Episode 47: The Song Of Falling Stars with Robot Hugs

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The Titanium Physicists Podcast

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Transcribed by John Robinson

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 of 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. And so I have assembled a team of some of the greatest, most lucid, most creative minds I've 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!

[1:48]

Ben: The thing you need to understand about the universe is that news can't travel faster that the speed of light. This rule is the root cause of many effects. I want you to imagine, for instance, that you traveled back in time, and now you're a lady in one those old fashion ball gowns. The huge ones with the hoops and the skirts and the skirts under the skirts, like in the movies. When you're standing still or moving in a steady speed, then fine. The skirt will sit around you or move with you and everything will be ok. But if you try to accelerate or turn or spin, the skirt won't follow you. You'll have to pull and push against it, and it'll take a moment longer for the edge of the skirt to get the news that you're moving in a new direction. If someone slow-motion videotaped you as you danced with some kind of old fashioned slow motion video camera, they'd see waves rippling across the surface of your gown as you turn or spun or accelerated. The fact of the matter is, that because it takes a while for news to travel, change causes waves. Like, for example, the static electricity field generated by a charged particle that pushes of pulls on other charged particles, it's kind of like your pretty ball gown. So if you accelerate a charged particle by waving it up and down, say, the electric field will have waves moving across it as the news of the particles moved travels outward. And those waves in those electric magnetic field are what we call light. So change causes waves. So one of the biggest wave making events in science history was the proposal of Einstein's theory of General Relativity. It was the theory of gravity set to replace Newton's theory of Universal Gravitation. Einstein had said at the heart of his theory the rule that news could never travel faster than the speed of light. And one of the consequences was that gravity could be explained in terms of curvature in a four dimensional surface called space-time. But this new theory had unforeseen consequences. Isaac Newton explained gravity in terms of forces like a rope between two planets that pulled massive objects together. His theory precisely predicted the motion of the planets around the sun. And one of the most fantastic predictions involved the motions of two planets in a big empty universe. If the universe only had two objects in it, they could orbit each other forever, a perpetual motion machine where each one could circle the other one in a dance that would last all of time. But Einstein's new theory had something to say on the topic. If two planets were in orbit around one another, if they were traveling in a circle, they must be accelerating, because you need to constantly turn just a little bit to go in a circle. But if your objects are accelerating, then something is changing. And change makes waves, right? In Einstein's theory, as the two planets dance around one another, they would make waves in the surface of space-time, and these waves carry away energy. So slowly, slowly, the two dancers get closer and closer together, until they kiss, and everything changes forever. Today on the *Titanium Physicist* podcast, we're going to talk about the orbital decay of binary systems. The web comic Robot Hugs is an interesting read. It's difficult to describe. It is in its own way an ongoing essay about the decay of binary systems, and the reconciling of archaic fears of how people should live with more realistic understandings of the forces that drive us. I've often seen their comics posted around Facebook and Tumbler, and so I've decided to invite them on the show. Welcome, Robot Hugs!

Robot: Hello!

[5:11]

Ben: Hi. So, Robot Hugs, for you today I've assembled two of my finest titanium physicists. It's the A-Team! Now arise, Dr. Jocelyn Read!

Jocelyn: Rawr!

Ben: Dr. Jocelyn did her undergraduate at UBC, her PhD at the University of Wisconsin, Milwaukee, and she's currently faculty at the physics department at Cal State - Fullerton. She's a specialist in neutron stars, and she's also a member of the LIGO Scientific Collaboration, but everything she's about to say is in an unofficial capacity, and does not represent the opinions or findings of the LIGO Scientific Collaboration. Now arise, Dr. David Tsang!

David: Mua ha hahahahaha!

Ben: Dr. David did his undergraduate at UBC and his PHd at Cornell. He's currently a post Doc at McGill and Cal Tech researching black holes and neutron stars and planets. Alright, everybody, let's start talking about the decay of orbits.

[5:56]

Jocelyn: So, the big thing that Newton did was basically realize that the same thing that has things falling on Earth also explains why the moon is moving through the sky because the moon is just falling towards us, but it's going fast enough that is always misses, and that's all that an orbit is.

Robot: Right.

Jocelyn: The idea is that the same kind of way that you try to understand how things fall when you drop, you know, apples on people's heads is the same thing that describes how things in the sky interact with each other. But the Newtonian theory has basically instantaneous knowledge of what the other object is doing. So the moon is being pulled directly towards the earth, and the earth is feeling a tug directly towards the moon, and as they change their positions, they always know exactly where the other one is.

Robot: Right.

Jocelyn: But, that's not going to work once we have the light propagation time. As the moon moves, it will take a little while for this space-time to shift enough that Earth can feel the pull in the new direction.

Robot: Right.

Ben: Ok, so it's like this. The sun is moving and the Earth is moving, but the Earth isn't moving around where the Sun is right now. The Earth is moving around where the sun was eight minutes ago.

Robot: Yes, screws up your head, doesn't it?

Ben: You get used to it.

Jocelyn: Ok. So the other thing that you have with Newtonian Gravity, is if you're holding a rock above the ground, and it's got potential energy, and then you drop it and it loses potential energy and it gains kinetic energy. You've gone through this sort of physics stuff before?

Robot: I have. It sounds vaguely grade 8 physics to me.

Jocelyn: Yeah. That's all be basically need. So the idea is the rock loses energy, converts it into kinetic energy, and it falls down. So now we have, say, the Earth and the moon orbiting around each other, mostly orbiting around the Earth because the Earth is really big, so it stays at the center. And now, they lose a tiny little bit of energy due to gravitational waves. And we know that gravitational waves carry energy because they can have effects far away. So, they're losing energy, and that means they're going to fall together. And for the Earth and moon, this is such a tiny, tiny effect that it's basically not going to make any difference over the entire age of the universe. But just with the fundamentals of Relativity, the Earth and the moon are losing some tiny amount of energy and falling towards each other a little bit because of the way that gravity works.

Robot: Do we have a timeline on that?

David: For the Earth/Moon system, the thing that dominates most is the ocean tides, actually. So as the moon pulls on….

[8:24]

Ben: Generating gravitational waves, it's kind of a matter of acceleration and mass. The more mass and the stronger the acceleration is, the more you're going to cause gravitational waves. So, let me say it this way. Gravity is a fairly weak force. Gravity is the manifestation for the curvature of our space-time. So, to get a really big acceleration, a really big change in the curvature of gravity, something that would carry off a lot of energy, substantial amount of energy and gravitational waves, you need bodies that are fairly dense, and that cause a whole bunch of gravities, so like a black hole or a neutron star, or two neutron stars orbiting each other.

Robot: So I think I need you to go over this curvature, gravitational curvature, and what you're talking about when you're talking about that.

[9:06]

Jocelyn: So, have you ever seen one of these demos where you take a flat sheet of spandex, and that's sort of what flat space is like. You can just roll a little ball across it, and it just travels in a straight line.

Robot: Yes.

Jocelyn: Then you put a bowling ball on it, and it stretches it down, so that if you rolled something, it would move in a curved path, because it's traveling on this curved surface.

Robot: Right.

Jocelyn: So it's like if you're playing croquet, and there's a hill, your croquet ball will get deflected and go somewhere else.

Robot: So curvature is sort of what orbits are made out of?

Jocelyn: Yeah, yes. So when the moon is going around the Earth, the moon is trying to go in a straight line, but it's moving through this curved space-time, that the Earth has curved this space-time, so that the moon ends up getting deflected around it and around it, [i.e.] the orbit.

Robot: Ok, yeah. Got it.

Jocelyn: And so the gravitational waves are ripples in the shape of space-time; they end up acting on something. Like if I'm sort of standing, and I'm going to stretch out my arms, and then a gravitational waves comes towards me. I don't see anything, but I would feel my arms stretch, and then my head to toes would stretch, and then my arms would stretch again. There's this sort of stretching and squeezing. As the waves travels through things, it causes this effect.

Robot: Ok.

Ben: One way to think about this, is we're not used to the idea of the length or distance being mutable. So, if you take a farmer's market, and you put it ten kilometers away from you, it's always going to be ten kilometers away from you, and that distance doesn't change. In Einstein's Theory of Gravity, the idea is that it's curvature causing these curved trajectories, causing these orbits, right? And so the question is, what's curving? There's obviously not a great big concrete bank that things are rolling off of. The curvature is manifesting itself in terms of mutable distances and quantities of time. So the deal is that the distance between me and the farmers market one kilometer away might change as a result of gravity. And it's not that I'm getting closer to it, or that it's getting closer to me, it's the very definition of what a kilometer is, it's shrunk or grown.

Robot: Ok.

Ben: So, the deal is, when you get waves in space-time, these waves manifest themselves in terms of, you know how if you have a duck on a lake, it'll go up and down as waves pass under it? Well, in space-time, if a wave passes between us, what happens it the distance between us grows and shrinks because it's space-time, this quality of distance, is mutable now in Einstein's Theory of Gravity.

Robot: Ok.

Ben: Weird, huh?

Robot: Yeah. Very weird.

[11:38]

Jocelyn: It's sort of like going back to the rolling balls on curved surfaces. You can sort of roll two balls beside each other, and if things are flat, they just stay beside each other. The distance between them is fixed, as they travel through time or space or whatever. But if there's curvature, they could get deflected away from each other, or deflected towards each other.

Ben: Yeah, or the classic demonstration that the universe is curved, is you imagine you going up to the moon. Like Jocelyn said, if you have two objects that are traveling in the same velocity parallel to one other in flat space, they'll just keep going along parallel lines. But if you take two objects and throw them along parallel lines out by the moon towards the Earth, they'll both kind of converge towards the center of the Earth as gravity pulls them together. So you have these parallel lines getting warped towards each other.

Robot: Yeah.

Jocelyn: So we've been talking about it with the Earth and the moon and the stuff in the solar system, but then we've said it's too tiny an effect, so it doesn't really do anything. So where does this matter in the universe?

David: So if you have two objects that are in orbit around one another, the total amount of energy they have is the sum of their negative potential energy and their positive kinetic energy. The potential energy is usually twice the amount of kinetic energy if they're in a nice circular orbit. If you somehow manage to take energy away from their orbit, what would happen is their orbit would gradually shrink, and they would get closer and closer, but they would also move faster and faster. And so, as you remove energy from the system, they would gradually approach each other, going faster and faster and faster, until they smack together.

Jocelyn: And it's kind of a positive feedback loop once it gets going because they get closer together so the gravitational interaction is stronger, and then they move faster around each other, which kicks up bigger waves, which carries away more energy, which brings them closer together which makes bigger waves, which brings them closer together. So we have this scenario where there's this runaway effect, I mean over a million years or so, and these two stars or these two black holes off the universe are going to collide.

[13:42]

David: So this effect has actually been seen in the system called the Husle-Taylor binary, which is a pair of neutron stars. It was discovered in 1974 by Russell Hulse and Joseph Taylor, and in 1993 they won the Nobel Prize for discovering this because one of these stars is a pulsar, meaning that it's a rapidly rotating neutron star that has a lighthouse pulse on it that we can detect in the radio. Each time one of these pulses hits our radio dish, we can keep track of sort of where it is in its orbit. By keeping track of it orbit, we can see that its orbit is gradually shrinking. The orbit of it and its partner is gradually shrinking down, and they plotted this since 1974, and they can see that it follows exactly the prediction of energy loss due to gravitational radiation.

Jocelyn: And they've done this for a handful of other systems, to some other neutron star systems, some white dwarf systems, so you know this has been confirmed in a lot of different pairs of objects in the sky. You find a binary that has some nice clean wave of measuring its dynamics, and you'll see that the two objects will be slowly falling towards each other the way that would be predicted by the emission of gravitational waves.

Robot: This is what's kind of happening everywhere, right? Like, we kind of think of orbits as just being stable things that go on forever, where everything's just slowly smashing together for eons.

David: So, Yes? [laughter] Sort of. For most objects, the amount of gravitational radiation they emit is very, very tiny compared to the orbital energy. So they won't merge in sort of the age of the universe. So that's why we say the gravitational radiation doesn't matter. The Hulse-Taylor binary will actually merge in about three hundred million years. That's very small compared to the age of the universe.

Robot: Right.

David: Because we know it'll merge in not that long, compared to the age of the universe. That means that there should be other mergers of this similar type occurring often. But it's only because they're so dense, or they're accelerating quickly relative to one another, that their gravitational radiation is strong enough that it will cause the merger eventually.

Robot: Right.

Jocelyn: So the idea is that there are gravitational waves from this sort of thing passing through us right now, but most of them are from some mergers in very, very distant galaxies, so the effects are basically unnoticeable.

[15:59]

David: That's right. The gravitational radiation from these things is just propagating out into space. So you might ask what happens to these neutron stars that crash into each other? Do we see that happen? And the answer is we think so. There are these events called short gamma ray bursts that we see pop off in the universe. Not in our own galaxy so far, but in distant galaxies, we see them going off, and these are huge explosions of energy. I think the number comes out to about ten to the twenty nine (that's one with twenty nine zero's behind it) megatons of TNT. What happens is the neutron stars, which have about the mass of 1.4 times the mass of the sun, or one and a half time the mass of the sun, packed into something with the radius the size of a small city. These things will smack into one another, a black hole will form, and all that material forms a disc around that black hole, and it falls onto the black hole, heating up, causing a jet to blow out the top and bottom. If the jet is pointed directly at us from a very, very long distance away, then we call that a short gamma ray burst. And we see this as a very bright, very short few second burst of intense gamma radiation. Not enough to turn us into the Hulk…

Robot: No.

David: But very intense nonetheless. We actually have satellites out there that are looking for these.

Robot: So the only way we can catch these bursts of that collapse is aligned in that particular way that it's pointing right at us?

David: That's right.

Robot: So there must be many, many more of them that we're just not seeing.

[17:24]

David: That is a very good inference. Now, this may not be the only signal that comes from these gamma ray bursts. There's also things called kilonova. Now, the material that's in the neutron star, you might be able to tell by the name, is very neutron rich, it's basically all made of neutrons. So, you might remember that starts will fuse up to iron. It's not energetically preferable to fuse nuclei to heavier elements than iron. And so you have a lot iron in this neutron star, and a lot of neutrons lying around. Now, the neutrons prefer to remain neutrons because of all the intense pressure in this neutron star. When these two neutron stars get distracted, and throw the material out, then those neutrons aren't under that pressure any more, and they sort of glom [adhere] on to nearby nuclei, glom on to nearby heavy nuclei like iron, and they'll create even heavier elements through radioactive processes. And this is actually where we think a large fraction of all the heavier elements like gold or platinum comes from. These glows, these sort of radioactive brightenings are isotropic, meaning they go off in all directions. So even if we don't see that jet, we may be able to see the softer glow of what we call kilonova because it's… But a thousand times brighter than stellar nova, or about one tenth to one one thousandths as bright as a supernova.

Robot: Hmmm. Is this how black holes are formed? Is this the only way they are formed, or is this the most common?

David: This is actually a pretty rare way. Well, the most common way they're formed are massive stars will collapse.

Robot: Yes, it's what I thought.

David: So, if the star isn't so massive, or it's managed to blow off a lot of its material through stellar winds, then it'll form a neutron star. If it can't blow off enough material, then once it gets above a certain mass, the core will collapse, and it'll form a black hole. This is another way of forming a black hole, though it's not a very common way. Most stellar mass black holes are probably formed in collapsing massive stars.

Jocelyn: There's also other types of gamma ray bursts which are probably collapsing massive stars, so all of this is still a bit uncertain, because we see this burst of gamma rays, and we just try to work backwards what could have caused that. We can't see this happen directly… yet.

David: But there has been a detection of a suspected kilonova. The radioactive process that I described earlier, it was theoretically predicted only a few years ago, and we've recently just think we've seen one, this sort of afterglow from some sort of effect that has all the properties that we think such an event should have.

Jocelyn: So that's evidence that this picture is kind of hanging together.

Robot: Great.

Jocelyn: Which means that if you own any jewelry made of gold or other things like heavy metals like that, it was probably formed in a collision of neutron stars driven by gravitational radiation in the distant past.

Robot: That's really cool. That's pretty badass, isn't it?

David: It may have also been formed by massive stars, but a large fraction of your gold ring or your gold earring could have been formed by two merging neutron stars. Some of our friends call them bling nova.

Robot: When you see these gamma bursts, are you able to tell from the pattern of the burst or what you're looking at, how it happened, or do you have to relate that to data you had before you saw the burst, or…?

Jocelyn: We do things like we try to figure out what kind of galaxy it happened in, and what kind of stars are more likely to be in that galaxy.

[20:44]

David: So if it's a long gamma ray burst, what Jocelyn was talking about, where you have a very massive star that collapses to a black hole directly, and then has this jet. You can also look for supernova that may also have occurred. So they're often associated with a certain type of supernova that are coming from these massive stars.

Jocelyn: And massive stars don’t live very long. They burn fast and they die young…

David: Like Kurt Cobain.

Jocelyn: Ohhh…. sad. So if you see a gamma ray burst that’s coming from a type of galaxy that’s not forming stars anymore, so it has only old stars in it, they’re like ok, this is probably not a massive star because that galaxy doesn’t have any of those anymore. So you’d use these kind of chains of evidence, but…

David: Wait, wait, wait, wait… Should we talk about M31 first?

Robot: It’s so secret.

Jocelyn: So it’s actually a galaxy. You can see it in a telescope.

David: It’s the closest non-dwarf galaxy.

Jocelyn: It’s the only galaxy that you can see with the naked eye, I think.

Robot: Am I mixing this up with Andromeda?

David: It is Andromeda.

Robot: Oh, hey! I’m smart. I got it.

Jocelyn: M31 is the super-secret astronomy code word for Andromeda.

David: It’s so that we don’t confuse it with the show.

Robot: Right… smart.

David: Ok. Recently, if you were on Twitter at the correct time, you may have noticed a Twitter firestorm over something that's really potentially cool that we thought for a brief period of time had happened in our closest large galaxy, the Andromeda….

Robot: There was a gamma burst, wasn't there?

David: There was what we thought was a burst of gamma rays. So there's a satellite that's up in the sky right now called the Swift satellite. And onboard the Swift satellite is a gamma ray burst detector called the B.A.T. It detects bursts of gamma rays, and tells the satellite, "Hey, look! In that part of the sky, a burst of gamma rays just went off". And it'll very quickly slew its X-ray telescope over and look at that part of the sky, to see if they can catch one of these gamma ray bursts in action. And one of the main points of the satellite is to make observations of these gamma ray bursts, and also tell all the other telescopes on Earth and in the sky that something cool is going on. And it's caught many, many of these gamma ray bursts. So on May 27th, Swift thought it saw something in the part of the sky that Andromeda's in. And then it slewed over and tried to take a look at it. Unfortunately, this was also right when a thunderstorm hit the Goddard Space Flight Center, which is where the Swift operations is run from. And it took down their servers.

Robot: Oh, no!

David: So, astronomers got some partial data, and they took some secondary data sources, and tried to look to see what happened. Because these weren't the primary data sources, and there was an error in some of the automated scripting, it looked a lot brighter than it actually turned out to be. And so everyone got very excited because if a short gamma ray burst had gone off in Andromeda, that's extremely close, it's like our next door neighbor in a cosmic sense. And we should be able to observe the heck out of, well, observe the hell out of that. That would tell us a lot about whether or not the neutron stars are really merging to cause these short gamma ray bursts, will tell us a lot about other signatures that we might be able to find, including perhaps nurturing these gravitational waves.

[23:47]

Jocelyn: Ok. So, we are actually trying to measure gravitational waves from Earth, which is a bit crazy, because one of these gravitational waves coming through would change the distance between us and the nearest star, 4.3 light years away. It would change the distance between us by 3 millimeters.

Robot: Hmmm.

Jocelyn: Something like that. So this is not a big effect, but we're trying to measure it with these gravitational wave detectors on Earth, which is probably a whole other podcast in itself. But one of the things we are doing right now is so we did I guess a practice run maybe? We did an initial run of a detector, in the first part of the century, and then for the last five years or so, it's been offline. They're pulling everything out and upgrading it to fantastic new levels of sensitivity, which means that chances are if all our models are correct, we should be able to directly measure gravitational waves in the next five years.

David: Now, if this short gamma ray burst in M31, or Andromeda, had been real, this would have been extraordinarily disappointing for the gravitational wave community because their detector was turned off. Now, a small version of the ground based gravitational detector was turned on, called Geo600. It's not certain whether it… Jocelyn, it should have been able to see something, right?

Jocelyn: Yeah, so Andromeda, if something had merged in Andromeda, the gravitational waves would be strong enough that the initial LIGO detector would have been able to detect it. So I think the one in Germany, Geo, would be able to measure something. But we're just about to put this massively precise instrument online that was designed to measure these incredibly cool events and then we get the really rare loudest event possible in our lifetimes. And it's just a year too early. So…

Robot: Ahhh! So it wasn't a big deal, was it? Or it wasn't was everyone thinks it was.

David: So thankfully, or maybe not thankfully, it turned out it was just noise on the detector. The extra source that it saw was just a steady source that people had known about before. It's just that the calibration was off because we couldn't access the data until the Goddard Space Flight Center came back online. It turned out to be nothing, but it was extraordinarily exciting for that evening.

Jocelyn: This is the fun thing about science these days. It's a lot more of a roller coaster than back when we were students.

David: But in other fields, people take a long time to make sure about results. We're just catching what the universe throws at us.

Robot: That's kind of what I am gathering is you're sure looking out in space. You're trying to cover as much as you possibly can and something is happening and everyone goes, "Do you know about that? Did you know that's a thing happening over there?"

David: So the reason it exploded across social media was as soon as it thought it saw something Swift posted a notice to the astronomical community that's just public that said, "Everyone! Something might be going on. You should pay attention to this area of the sky." And that's why everyone got excited.

Jocelyn: It's definitely enough potential that people are willing to accept some of false positives because it if something like this happened for real, you would want everyone dropping everything and look at it because of this close and rare event is a gold mine of data across the spectrum.

David: It’s an extraordinarily rare thing is very unlikely to happen, a short gamma ray burst in such a close galaxy.

[27:09]

Jocelyn: So certainly when something might happen, the threshold for reporting. Actually this is going to be an issue with LIGO, too. The first you time LIGO sees things, we're working on trying to get alerts out, but we're still calibrating the detector. We’re not going to be publicly broadcasting this right away. But there's also this discussion going on right now. It’s like, "Ok, how many of these do you want?" What chances of this being a real signal, or maybe, "Oh, this looks promising. Just in case, we'll send an alert." The astronomical communities have to talk to each other and try to figure out what’s going on. So there is a fun story with initial LIGO detector. One of the things we do is we do what's is called the blind injection. Which means secretly, there's a team of people within the collaboration...

David: And we call them a secret Cabal?

Jocelyn: They're pretty much, yes. A secret Cabal, and they go to the detectors and they artificially wiggle the detector system to pretend to be a gravitational wave.

Robot: And I'm imagining this is a physical wiggle. Am I wrong? Oh, my God, that's adorable.

Jocelyn: Well I mean they're not putting their hands in. They use some...

David: They have some solenoids or something.

Jocelyn: Yeah, there's ways to control. What they basically put a little wiggle into the computer system that controls the mirrors, so that from the measurement outwards it looks exactly as if there's a gravitational wave signal there. And then the challenge is because we've never been able to detect this before are we going to be able to do with this in real life. So they secretly put the signal in and then the gravitational wave data analysis pike up the signal and I believe they pointed the Swift telescope at the point in the sky that the fake signal seemed to be coming from. Because forehand they said we're going to do a blind injection at some point, it's a blind injection so they are like if this were real it's a brilliant enough opportunity that when that alert came in, they pointed a bunch of telescopes at the sky just in case.

David: And the LIGO collaboration actually went all the way to the point of preparing a paper for submission before the secret Cabal opened the envelope to show them if it was actually a fake injection but I think you guys knew.

Jocelyn: It's sort of a thing that would have been gamma ray bursts in Andromeda level. We would have had to have been really lucky to measure something in initial LIGO.

Ben: Ok, so LIGO's really funny. Essentially there are these two arms. It's kind of a big 'L' shaped system essentially. These long hallways. They put these mirrors and they bounce lasers back and forth along each mirror.

Robot: When you are talking about longer, are talking about meters or kilometers?

David: Kilometers long.

Jocelyn: Four kilometers.

Robot: Ahh, super neat.

[29:55]

Ben: And so what they do is they compare the signal of one laser going down one arm with the laser going down the other arm to see if the distance changes. So it's been a really interesting time as a gravitational physicist these kind of the last ten years as we've all kind of developed our careers from undergraduate. When we were young undergraduates, we're still kind of building them. The idea is that they kind of listen to gravitational waves in the same way your ears might listen to the things. They would get this signal that they are listening for, but then they have to process the signal. It's kind of like, have you ever gone somewhere exotic and it's night, and maybe you're in the jungle and you hear all of these sounds. You're camping and you're like, "What made that sound? I don't even know. Is that a bear? I can't tell." Right? You don't know what the sounds anything makes, so even if you're hearing something, it might be meaningful or might not be meaningful. And so over the last decade and a half or so or maybe longer, it had these theoretical physicists working on figuring out what kind of... we'll call them sounds, these different systems will make. So like to colliding neutron stars with various masses, what sounds are we looking for in the data what would that sound like? And so they're building a big, big kind of database full of different sounds, that they pour through the information when LIGO's running to see if they can decipher any of these sounds.

David: They also have a speaker in the control room.

Ben: Do they?

David: Yeah.

Ben: Oh, that's amazing! Ok, so let's actually listen to the sound now. I sent you a sound file. Have a listen to that now...

[WwoooooOOOO-OOP!] [WwoooooOOOO-OOP!]

Robot: A 'Woop' sound.

Jocelyn: Yes. Ok, so just like sound is fluctuations in air pressure, this is the fluctuations in the distance between things that we've talked about earlier. And the way your ears converts air pressure into sound, we've converted the pattern of fluctuations of distance into a sound.

Robot: That's cool.

Ben: So this is merging neutron stars, and Jocelyn mentioned earlier. So what happens is you get kind of a runaway effect. So it's a fairly subtle effect is this slow ebbing away of energy in gravitational waves until the neutron stars get fairly close together. And then they're moving so quickly, so they must be accelerating so hard and they're so dense. So their gravity's so impressive that they leach a ton of energy. It's something like 5% of the systems energy, so am immense, a ton of energy goes into these things as they slide together, and so that's the WooooOOP!

Robot: It's such a cute little sound for such a ginormous astronomical event.

Ben: I know, right?

David: That's very far away.

[32:32]

Jocelyn: Well, it's also because it sounds high pitched and cute because these neutron stars are moving around each other hundreds of times a second at the end, so which is 100Hz, which is sort of like the mid frequency in that chirp, and so as they go faster and faster and closer and closer, your ear just hears that as a Whoop!

Ben: so Jocelyn mentioned earlier that the LIGO ear, if we want to call it, is sensitive to certain phenomena, the same way ours are. We can't hear some things that are too high pitched or low pitched, right? So analogously, the original LIGO that they set up could only hear certain phenomena, and it turned out these phenomena are kind of rare. It's a rare thing to hear two neutron stars colliding. It doesn't happen very often, and so the deal is there might be only one bird in the forest, but if you've got good enough ears you can hear it from far away. So the original LIGO detector wasn't sensitive enough to hear over a large enough volume of space. So when they finally turned it on and got it tuned up and everything was great, they didn't hear anything because what they were listening for was too rare.

Jocelyn: Too faint.

Ben: Yeah. To faint, too far away. It wasn't scandalous, it made sense, but it was kind of disappointing, gravitationally, because all this work went into it. You go to conference after conference and people would talk about how, "Next year, results! It's going to be all tuned up next year!", and they finally turned it on and they didn't hear anything.

David: People knew that the odds of hearing something were initially very low. It's always about what they could do.

Jocelyn: Yeah. It's like one in a hundred or something where the odds that over the whole initial LIGO run it would actually get a detection.

Robot: So how much more are they expecting to hear with this new release?

Jocelyn: A thousand times more!

Robot: That's a lot more!

Jocelyn: The expectation is tens of signals. It could be maybe a couple a year, it could be hundreds a year.

[34:24]

David: This comes back to a point that you mentioned, Robot Hugs, is that it all depends on how being these short gamma ray bursts are. If they shoot their jets off in a very, very narrow cone, then there are a lot more of them. But if their cone is very wide, then there aren't that many more mergers that we just don't happen to be looking at. So depending on whether they're really, really skinny cones or really, really wide cones that's sort of what sets the rate of detection for these neutron stars.

Jocelyn: I mean yes. So that's one of the ways you can try and predict how many signals advanced LIGO will be able to see, is to look at the rate of short gamma ray bursts and make some on assumptions about the beaming. That's what gives you sort of one to tens per year of these signals. Once the detector is working at design.

Robot: Is the detector… Should it be able to detect these collisions that we wouldn't be able to see through that gamma rays?

Jocelyn: Yeah, it's sensitive a bit. If it's 'face on', it actually hears it better, too. But it can see sideways ones, too.

Ben: Analogously, you suspect there are lots of people in the crowd with laser pointers but only a few of them get shot at your face. So this will let you hear people turning on and off their laser pointers. You'll say, "Yeah, OK." We know we only see one in every three hundred laser pointer clicks.

David: It's like you're Daredevil.

Ben: It's like you're Daredevil.

David: Daredevil doesn't notice if you shoot a laser pointer in his eye, but he can hear it turning on.

Robot: It's a good analogy.

Jocelyn: So we've been talking off and on about how like, yes, this is super weak. And you know the number I gave you before was so, yes. Advanced LIGO, it detects this relative change in distance between its two arms, and the relative change is equivalent to changing the distance between us and the nearest star by three millimeters. So, over the distance of four kilometers between the center facility and the ends of the arms for kilometers away in two directions, the distance between the mirrors are changing by less than the diameter of a proton.

Robot: Wow. Can we measure that?

[36:30]

Jocelyn: Yes we can. With lots of laser power, very careful seismic isolation, some cool quantum effects, basically all sorts of really crazy awesome experimental development that's been going on for the last decades that allows people to set up this optical cavity. So it's not actually just one laser that gets bounced off the two ends. It actually goes into a cavity and bounces back and forth in the arms, building up power for a while before it comes out. So there's a lot of very delicate commissioning, but, oh! But the exciting news… So in the U.S. there are two LIGO sites. One of the reasons is that a detection has to happen simultaneously with the same signal at both sites for us to be convinced that it's astrophysical and not just some random noise that looks like a gravitational wave.

Robot: There must be an incredible amount of noise that these things have to sift through. I mean, locally and astronomically to get the things you want, right?

Jocelyn: Pretty much all locally. The astrophysical noises all signal to us. So, yeah, there's noise from trucks traveling across roads in the vicinity, airplanes flying overhead...

David: People in Louisiana shooting at the...

Jocelyn: They don't do that anymore.

David: Running trucks into it.

Jocelyn: Yeah. So almost anything can cause the mirrors to jiggle by less than the diameter of a proton. So there's a lot of careful isolation, and then there's also using the models, the ones for the sounds we've made. We look for things that sound like that. For example, like the merger of neutron stars, it actually happens over a couple of seconds. If you can find a sound that changes in the right way, and matches up over the full couple of seconds, you can actually add together the information from a bunch of instance, and get more information out of it and you might be able to without that. So there's a lot of careful signal processing to try to pull out the signals from this noise stream.

[38:45]

Robot: Yeah. You know my profession as an information specialist, I'm just sort of boggled by this. Just the amount of information that is around you that you must be collecting, and then somehow finding this thing that happened hundreds of thousands of light years away making a mirror move a fraction of a proton. Like, just being able to isolate that is an incredible feat.

Jocelyn: I mean, there's also piles of other sensors all the way through the facility, like microphones, magnetometers, and things like that. It's actually one of my colleagues at Fullerton that leads what's call the Detector Characterization Group, and what they do is they look for correlations between the output of the gravitational wave detector and any other fluctuations that happen. So that they basically proactively hunt down anything that could pretend to be a gravitational wave, and try and minimize its effects.

Robot: Right.

Jocelyn: So they like, "Oh wait. There's something happening. This microphone gives a little burst, and then we see it in the gravitational wave channel, so that's coupled together so, you know, is there something squeaking? What can we do to reduce that effect? So there's a massive experimental effort to understand and reduce all the possible sources of noise.

Robot: Yeah. I think I just wondered, you know, when you talk about gravity being a wave, if there's a frequency to that wave.

David: It depends on what the source of that wave is.

Jocelyn: That sound we've played, that's exactly the frequency that the gravitational wave would be wobbling things.

Robot: Right.

Jocelyn: That's sort of, what, 10Hz to 1000Hz.

David: Yeah. So that frequency is twice the orbital frequency of the neutron star binary. Right before it crashes, it gets to probably a few kilohertz, and that's that Whoop! And so it depends on what it is.

Jocelyn: Yeah, so, the ones that we've talked about today are the gravitational waves that are at the kind of audio frequencies because those are the ones that the LIGO detectors are sensitive to. And that's what the sort of typical binary neutron stars or stellar mass binary black hole in the few minutes or seconds before they merge. They are in that frequency band.

David: There's also a much, much lower frequency gravitational waves from, say, merging supermassive massive black holes at the center of merged galaxies. And pulsar timing arrays, where you measure very precisely the timing of certain pulsars, and you see the variation on the distance to the pulsar. We'll be able to measure things in these nanohertz, gravitational waves. Because these supermassive black holes are much, much further apart than the binary neutron stars.

Jocelyn: So their orbits are happening on a slower scale, and then…

David: But they're so massive...

Jocelyn: Yes.

David: Ten to the nine, Supermassive!

Jocelyn: Super is exactly ten to the nine, of course.

David: it's like superman is exactly ten to the nine.

[Laughter]

[41:36]

Jocelyn: Yeah. Pulsar timing is cool because it's actually kind of goes back to the binary pulsar measuring gravitational waves by the orbits changing. That's using the very precise timing of the pulses to measure how the distance between Earth and our nearby pulsar friends changes as a gravitational wave might go through on the scale of the distance between earth and the nearest pulsars.

David: It's a little bit like if you had a really, really precise GPS, that you might be able to tell how you are swaying back and forth by changes in the GPS.

[42:08]

Ben: Well, that was fun. Thank you Jocelyn, thank you Dave. You've pleased me. Your efforts have borne fruit, and that fruit is sweet. Dave, you get a pair of cherries!

David: "Amm Nom Nom!" [Chomping of Cherries]

Ben: They're stuck, now they're merged. Now they're all just one big, mushy… Jocelyn, you get an avocado!

Jocelyn: Wait, wait. I don't think I can bite through this. Ok. "Shunk Shunk Shunk Shunk" [Chomping of avocado]

Ben: Very good! I'd like to thank my guest, Robot Hugs. Hey, Robot Hugs. Did you have fun?

Robot: I certainly did. Thank you for having me.

Ben: All right, that's a great! Ok. Hey, Ti-Phyters, listen. There's four things you need to know. Firstly, please leave us an iTunes review. Whenever I feel sad or tired, I checked the iTunes store, and I read your reviews and they make me feel better. You're nice words are giving me power. Second, there's a podcast out called *Podiversity* for the android phone. It's a subscription for context based app, and it's nearly like Netflix, but it's for podcasts, and they pay us money for each downloaded episode. So, if you get the app, listen to our show on it. Good work. Now, T-shirts! Go to our store off the Ti-Phyter web site, and buy yourself a sweet shirt. Some of them were designed by brilliant designer, Chelsea Anderson from Calgary! They are wonderful shirts. They don't even wear out. You can wear them for years and they won't wear out, and they're gorgeous. People talk to you in the streets if you're wearing them. Fourth thing. If you'd like to contact us, you can send us an e-mail. My address is barn@titaniumphysics.com. I forward people their fan mail, so if you want to tell Jocelyn how great she was, if you want to tell Dave how good his jokes were, you can do that and I'll pass them on. Also, we are on Twitter and Facebook, and Tumblr. If you can find me on Tumblr, good for you. OK, that's it for the main part of todays show. Remember, if you like listening to scientists talk about science in their own words, you might also want to listen to the other shows in the Brachiolope Media Network. I'm gonna talk about *Astrarium* . *Astrarium* is about astronomy, and our good friend James is on it. Or you can listen to *Science... Sort of*. That's pretty fun. There's other ones. *Technically Speaking*, *The Collapsed Wavefunction*. It's about chemistry. Hey guys, we need other shows on science, biology show, that would be good. Show on birds, and, a medicine show? Cool. Ok. So, the intro song for our show is by Ted Leo and the Pharmacists , and the end song is by John Vanderslice. Until next time my friends, good day, and remember to keep science in your hearts.

[45:00]

[Excerpts]

Robot: And so, I remember this argument I was having, and when we looked it up, I was probably going way ahead of you guys. So I was like, gravitons? The theory of what creates gravity and…

Jocelyn: So that's getting a little into something that doesn't actually work very well to describe the Earth/moon system.

Robot: Right.

Jocelyn: So really, whenever you have particles like gravitons or other things, they are excitations in a field, right? We try to detect the Higgs boson as and excitation in the Higgs field. Move up of the effects of Higgs' are from the field itself.

David: Like photons are excitations of electromagnetic field. You can think of them as particles or think of them as waves within the electromagnetic field.

Jocelyn: So if you have the earth and the moon, it's not really a useful way to think about them. They're not firing gravitons at each other. They are close enough that is really better to think of the field as something that's changing in a different picture. So we want to really go back to the field, even though if we have a Quantum Theory of Gravity, then it will produce gravitons. But, Einstein's theory doesn't actually need gravitons at all. It just needs the fields.

Robot: Ok.

Jocelyn: But still, even without the particles, we can have ripples in the space-time, and they will travel like photons to, or like ripples in an electromagnetic field do, the ripples and the gravitational fields will travel at the speed of light.

Robot: Yes.

Jocelyn: And that's basically because the speed of light is just a unit conversion between what we call space and what we called time, which in a relativistic picture, they are not really distinct things. We just happened to use these two different time units and space units but that's the same stuff, and so we have to convert them between them. Ok one 'second' is however many meters.

[46:56]

[Excerpts]

Robot: You know, this is actually very timely because I was watching Cosmos as you do with my partner, and we were arguing about gravity and stars and orbits, and whether gravity moves at the speed of light or not. There was a fairly intense argument until we realized Wikipedia was right there, and resolve it almost immediately. But I'm looking forward to being even more right than I was before.

David: According to Einstein, you are correct.

Robot: Always.

David: like, that's actually what he wrote in the paper. Robot Hugs is correct.

Ben: It's a little bit a big controversy, because nobody knew what he was talking about. But, it was still... Everybody cited it because it was Einstein.

Jocelyn: When was the term robot first used?

Robot: I don't know.

Ben: Are you asking because you know, or are you asking because…

Jocelyn: No. I'm asking because I want to know.

Ben: Oh. There's like a Czechoslovakian play or something, wasn't it?

Jocelyn: Yeah.

David: Yes, yes it was. It may have been a movie actually. I'm not sure.

Ben: They definitely called them robots in Metropolis.

Robot: Yes.

Jocelyn: Right. The term robot was first used to denote fictional automata in a 1921 play.

Ben: From where?

Robot: Wait, wait. Are you looking up Wikipedia right now? Are we allowed to do that?

Jocelyn: Oh, yeah. That's basically how we record these entire things. We just read you Wikipedia.

Ben: Did I get the nation right, too?

Jocelyn: Yes! It was a Chech play. So, so that would be after Einstein's papers. So it was particularly weird if he was referring to robots at that time. We need to rewrite Wikipedia.

David: Actually, he was actually referring to Robo-thugs.

[Laughter]

Robot: That is the bane of my web comic.

Ben: Dave gets the point for doing the pun that I wanted to do but earlier than I got to do it.

[Laughter]

David: Great lines, Ben.

Jocelyn: For a little something different.