Episode 6: Gravitational Waves
Physicists: Dave Tsang, Jocelyn Read

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!

[1:49]

Ben: If we turn our gaze to the depths of outer space there's one hideous thing which we are sure not to see, monstrously massive objects. Older than the sun and stars which pull and twist at space time. And push and play with celestial objects as easily and violently as a child in a bathtub plays with his toys. Oh, but these objects are dark. We can't see them but we can witness the havoc they wreak as they as they violently and capriciously toy with the gas and stars which swirl about them. Oh, and they sing the sweetest and subtlest of songs, they chirp merrily in a hellish language of their own devising. But through which ether do these words carry? There's no air in space, only void. Why the waves of their song travel as vibrations in spacetime itself. But these vibrations are subtle. Too rarified for our human senses to feel. But still, now that we know of these terrible songs we cannot but crane our ears to listen for them. Even now our greatest academics and engineers are building great engines housed in tunnels, leagues in length. Apparati which will let us hear these horrible, jibbering songs, bubbling from the depths of space which will inform us about the cold nature of the ancient unknowable. Today, our topic is gravitational waves. And to talk about these deep, unknowable objects and the sounds they make we've invited guests Chad Fifer and Chris Lackey from the HP Lovecraft Literary podcast at www.hppodcraft.com. A delightful and easy to listen to podcast is a book club format wherein they introduce and summarize and review the stories of HP Lovecraft in chronological order. In contrast with the stories, Chad and Chris' discussions are always bright and succinct. Hi Chad and hi Chris.

Laughter.

Chris: Thanks for having us on the show. That was a really beautiful intro...

Chad: Yeah, that was amazing.

Chris: I was frightened for awhile and then I realized we were talking science.

Ben: Yeah, well science is creepy in its own way.

Chris: Yeah, that's why it's good.

Ben: So, Chad and Chris, for you today I have assembled two of my Titanium Physicists. Arise David Tsang!

David: Mwwwwwhhhhhaaaawwwwhhhhaaaahahahahahahaha.

Ben: Dr. Dave did his undergraduate at UBC and his PhD and Masters at Cornell University. He's currently at CalTech working as a PostDoc astrophysicist. Now, arise Dr. Jocelyn Read!

Jocelyn: Whhhhhhhhwwwwaaaaaaaaaaaaaaaaa!

Chris: Oh my god.

Ben: Dr. Jocelyn did her undergraduate at UBC and her PhD at the University of Wisconsin Milwaukee. She's currently at the University of Mississippi working on neutron stars. Alright, so, today we're going to talk about gravitational waves.

Chris: What is a gravitational wave.

Jocelyn: These are ripples in the fabric of spacetime itself which are these infinitesimally tiny motions coming from space itself warping in response to the movement of distant objects. And we're actually trying to detect the signature of distant black holes and other crazy compact objects on earth.

Ben: Yeah, so, specifically Einstein, Albert Einstein, described gravity in terms of a four dimensional sheet kind of. It's a surface that has curvature on it. And objects will curve their trajectories according to how this object is curved, kind of like if you rolled a marble over a bent up bedsheet. And also the mass of objects is what causes this surface to curve. But if you look at what happens when an object accelerates a little bit it won't cause a big amount of curvature. What it will do is it will cause a kind of ripple of curvature that moves outward from the object at the speed of light.

Dave: That ripple of this curvature is gravitational waves. They propagate out just like an electromagnetic wave but by rippling spacetime rather than the electromagnetic field.

Ben: So light is generated in an electromagnetic field when you accelerate electrons. And the generation of gravitational waves is kind of like the generation of light.

Chris: Well, wait a minute. So, how do you measure these waves? How do we know they exist? Is it theory or speculation or is there some physical measurement of it?

Dave: So, Einstein's theory of general relativity predicts that, like, one of the solutions to his equations is these waves. And we know that they should be generated when you have two massive objects orbiting each other. Now, we have never actually directly measured a gravitational wave, we haven't measured a ripple in spacetime but we can see its effects. For instance there are these very famous systems where there are neutron stars orbiting each other. One is called the Hulse-Taylor binary and the other is called the double pulsar. And so one of these objects in the Hulse-Taylor binary is a pulsar. A pulsar is a rotating neutron star where it has a beam of radiation coming off of it and acts as a clock, as it sort of sweeps around in a circle that pulse hits us and we can sort of use that as a clock for the neutron star. And as these neutron stars are circling each other we can see that their orbits are getting closer and closer together as they loose energy to gravitational radiation.

Chris: Sorry, gravitational radiation?

Dave: Yeah. Gravitational waves.

Chris: Oh, that is, gravitational waves are gravitational radiation.

Dave: Oh yeah, sorry.

Chris: Okay, okay.

[6:47]

Ben: These pulsar stars are kind of like sirens in space that are spinning at a constant frequency. And so, by saying that it's a clock means that we know that they're not slowing down as they spin. And so, we can tell.

Dave: They are slowing down.

Jocelyn: They are slowing down.

Dave: But we know the rate at which they are slowing down.

Ben: Yeah.

Jocelyn: And they're very regular in their behavior, most of the time. They glitch sometimes but we just don't, we ignore those ones. Don't pay attention to those ones.

Chad: So, my question is, if I am, say am Randolph Carter, floating in the void of space and I'm near a pulsar, how would this gravitational wave manifest in a physical way that I could, would the images of planets and stars shimmer? Or is it just, I wouldn't even be aware of it?

Jocelyn: So, you need, say, two pulsars orbiting each other.

Chad: Okay.

Jocelyn: And say you're hovering in space above the plane of the orbit so you could see them both going around each other. What you feel is kind of like a tide, of squeeze and stretch, that's pulling your body in a rotating direction.

Dave: It's extremely subtle.

Jocelyn: Yes, this is, well actually if you're right above it, it would be a bit more.

Chris: Right, right.

Jocelyn: So, it's a very subtle thing. It's not something you'd be able to measure particularly easily in, it's very difficult to measure them on earth even though we're trying. But what it does if you're sort of directly above the two objects circling each other you feel this kind of stretching, that's parallel to the plane of the orbit is this stretching out you're feeling rotating around, following the orbit of the stars.

Dave: Right, so if you had like a little rubber ring you'd see that ring sort of be squished into an ellipse and then squished into an ellipse the other way.

Ben: So, Randoph Carter, floating out in space, would feel his arms pull apart and his head and legs get squished together. And then his head and legs would get stretched apart as his arms got squished.

Chris: Oh, I see.

Ben: It's kind of X shaped pulse. But it deforms things instead of heating them up or getting absorbed by them.

Chris: So, it would be like if he was in a shifting funhouse mirror.
Like he would be tall and thin and squat and...

Dave and Jocelyn: Exactly.

Ben: One way to imagine it I guess, is if you imagine speed boats tied together.

Chad: I imagine that all the time.

Ben: On the surface of a lake

Chris: Are they doing a jump?

Ben: Right. So, the individual...

Chad: Finally somebody's putting science in speedboat terms, man. I've been waiting for that my whole life.

Jocelyn: Okay, rest of the podcast entirely in speed boat terms.

Ben: So, as these speedboats, they're tied together and they're, say they're trying to move in opposite directions, and in the end what will happen is they'll end up spinning in a circle because they're tethered together. And just imagine the waveform kind of generated by these speedboats on the surface of the lake kind of spirals out. And their system looses energy due to the waves they're making. So, Newtonian gravity, two objects can orbit each other, forever. Like you take two stars and have them orbit each other and stay in orbit from the beginning of the universe to the end of the universe without anything changing.

Chris: But Newton was an idiot.

Ben: Yes, Newton was a jerk.

Jocelyn: Well, he was a jerk but not an idiot.

Ben: Oh, yes, good correction. So, when you add in Einstein who said that that there was a maximum speed at which information could travel through the universe. What it meant was, as these objects were spiraling around each other, the gravitational waves that they made in doing so would carry energy away from the system. And so these stars would slowly loose energy as they spiraled around each other and they would get closer and closer together.

Jocelyn: So, you can see this is a kind of conservation of energy argument because if you have the squishing and squeezing you could use that to do some kind of work. You could get energy from it. That energy has to be coming from somewhere.

Dave: You could put a spring on there or something.

Jocelyn: Yeah, you could be putting a spring on or I don't know, some sliding rings on a stick that do something.

Chad : So, could this be harnessed to propel you as if, like, you had a surfboard and maybe it's silver, and you could ride that wave through spacetime?

Chris: Yeah, to let people know that...

Dave: Unfortunately, unfortunately, it's much weaker than the power cosmic, which, you know, is, essentially infinite. The distances we're talking about, to these objects, are so far away that the amount of power incident on something the size of, say, a surfboard, is infinitesimal.

Chad: Oh. Boo.

Jocelyn: You'd need to have a black hole chasing it.

Chris: How far away are two pulsars from each other?

Jocelyn: So, that's the whole point. So, they start off quite far away. But as they loose energy from the system, the energy is carried away and that causes them to come closer together so they are converting some of their binding energy is being lost to the gravitational waves. So, they'll start out quite far apart, you know, sort of the earth/sun distance or sort of the standard binary star distance. And then...

Dave: Right now the Hulse-Taylor pulsar, two neutron stars only about a solar radii apart. So they've started

Chris: Oh, okay, that's much closer than I had thought. I thought it would be like a light year away from each other or something.

Jocelyn: Oh no, and you have to recall also that a neutron star is something that's typically a bit more massive than the sun but it has collapsed down into a ball of, basically, a nucleus, nuclear type matter.

[11:44]

Dave: About 10 kilometers in...

Jocelyn: Yeah, about 10 km in radius. So, that's the size of a small town or city, small city. So it's this just ridiculous compression of matter and that's why these objects that are compact enough, and they are moving at a sort of, substantial fraction of the speed of light by the time they get that close. And that's how they can actually churn up space time enough to create these sort of observable signatures in their dynamics of their orbit and then potentially something we can measure directly on earth.

Chris: So, you need something pretty powerful in order to be able to have a, even like a tiny tiny signal that we are able to measure from that far away.

Ben: Almost anything accelerating. So, if you wave your hands around you'll be generating gravitational waves. But, unless we're talking about black holes or neutron stars, things that are very dense, they won't generate enough of a signal for us to be able to measure it.

Chris: So, Lovecraft, the author that we cover in our shows was a real science nerd and he would take different explorations, things that were going on in the science world and kind of twist them around in horror stories like *At the Mountains of Madness* is all about polar exploration. We just covered a story called *Out of the Eons* where he talked about all time happening simultaneously. He was interested in quantum theory and that kind of stuff. So, how in gravitational waves, how could they be twisted into a horrific thing. I mean, is there anything that could be detrimental, I mean is there anything horrible associated with this or does it provide us with evidence of stuff that would blow our minds?

Jocelyn: Well, ripples in the fabric of space time, reality itself is warping around you. That can get kind of crazy when you think about it. There's nothing there but the space between two points. There's no stuff there. It's just that there's some change, some deformation that's traveling through nothing and we can still experience it.

Ben: Yeah. It's not like there is an actual surface of a pond that's waving. What's actually waving and oscillating is the definition of distance. So, it's like the definition of a meter has been modified by and is traveling through space and goes and twists your definition of what a meter is for half a second.

Chris: Well, some science fiction writers talk about gravitational wave guns or gravy guns. Where like, you know, just like you can take electromagnetic waves and make a laser. Like, maybe in the future you could take gravitational waves and make some sort of focused gravitational wave engine of destruction. But that seems a little hard to imagine given the amount of energy and mass that you would need to manipulate in order to do that.

Jocelyn: Oooh, Oooh, here's another another creepy thing though. There's nothing that can stop them.

Ben: Oh no.

Chris: It's also very hard to hit anything with them, right?

Jocelyn: Well, they're very weak but they'll just keep passing through almost everything in the universe. They'll just shift it around but continue moving without any, you know, you can't screen gravity. You know, if you have some electromagnetic thing you can put up this field of positive electric charges that will sort of absorb things. So, you really can't do that with gravity.

Chad: Well, isn't gravity the weakest of the forces?

Dave: Yes. It comes from the fact that you don't have negative gravitational charge. So, the fact that you have negative and positive electromagnetic charge lets you screen things out. A large electric field, say, can be cancelled out by placing a large negative charge near you, for instance.

Jocelyn: It's like how we do feel the gravity of the earth. There's a pretty strong presence in our life even though the thin layer of atoms of whatever we are sitting or standing on, there's some electromagnetic repulsion between those two layers of contact atoms supporting us against the pull of the entire earth combined. But the problem is that, on big scales, all those charges kind of average out and gravity only ads together more and more.

Dave: Yeah, most things in the universe are by and large electrically neutral.

Chris: Right.

Chad: So, does our sun give off gravitational waves?

Jocelyn: It needs to have a motion that is asymmetric in a particular way.

Dave: Like a dumbbell rotating or something. So, there are modes of the sun that do look like this but the amount of gravitational waves that they give off, the sort of energy that the sun looses to gravitational waves is tiny compared to the energy that sort of put into heating and dissipation within the sun itself.

Chad: Right. Now, what about a supernova? Would that generate...

Dave: A supernova can produce gravitational waves if there are these asymmetries about it. So, if it's not purely...

Chad: If it explodes in an unsymmetrical way then it would produce these gravitational waves.

Jocelyn: Exactly.

Dave: Yes.

Jocelyn: And... If one goes off in our galaxy or in a nearby galaxy there's...

Dave: Betelgeuse, Betelgeuse, Betelgeuse!

Jocelyn: Betelgeuse, Betelgeuse but not for a few years because we're still building it,

Dave: We still need to turn on...

Jocelyn: ...building detectors on earth.

Chad: Ohhh.

Ben: So, Betelgeuse, the star in Orion is on the verge of going supernova so if we build a detector in time we should be able to measure all sorts of fantastic things from Betelgeuse when it explodes because it is very large.

Jocelyn: Well, that will tell us how the mass in the center of the explosion moves which we can't see from the light which is only emitted from the outer edges. So, if we could measure a gravitational wave signal that tells us about what's happening in the depths of the explosion.

[16:41]

Dave: But it's likely that only a small fraction of the energy of a supernova will go into gravitational waves. So a supernova would have to be pretty close in order for us to be able to detect that gravitational wave signal.

Chris: Well, how would you observe the, I mean, how would you build an observatory, what device would you measure it with?

Dave: That's an excellent question.

Jocelyn: That's an excellent question.

Chris: Thank you.

Laughter

Dave: So, right now, we've built large, what are called interferometers. They're basically, two arms of laser light that, so remember, lasers are...

Chris: Pink Floyd shows

Dave: Right, exactly. That's all in phase. So, it's one particular wavelength that's, and you can think of it traveling all in phase. And what you do is have these lasers bounce back and forth along two cavities that are perpendicular. And if one of the cavities is stretched out a little ways compared to the other one. So, if you imagine your gravitational wave coming down and making one cavity longer and the other one shorter then that will change the phase between the two different arms of light and then an interferometer is something that measures that phase change very precisely.

Jocelyn: So this...

Ben: Alright, so let's back this train up. Okay, there's a tool called an interferometer that they use in physics. And in this tool it splits a light beam into two pieces. It has two different arms and each piece goes down an arm and then after it bounces down this length it comes back, it get's recombined. And when it does it creates an interference pattern based on how long the arms are.

Dave: So, if the laser is, if both beams of light have gone exactly the same distance they'll still be in phase. So, their signals add up. But if they're, if they have gone a slightly different distances then they can be out of phase and their signal is slightly less.

Jocelyn: If there is half a wavelength. If there is a half a wavelength of light difference between the two arms, that will put them out of phase when they add together again, when the waves combine. And they'll cancel out.

Ben: So, what you do in these, in these interferometers is, once, you look at the interference pattern and if the length of either arm changes by a little bit the pattern of interference will change. And so what they're looking at, is they've got these very long gravitational wave detectors is they've got these very long interferometer arms and...

Dave: 4 kilometers.

Ben: 4 kilometers long and once the photons recombine their interference pattern will change slightly if some distance in the two arms has changed. And so gravitational wave will come in with its different definition for what a length is and it will kind of make one arm just a little bit smaller than the other arm, for a quarter of a second. And so the result is, is that this interference pattern, when the photons combine, will be different depending on what kind of gravitational wave passes through.

Dave: So, an interferometer, basically a tool to measure very very small changes in distance and ah, Jocelyn, what's the size of, distance change, that LIGO can measure? Like something smaller than a proton, right?

Jocelyn: It's less than 1,000th the diameter of a proton.

Dave: There you go.

Jocelyn:10^{-18} meters

Ben: So, we were saying earlier that if you were in space and you had gravitational waves move through you, first your arms would get compressed a little bit and your torso and head would get stretched a little bit. And then your head and torso would get squished and your arms would get stretched. Gravitational waves are so subtle that they only do so at like, even if your arms were kilometers and kilometers long, they would only shrink by a distance of less than a proton. A very small distance.

Dave: If we're, if we're... so, this is for something that's like, you know, in the galaxy, like ah, several mega parsecs away from us, detecting it at earth, it moves say the distance of a proton.

Chad: Oh, wow.

Jocelyn: And the craziest thing is, we've built these. We're measuring this kind of distance difference right now.

Chad: So, since it's such a minor affect on things what relevance does it have?

Chris: Well, wouldn't, at the beginning, didn't you say something about we would, you would, measuring the waves would allow you to see things in deep, or black holes or be able to detect...

Dave: That's right.

Chris: ...supernovas or something?

Dave: Remember that, because gravity doesn't get screened, we can actually use gravitational, if we can measure gravitational waves, we can use these to probe what's going on in regions of space we just can't see.

Ben: Or in regions of space where light isn't being emitted from. So if two...

Dave: Right.

Ben: If two black holes collide they'll emit a lot of gravitational waves which we'll be able to detect.

Chris: Ah, I see.

Ben: So, there's all sorts of things we can't see. It's like astronomy let's us see things, gravitational wave detection will let us hear what's going on in the universe.

Dave: Yeah. So, gravitational waves are essentially an entirely new window onto the universe.

Chad: You know, like, in Predator, how he would switch his viewer to be like ultraviolet or infrared, if he switched over to gravitational waves he could see, like, black holes colliding with one another.

Ben and Dave: Right.

Dave: Or like the Dumb bell rotating or something.

Chad: That's awesome!

Dave: He could see Arnold working out and shoot him from there.

Jocelyn: We can actually, possibly see some of the background noise from the very beginnings of the universe. Even before the Cosmic Microwave Background radiation which is sort of the last scattering surface of electromagnetic stuff because gravitational waves go right through things that screen electromagnetic radiation we can look further back in time towards the beginning of the universe. If there's some sort of background mess of ripples.

[21:58]

Dave: It's called the primordial gravitational wave background.

Ben: The Stochastic background. Yeah, okay, so back this truck up. So, you guys know about the Big Bang, right?

Chris and Chad: Yes.

Ben: There's the theory of the Big Bang. And the problem with our universe is that we can't see the Big Bang. There's a curtain in time and what happened was very early in the universe there was a time before atoms existed. And so there were just charged particles flying around and then some time in the very recent past the universe had cooled down enough that electrons to start sticking to charged protons. And then...

Jocelyn: It's not that recent.

Ben: Ah, it's recent enough. Anyway, so...

Laughter.

Ben: The deal is that light can't propagate until the universe is kind of neutrally charged and until these atoms are made. So, the light we see in the universe now could only go back so far in the history of our universe. And so there's a curtain past which we can't see into the Big Bang. And so there's time when we can definitely observe it. Ah, the photons that were generated then are called the Cosmic Microwave Background, the Cosmic Microwave Background radiation. But the deal is that we can't see using electromagnetic waves, past that time. And so with gravitational wave detectors we might be able to see ah, what happened before that curtain, behind that curtain and so it would give us a window into even earlier in the universe when crazier things might have happened.

Dave: Now, the ah, gravitational wave detectors that we've been talking about so far, which are these, you know, kilometer long interferometers, they wouldn't be able to see that background. But there are other...

Jocelyn: Unless you have some particularly weird stuff happening. Like, there's some cosmological models, like, cosmic string backgrounds, stuff like that, that would give some sort of signal.

Ben: Yeah, there's no telling what we'd be able to hear once we turn on these fantastic gravitational wave ears.

Jocelyn: There's a history of astronomy when we discover a new way to see things. Like, for example, when we learned to look at the sky in radio waves, that's when pulsars which have basically sort of been these fundamental assumptions about what we've talked about today, those were only discovered when we started being able to use radio which is just a new frequency of light. So, when we can actually have a different kind of sense altogether, the really exciting thing is all the crazy stuff we don't even know we're going to be able to see.

Chris: What, I mean, what are people predict or anticipate would be the odd things that you might learn if can have, if we had detectors of gravitational waves. I mean what are the crazy possibilities?

Ben: Alright, so there's this one crazy possibility called a cosmic string. And the idea is that it's just kind of an infinitely long one dimensional object. It's just kind of a string that's infinitely long floating out there.

Dave: So, you could think of it as, like, a you know there's a, you know when you have a flaw in a crystal that can show up like a one dimensional dislocation. It could be like, essentially a crack, a crack in the crystal. Basically like a crack in spacetime. It's kind of like in Doctor Who.

Chris: Okay.

Ben: As they whip about sometimes they make gravitational waves.

Jocelyn: So, if the two strings cross they can sort of switch partners like the intersection will split off in a different way and then what's left are these sort of cusps where they all touched and when those evolve the cusps will emit a burst of radiation and gravitational waves.

Dave: So, you don't want to cross the strings.

Chris: Aaaahhhhhh.

Ben: So, yeah, that's one of the potential objects we might see.

Dave: That's one of the more out there possibilities.

Jocelyn: Some sort of string theory ideas led to considering maybe giant theory strings as well which is a different thing but has a similar kind of signal. Some of the theories have been ruled out, actually, already because they predict crazy things.

Chris: So, gravitational waves will be how we can hear the servants of Azathoth piping madly at the center of the Universe.

Ben: That's right. There might be terrible monsters out there that we can't see but suddenly will be able hear.

Jocelyn: Oooh, Oooh. Do you want to hear what two neutron stars sound like when they merge together?

Several: Yeah!

Jocelyn: Okay, let me, it's been awhile, so... wwwwwwwhhhhhhhhrrrrrrlllllliiiiipp. That's what the gravitational wave sounds like.

Ben: They chirp.

Laughter.

Chris: So, so they.

Dave: As they spiral, as they spiral inwards the frequency gets higher and higher and higher and that's why it ramps up to a chirp.

Ben: And the kind of, the volume of the gravitational wave, the amount of energy they are putting into gravitational waves, increases dramatically as this happens.

Jocelyn: Because they're together so they are churning spacetime around more and more and that drives them together faster. Which, sort of, this, inevitable collision that becomes more and more dramatic until either the two neutron stars smash together or the two black holes form a single black hole in a sort of weird, bizarre horizon dance.

Dave: So if your monster has a vocal cord made of two black holes orbiting each other then they could be singing out in this sort of aetheric, you know, song.

[26:53]

Jocelyn: They can get, there's the, so that's sort of stellar mass object, that's the kind of thing that we would see with our earth detectors. There's other types of detectors. Doing giant space laser detectors or using the signals from pulsars around the earth as the ends of, the arm ends of sort of a giant galactic scale gravitational wave detector based on just what we can observe out there.

Ben: Yeah, let's go through one by one the variety of fun detectors out there.

Dave: The interferometers that we have on earth can basically see things at around a 100, around a couple hundred hertz or so.

Jocelyn: It's human audio frequencies.

Dave: Right. Whereas..

Jocelyn: You can just pipe the signal into an audio file and listen to it. There's LIGO and there's one in Italy called VIRGO, there's a little test one in Germany called GEO and then there's a cryogenic detector being built under the Kamiokande mine in Japan.

Chris: Cryogenic?

Jocelyn: Yeah.

Dave: It's just to cool the electrical equipment to make it have less noise.

Chris: Is that where they are keeping Walt Disney's head, down there?

Jocelyn: So yeah, we cool things to cryogenic temperatures and then we fire lasers at them, it makes total sense.

Dave: There's also a possible one occurring in India right? Called Indigo, that may or may not occur?

Jocelyn: Yes.

Ben: And all of these detectors are kind of of the same construction. They are all very long interferometers, several kilometers long, and they shoot lasers down them.

Jocelyn: Just depending on the frequency of the gravitational wave you are trying to measure, you have a whole array of noise sources that you decide which ones you want to focus on. So, if you want to be more low frequency sensitive you're worried about seismic background, you want to have everything suspended by complicated suspension systems to damp out any shifts of the earth and...

Dave: Or trucks driving by.

Jocelyn: Or trucks driving by or airplanes or tumble weeds.

Ben: So, any vibration in the system is going to cause the mirrors to get slightly closer to the lasers and make the interferometer pattern change.

Jocelyn: So, this is one reason there's a bunch of detectors. Because no one's going to believe a signal unless, so this is how you tell whether you're really seeing something from space. If all the detectors see it at once, even though there are more than
light transit time away from each other. That means it has to be coming from off earth and just hitting them all at the same time.

Dave: Yeah, so it's a coincident detection from several of these detectors is what you typically need to say, hey look we saw this gravitational wave signal. So, aside from the ones that are based on earth that we are currently building and have built, there was a gravitational wave detector that we were going to put into space. It has since been canceled but the Europeans may be taking it up and it was called LISA and it may now be called ELISA.

Ben: Okay, so LISA is an an acronym. They're all acronyms, all these different names.

Chris: Wait, who was, NASA was going to put this in space.

Dave: NASA was going to.

Jocelyn: Yeah, it was going to be a joint NASA and ESA, the European Space Agency, space mission but NASA basically, NASA couldn't commit the funds. And so the Europeans are going to go it alone.

Dave: There's no ah, there's no money. The U.S. is running out of...

Jocelyn: Because Americans don't love science anymore.

Sobbing and crying sounds.

Chris: It's true.

Ben: So, LISA stands for Laser Interferometer Space Antenna.

Dave: And it consists of three, basically robots, that float in space and shoot lasers at one another. They trail behind the earth as it goes around the sun and they're, the separation between the robots is about ten times the separation of the earth and the moon. And they shoot high powered lasers at one another and, ah, measure that, their change in distance as gravitational waves pass by.

Ben: So, there are three robots in a triangle. There are supposed to be, this is the plan. Three robots in a triangle shooting lasers at one another.

Jocelyn: Nuclear powered space lasers.

Ben: Nuclear powered space lasers. At a distance, ten times the distance between the earth and the moon. Somewhere in orbit around the sun and the distance between them is, each individual robot is so large that it would be very accurate for gravitational wave detection.

Jocelyn: So, this kind of thing would be sensitive to lower frequencies. Lower frequencies are coming from bigger objects that move more ponderously. The super, the massive black holes in the centers of galaxies.

Dave: So, things that are millions of times the size of the sun merging together when galaxies come together and merge.

Jocelyn: So, they're not orbiting around each other at you know, a hundred times a second, they're orbiting each other at several times a day or ...

Dave: Yeah, once every, once every few thousand seconds.

[31:28]

Jocelyn: Yeah.

Dave: And then, so the lowest, very, very lowest frequency way we have of measuring gravitational waves is what's called a pulsar timing array. Remember when we told you how pulsars can act as clocks.

Chris: Yeah.

Dave: Well, if you have a whole set of pulsars that we've, you know, been tracking somewhere in the galaxy, we can stare at those pulsars and see how their timing pulses shift. And as a gravitational wave passes by us we can see the pulsars sort of shift in a correlated way. And from that we may be able to measure extremely low frequency gravitational waves. Something along the one orbit or one cycle every 10^9 seconds.

Jocelyn: Every year or few years or ten years. Just depending on how long you observe these. So, this would be like the biggest, biggest black holes merging together.

Dave: If you were going to see a, the gravitational waves from the beginning of the universe, from before the Cosmic Microwave Background, it's likely that you'd see it in this extremely low frequency.

Chris: Hmmm. Alright then.

Ben: So, thank you Jocelyn and Dave. You have pleased me, your efforts have born fruit and that fruit is sweet. Here's some fruit. Pomegranates for Jocelyn and Dave. Pomegranates from hell.

Jocelyn: Wooooo.

Ben: Yes.

Dave: Mmmmmmm. Hell pomegranates.

Ben: You're damned now Dave. Alright, so, I'd like to thank my guests.

Dave: MMMMmmmmm. Damned good Pomegranates.

Ben: I'd like to thank my guests. Chad Fifer and Chris Lackey. Thank you you guys.

Chris:Thank you for having us.

Ben: It was really fun. You guys asked fantastic questions. Everyone was very impressed.

Chad: And we're very, I feel like I'm a whole lot smarter now.

Ben: That's good.

Jocelyn: Hurray!

So yeah, everybody please listen to theHP Lovecraft Literary Podcast. It's lot's of fun. Alright, so let's close. 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 . If you are a physicist and would like to become one of my Titanium Physicists email physics@titaniumphysics.com we're always recruiting. 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.