So, we talk about how to make warp drives in episode 9 but the idea behind it is actually fairly straightforward. Positive mass attracts things towards it so, the gravity of the Sun pulls things towards the Sun, the gravity of the Earth pulls us down towards the Earth. But if you have negative energy, negative mass, you can cause a type of repulsion and so if you play your cards very carefully what you can do is you can cause the spacetime in front of your warp drive bubble to contract faster than the speed of light and the spacetime behind your bubble to expand faster than the speed of light.

[35:32]

Megan: It sounds like a jet engine.

Ben: It's kinda like a jet engine for spacetime. There's a rule in spacetime that nobody can move faster than the speed of light but what you can do is you can make yourself a little bubble of spacetime where inside the bubble you're not moving faster than the speed of light but the bubble itself is traveling through the outside spacetime faster than the speed of light and you can do all this using negative energy. And so there's a possibility that you might be able to do it using the Casimir effect.

Megan: Fascinating and logical too.

Ben: Well, that was lots of fun! Thank you Mike, thank you Tia, you've pleased me. Your efforts have born fruit and that fruit is sweet! Tia you get a pomegranate - welcome to hell. Mike, you get a peach.

Mike: Oh, nice! Nom, nom, nom.

Ben: Good. Now, I'd like to thank my guest, Megan Harns. Thank you Megan.

Megan: Oh, thank you for having me on, it was a lot of fun.

Ben: Oh, great, alright.

Ben: So, my Ti-Phi-ters, let's suppose you want to interact with the Titanium Physicists a little more, if you'd like to keep track of us, why not follow us on Twitter @titaniumphysics or join our Facebook group. If you'd like to hang out with us and socialize why not join our online forum go to the website for a link. It's called the BracioBoard. Or, if you'd like to send me an email directly to ask a question or propose a topic email me at barn@titaniumphysics.com. Let's suppose you want to listen to us more conveniently, if you've got an iPod or an iPad try subscribing to our show in the iTunes store and while you're there write us a review. Your reviews determine our ranking in the iTunes Store which in turn determines how many new listeners will discover the show. If you have a Zune or Blackberry you can subscribe to our show on those doodads as well. You can download the Stitcher radio app which will let you subscribe and listen to your favorite podcasts. Okay, so for all this and more information visit our website at www.titaniumphysics.com. The Titanium Physics podcast is a member of the BrachioMedia Network. So, if you like listening to scientists talk about science in their own words you might enjoy listening to other shows on the BrachioMedia Network like the Weekly Weinersmith where

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