Episode 36: Useless Spheres and Wasteful Rockets
Physicists: Jocelyn Read, Jacob Stump

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!

[1:46]

Ben: It's summertime right now and in the summer I like to think about fun things. Now, a megastructure is defined as a rigid, artificially constructed structure which is really, really, really large. So, the Great Wall of China is a megastructure. It is over 6,000 kilometers long. And anyway, let's talk about science fiction because one of the fun things about science fiction is the sciencey part of it. Mostly science fiction writers think about space. They think about what will happen when mankind can
engineer structures that take advantage of space. Objects which are huge! Objects which are megastructures. Megastructures in space. Objects which are wide as a planet, I'm talking about Dyson Spheres, I'm talking about space elevators, I'm talking about ring worlds, I'm talking about things which are so big we'll have to change the world to make them. So, today, on *This American Life* we're talking about space-based megastructures. Now, speaking of changing the world, I'm not sure if you're aware but podcasting has a godmother and she's the prophet of change. She is an author who has been distributing her writing online and she's been podcasting since 2004. Her most popular currently running podcast is called *I Should be Writing*. It's a podcast for wannabe fiction writers where the issues which writers encounter are discussed. It's won the Podcast Peer Award and the Parsec Award. She's also been the editor and host of both the *Escape Pod Podcast*, a show where you get to listen to science fiction stories and she co-founded the *PseudoPod Podcast* where you get to listen to horror short stories. She even founded the Parsec Award, an award show for the best science fiction podcast. And she's been nominated twice for the John W. Campbell award for best new writer. Since the days when I was planning the first episodes of *Titanium Physicists* I've been looking forward to the day where I could teach her a little bit of physics. Welcome to the show Mur Lafferty.

Mur: Thanks for having me.

Ben: So, Mur, you've got a new novel out. It's a monster travel guide, *The Shambling Guide to New York City.*

Mur: Yes

Ben: Ti-Phyters can purchase this from local bookstores or Amazon and we'll link to the book in the show notes. So, Mur, for you today, I've assembled two of my Titanium Physicists. Arise Dr. Jocelyn Read.

Jocelyn: Raaaaaaarrrrrrrrrrr.

Ben: Dr. Jocelyn did her undergraduate at UBC, her PhD at the University of Wisconsin Milwaukee. She's now faculty in the physics department at CalState Fullerton. She's a specialist in neutron stars. Now arise Jacob Stump.

Jacob: Chhhtwwwwaaaaaa Rarrrr

Ben: Jacob Stump is an aerospace structures engineer who works for a major American defense contractor. He got his engineering degrees from the Embry-Riddle Aeronautical University and the Florida Institute of Technology. He's the host of one of the newest podcasts in the BrachioMedia Network, *Technically Speaking* where they talk about engineering. Okay guys, let's start talking about really big space things.

Ben: The deal with space-based megastructures is that it's fun to go into space and getting up into space is a possible solution for a lot of mankind's woes. And we can go into space already but there's a problem with going to space using rockets. It's that, essentially, the higher up you want to go, the faster you want to go, the more fuel you have to take with you as you go up. Have you heard of this before.

Mur: Yeah.

Ben: Yeah. It's kind of like, imagine the days before there was anything outside your hometown. If you wanted to go on a multi day trip you had to bring food and supplies with you in your backpack. But the more food and supplies you brought the heavier your backpack would be and so the more calories you would use and so the more food you would need to go.

Mur: Right.

Ben: Kind of diminishing returns and the same goes for rocket travel. You just need larger and larger amounts of fuel to go higher up. So, now travelers don't have to bring all of their food with them. Like, even if you're hiking on the Appalachian trail, you can pop in small towns every couple of days and get more supplies. And, in essence, there's an idea where, in essence, you build a very large structure, you know, you want to get your little ship out into space, you can build a structure which gives your ship energy along the way and keeps you from having to load up your ship with a whole bunch of fuel just to leave the atmosphere. So, the first one we want to talk about is space elevators.

Mur: Okay.

Ben: So, space elevators are really fun. It's an elevator that goes up into space.

Laughter.

Ben: The name is kind of descriptive. The way they're built is pretty fun. They're not actually towers, you're not building a ziggurat that's a hundred kilometers tall...

Jocelyn: Maybe we should explain geostationary orbit first. So, when we talk about having stuff in a stable orbit around the Earth, the distance the thing is from the Earth will affect the period of its orbit. So, this is like one of Kepler's famous laws of planetary motion and it tells you if you are closer into the thing you're orbiting, you're period of orbit is going to be a lot faster than if you far away. And so there's a sweet spot of stuff orbiting Earth where the thing orbiting will naturally follow a point on the surface of the Earth. So, they always stay on top of each other as the thing orbits and the Earth spins. So, that's what we mean by geostationary orbit.

[6:44]

Ben: So, what a space elevator is, in essence it's kind of like, you know, if you had a tree fort you wouldn't necessarily build a ladder up to the tree fort. Sometimes you would have a rope ladder hanging down from the tree fort that you could climb up. A space elevator is not that different. In essence, it's a rope that leads up to geostationary orbit.

Jocelyn: Well, it has to go a little past geostationary orbit. It's basically the total rope from the part close to the Earth to the part at the farthest end is orbiting as a total object in one of these geostationary orbits so the center of mass is in a geostationary orbit and so it orbits around and it stays with the bit close to Earth staying fixed above the Earth's surface.

Jacob: So, that means you've got to have a nice counter weight out past geostationary orbit in order to keep your center of mass there.

Mur: I think I've got it. I'll go build one right now.

Ben: Yeah, I like to imagine it in terms of throwing a broomstick. Like, you take off the broom handle and the end and you throw it up in the air so it kind of spins a little bit. You can describe the broom handle's motion in terms of two different things. Its rotation around the central point, right? So, it's spinning but then it flies through the air and falls and you can talk about the trajectory of the center of mass. So, there's rotation around the center of mass and then the center of mass is also moving if you do this and you can build a space elevator with a really, really long broom handle if you wanted to. So, the center of mass would be in geostationary orbit and then it would be rotating around the center of mass with the same period that it goes around the Earth so that as it goes all the way around the earth the bottom of the stick is facing the Earth.

Jacob: The unit of gravity is...

Mur: So, why don't we have one of these?

Ben: Good question. Okay, so part of the reason we don't have one of these is that there's a significant amount of force on the string hanging down from orbit. And so you need a material that's really, really strong. And, so if you wanted to build one on the moon you could make it, the string out of Kevlar and your little elevator could attach itself to the string and get electricity from the ground on the moon and power your way up into orbit. But if you're doing around the Earth it's too far. The gravity of the Earth is too strong and so it requires quite a lot more tension. And so there's only one material that we know of that's strong enough that we could build a space elevator out of.

Jacob: Carbon nanotubes.

Jocelyn: Yeah, if we try and build it with, you know, things that we're used to building stuff out of, it will tear itself apart from all the stresses of the tension that's holding it taught. So, that would be bad.

Jacob: Yeah. What's really cool is that these carbon nanotubes have been theorized for a long time and science fiction authors called them carbon monofilaments a long time ago. And the basic idea is just that on a molecular basis it's very, very strong. It's a really strong molecular structure and so it can withstand much higher tension than anything else in the world. I think what I heard for a space elevator is you would only need a carbon nanotube rope about an inch or two thick in order to build your space elevator on. So, really, just the problem is building it long enough because we can already build carbon nanotubes. It's just a matter of making enough of them and making them connected.

Jocelyn: I guess, I mean, if you think about nanoscale, that's the sort of, the scale of atoms themselves and so even getting from that scale up to only an inch thick is a significant amount of building.

Jacob: Right.

Mur: Uh, you would need other building materials to actually make it an elevator. Just attaching a weight to the top of a string and saying, yay, we did it, doesn't really accomplish anything.

Jacob: Right. Yeah, I mean that, that's kind of like the base on which we would build the elevator. We could climb the rope once the rope is aloft. That's the basic idea but you're right, we would need to build some sort of climbing system either with a counter weight that actually drops back down to the Earth or with just an electrically powered climber that slowly climbs from Earth to space. And the really cool thing about it is that with rockets it becomes easier and easier to change your elevation as you get higher up in the atmosphere. But with a space elevator it's the same constant effort all the way up. You're not really having to contend with air resistance, especially if you're going slowly. And so you can do it by taking your time you can really use engines that totally, 100% exist already in real life. So, we could get huge amounts of material up into space with this method if we just get the string up first.

Jocelyn: Once you have a string you can imagine running some sort of electric source up it so that you can just power little motors to climb up it and it doesn't have to be carrying it's own energy the whole way, it's just using the energy that it gets from the strand so that's sort of maglev style transportation up and down the string. That's one of the common scenarios that you'll see.

Mur: Okay.

[11:28]

Ben: So, space elevators are fun but they're only kind of the tip of the iceberg for awesome things. It kind of leads to another totally awesome way of getting into space that's a lot more ridiculous and fun. So, when we started out saying that, you know, a big extended object will have a center of mass and that center of mass can be in orbit and then it will rotate around that center of mass and if you're not too attached to the idea that your space elevator is stuck at the bottom to one point, you can make, essentially, a great big hammer in space that is spinning around a center of mass in orbit but whose handle enters and leaves the atmosphere. A big, you know, 100 kilometer long handle that swings down, almost touches the Earth, and flies back into space. And that doodad is called...

Mur: You've been watching *The Avengers* again, haven't you?

Ben: No! It's called a space hook!

Jacob: Mur, do you know what a bolo is?

Mur: Yes.

Jacob: Okay, so a bolo is a thing that you'll throw that has two counter weights on either end and when you throw it there's tension between the two counter weights and it spins but the trajectory of the entire bolo is defined by the center of mass of the two spinning objects. So, when you throw a bolo each one of the balls is spinning individually around a center of mass but if you just plot that center of mass as it travels it would do the same thing as if you had thrown a ball. Well imagine you have a bolo that is spinning in space in orbit. So imagine instead of the moon we have two moons that are connected by a string and they're just spinning like a bolo but they're still orbiting Earth about that center of mass. Well, what you can actually do is you can make an engineered structure where you put this into a low orbit such that one of the ends of the bolo just kisses the atmosphere for a little awhile. The other end is well out into space but one end kisses the atmosphere a little bit and then comes back out into space. And we can take advantage of that because we can fly an airplane or a rocket or something and catch on to one end of that bolo and then ride it up into space. So, we're using the momentum of the sky hook, we can ride the sky hook up into a higher orbit in space. And the amount of energy that the sky hook has lost because of us grabbing onto it and because it went into the atmosphere is relatively minimal compared to the total amount of inertia that it has. So you can stabilize the orbit with just a little bit of rockets here and there. But it's pretty cool because it allows you to use reusable aircraft to launch large payloads up into space. You know, you could just fly some cargo aircraft up and catch one end of the bolo, drop off your cargo and then go back down and pick up your next load.

Jocelyn: But you'd kind of have to build it in space. How would you get it rotating?

Jacob: Yeah, you definitely have to build it in space. In order to get it rotating you would have to have each end of the bolo have it's own rockets or some sort of propulsion. And then after you get it spinning you can use that thrust vectoring, that's the term that we use for, like, fighter aircraft, you can use the thrust vectoring to stabilize its orbit by shooting just a little bit of thrust here and there in odd directions. It wouldn't just be rocks on an end of a string, it would be like spaceship on the end of a string and a spaceship on the other end of the string.

Ben: Jacob, what's a mass driver? Explain what a mass driver is.

Jacob: So, a mass driver is just an electromagnetic rail gun. It's like a maglev train except that one end of the track hasn't been finished yet so whatever's on the track just flies off. It's actually one of the other ideas for a space superstructure for launching. You know, back in the 50's Arthur C. Clark, when he wrote in *2001 A Space Odyssey*, he theorized that in the future all space launches would be done in three stages. The first stage would be an electromagnetic rail launch where you have a vehicle that you're bringing up to massive speeds like Mach 5 on an electromagnetic rail and then that vehicle launches off the rail and goes high up into the atmosphere. And then at a certain point it separates and it has one portion that's a rocket that continues into space and another portion that's an airplane that comes back down to Earth and collects the next payload to go on the electromagnetic launch track again. So, the only difference, really, between that system and a mass driver is that typically when we say mass driver we assume that what we're shooting is not going to provide it's own thrust afterwards. That it's just going to be momentum that's carrying it after that point.

Jocelyn: This is kind of like how CERN works, right. The Large Hadron Collider is basically accelerating stuff, electromagnetically, to super high speeds to smash it together. But you could also use this to fling stuff off the planet instead of crash it together.

Jacob: And the reason why we have built something like CERN but we haven't built something like an electromagnetic launch track is that particle accelerators can be done in a loop. Where you can make really big loops maybe five miles long but if you want to really launch a space shuttle you're going to need a linear track and that linear track is going to need to be hundreds of kilometers long in order to really be affective. So, it's a much larger structure that would be required.

Jocelyn: And also you want to accelerate things that are bigger than protons or whatever. At, like, CERN they go around in a circle, each time they go around they get a bit faster so you build up the speed. But to launch it off Earth you can't do that. But that would be another way to avoid rockets because the power is coming on the ground and then you just fling the thing off.

[16:40]

Ben: So, none of those particular ways of getting into space are that crazy. I've just learned about one called a launch loop though that's totally crazy. And the idea is that it's kind of like a ski lift so there's going to be a big cord that you're kind of going to attach yourself to but unlike a ski lift it's kind of held aloft by it's own momentum. So, the idea is that you have this long strip 4,000 kilometers of this metal cord. You know, imagine you take some rope and you throw it, it's going to kind of fly forward, land on the ground. But instead of just throwing it a little bit you're going to throw it really, really hard, so hard that it comes back to Earth 2,000 kilometers away. And then at the other end you're going to catch it and turn it around and relaunch it in the other direction. So, it's going to fly along on a parabolic arc through the atmosphere and then it's going to turn around and come back 2,000 kilometers and then your going to detach the ends of it so you have one single loop that's going up, you know it's 2,000 kilometers either way, and down and it's held aloft by its own momentum. And the deal with this is, you know, it can go up, out to space. You know, you engineer all sorts of things around it, you make it so it doesn't lose energy to friction so you're always pumping a little bit more kinetic energy into it but in essence you could attach yourself onto one end of it the way you do, say, a tow rope on a ski hill and once you're up into space life is easy. Crazy!

Jacob: Did you follow that Mur?

Mur: Totally.

Laughter.

Mur: Now, see there's a point where I don't even know what question to ask.

Ben: I know. Can you, I mean, it would be like bigger than mountains. Can you imagine this great big cord jut flinging off into the sky? And then you, like, tell your grand kids, Oh yeah, that thing lands on the other side of North America. And then they can use it to get into space real easy, not like when I was a kid.

Jocelyn: Just do your grappling hook up and get carried off like Mary Poppins except with a giant cable.

Mur: So, you say it's so easy but why don't we have it yet? Is it because it would be very difficult to build in the first place and after that it's easy?

Jocelyn: Well, first off it requires like crazy, advanced materials to withstand the kinds of tension and forces. And it also requires like huge amounts of energy of that investment to get things started. And it also usually requires like really complicated engineering to control it and keep things from going unstable and having like a massive like mountain sized pile of cable crashing into some city.

Jocelyn: Another thing is, a lot of these things, they have a sort of a lower limit of making a prototype which is a huge initial step. Right, like, with a rocket you could make a little rocket, you can build up from there. But if you're making a space elevator, without say, going to the moon and making a little prototype moon sized space elevator which has it's own set-up costs, you have to start with something that's pretty huge to even get anything that works as a space elevator. It's a complex system and you can't build up to it in pieces and really test them until you have the whole thing.

Jacob: I think the real answer those is the sad reality that these systems are so expensive that it would require huge international commitments to build them and it just, nobody is willing to do that. It would be like building an underwater train tunnel from here to England. It's definitely possible but we don't because they're extremely expensive But once you ignore that fact and just think about with an unlimited supply of materials and an unlimited supply of manpower and an unlimited supply of capital, what could you build?

Mur: Okay.

Ben: There's this movie *Elysium* coming out about a space station. In essence, there's no room left on Earth to, you know, suntan and enjoy a good life so the rich people all build a space station and go live on that. So, one idea is that building things out in space might help us deal with the fact that there is a finite amount of area on which we can live on the Earth. So, let's start talking about building things in space that you could live on. Suppose that we've conquered the getting into space part of it, let's start building things that we can go live on.

Jacob: Mur, have you seen the preview for this movie?

Mur: I have, it looks like if I lived on Elysium I'd be vomiting a lot. Because isn't, isn't the Earth right above your head?

Ben: Ah, no.

Mur: No?

Jacob: The idea is that the space station is constantly spinning in order to simulate gravity while you're on this circular space station.

Mur: Sure.

Jocelyn: But it would have to be big enough that you don't really feel it as a spin. There's this relativity thing is that any acceleration is indistinguishable from gravity on like a small enough scale.

Mur: Sure.

Jocelyn: So, you spinning around, you're continuously getting pushed to keep in this circle and that feels exactly like gravity would be and as long as it's big enough that your head and your feet are not feeling different accelerations you'd walk around on this thing and you'd feel like you were just walking around on a planet. But, the acceleration downwards from your perspective is actually a centrifugal force.

Ben: There are these rides at the fair...

Jacob: It's called the graviton.

Ben: Yeah, yeah, gravitron! Have you ever been on the gravitron Mur?

[21:37]

Mur: Yeah, but that's not quite what I was talking about. I was more talking about just the visual vantage point of living somewhere where the Earth is above your head by your point of view.

Ben: Right.

Mur: And yeah, I know you would have gravity. I know how that would work. I'm just, just the optical illusion of I'm about to fall into the Earth would be enough to make me vomit.

Jacob: So that the thing about the movie *Elysium* is that they used the design of the, of something that a group in Stanford came up with back in the 1970's called the Stanford Torus. And the Stanford Torus had like glass panes on the ceiling that could be shuttered to direct the sunlight into the area so you wouldn't exactly have a single point light like you're used to. It would be more like having natural sunlight coming in through skylights in the ceiling. And so you'd have that all the time and it would kind of cause the windows and the ceiling to be opaque and you wouldn't really be able to see through them during the simulated daytime. But then at simulated night time the glass would shutter a different direction and cause the sun to not be reflected through and then you might be able to see the Earth depending on if they want that.

I'm sure there's windows in the sides where you could see the Earth whenever you wanted though.

Jocelyn: It's the view that's the best part of going into space.

Jacob: Right.

Ben: So these Stanford Toruses are about a mile in diameter. You can imagine making even larger structures right. Tube shapes are nice because you can spin them around one axis...

Jocelyn: Oooh, Oooh, Oooh. We should... so, have you read *Ringworld*?

Mur: No.

Jocelyn: Oh my gosh...okay.

Mur: I know what it's about but I haven't read it.

Jocelyn: So this is just one of the classic science fiction stories of a mega structure and it starts from the same thing where you just have a ring and it's spinning. But this time instead of being a mile across you have the ring covering the whole orbit of the Earth. So it's a ring around the Sun at the distance of a planetary orbit.

Jacob: So it would just be massive. More massive than we could probably comprehend.

Ben: So, if you wanted to make one it would take two Neptune's worth of mass. So, you would go out and you would go phone god and you would say hey god, the solar system according to these specifics. And he would would say sure Ben and he'd go out and he'd grab Neptune and Uranus and he would smear them out like clay and make a big hula hoop with it. The radius would be about the orbit of the the Earth's radius and then he'd have to spin it. If it wasn't spinning the system, essentially it's a big rigid hoop. It would be able to kind of not collapse into the sun from it's own rigidity. But if it was just sitting there or even rotating once a year the way the earth does, it wouldn't feel any net gravity. The people sitting on the inside of the hoop wouldn't feel any net gravity or at least not too much. So, you'd have to spin it fairly quickly. The greater spin of this hoop is what provides gravity. It's kind of like on the Stanford Torus, everybody is stuck to the inside of the ring and the axis of rotation goes through the center of the sun so you look directly up and you'd see the sun at the center.

Mur: Okay and what was the point of the Ringworld?

Jocelyn: It's one of these like we ran out of room on Earth, we want more space, and so now you have three million times the surface area of the Earth.

Jacob: Yeah, and in the book they happen upon it and they arrive at a time so far past when it was constructed that practically none of the original creators of the Ringworld are still around. So, the only thing you can really assume is that somebody needed the space. But, you also have to assume that they had to destroy a ton of planets in order to make the material to make the space so maybe those planets were uninhabitable.

Ben: The planets aren't that good in terms of space. Like a sphere the ratio of the area on the surface of the sphere to the volume contained within the sphere is minimized. So the sphere, if you want to make something that things can live on, the sphere is pretty much the very worst shape that you can get if you want things to efficiently live on it.

Jocelyn: So for a different amount of mass if you want to create a bunch of area the sphere is the worst kind of way to do that. And the other kind of thing of making these kind of macrostructures is that one of the fundamental limiting things of what we could do on earth is we are limited by the amount of energy available. So there is a fundamental limit and it is set in sort of the long term by how much solar energy hits the earth. That is the energy input that we use to do everything that we would like to do. I mean...

Ben: So, if we wanted to use as much energy as we could we would eventually cover the face of the planet with solar cells and capture as much of the solar radiation as possible. But why not put solar collectors out space, eh? So then you like, unless you cover the entire area of the sun somehow with solar panels there is always going to be a little bit more energy that you can take from the sun. So eventually you're just like hey why don't we cover the sun with solar panels and use that to run our dishwashers and dog cleaners and...

Jocelyn: Ew. Priorities.

Ben: Yeah. Freeman Dyson came up with this idea. He's like hey why not capture every single photon that comes off the sun, will hit one of these solar collectors. Why not make something called a Dyson Sphere which is a big, rigid, hollow sphere that you surround a star with in order to capture every last bit of energy coming out of it.

[26:40]

Jocelyn: And give you lots of precious living space because this was before everyone assumed that we'd just upload ourselves into the Internet and so we just needed, like, physical space for huge civilizations to wander around in.

Jacob: But obviously this idea is pretty insane because it would require even more material then a ring world and so a more realistic way to capture massive amounts of energy from the star would be what they call a Dyson swarm where it's really just millions and millions of satellites with solar panels and you surround the star with those satellites so that it's basically like a constellation. We call our GPS satellites on Earth a GPS constellation of satellites because they surround the earth in a pretty symmetrical pattern all the way around. And so this Dyson swarm would be a swarm of satellites with solar panels that surround the sun or star and collect massive amounts of energy from it but not all of it. And it would be much simpler to create because then you just have to mass-produce individual satellites. You don't have to build a space superstructure.

Ben: Yeah, so somebody did a calculation on a big Dyson Sphere, the big solid one and they figured out how much usable mass, so mass that isn't gas in the solar system and they found 10^{-26} kilograms. If we made a Dyson Sphere with all this matter in the solar system how thick would it be? And the answer is you could get an 8 cm thick Dyson Sphere if you put it about the radius of the Earth.

Jocelyn: For, like, that's all the planets combined?

Ben: Yeah, yeah, that's right.

Jocelyn: That's actually bigger than I might have expected.

Ben: Yeah.

Jocelyn: Oooh, Oooh, astronomers are looking for Dyson Spheres.

Mur: Looking for them?

Jocelyn: Yeah, like when we look into space and we catalog all the stuff we see we try and see the signature of what we observing is not a regular star but a Dyson Sphere.

Mur: Okay, how do we see that?

Jocelyn: The key thing is that you would expect something that's a Dyson Sphere, it would eventually have the same luminosity as the star it's surrounding because what you do with the energy is you do whatever technology your civilization wants to do but you do always end up with waste heat at the end of the day. There's a limit on the efficiency of what you do. So, you end up radiating away the waste heat from what you've done with all that solar energy on the backside of the Dyson Sphere at what turns out to be an infrared temperature for Earth's orbit sized spheres. So, you look around space for stuff that looks like it's infrared radiating object that doesn't fit the parameters of like a really dim, cool star but is some weird, huge solar luminosity style structure that would be radiating in infrared. Isn't that crazy?

Mur: Cool. That is crazy.

Jocelyn: Yeah, so, I actually happened to meet, last week there was a professor at Cal Poly - Pomona, Matt Povich who is doing this work. He's actually looking through catalogs for infrared observations that could be Dyson Spheres and apparently, so far, no one's found anything, but...

Jacob: The implications of finding one would be crazy right. I mean, it would be evidence of not just alien life but alien life that is so incredibly advanced that they've built basically the most complicated structure that humans can possibly imagine.

Jocelyn: Well, that's not actually true because humans have pretty good imaginations and one of the other things you can imagine is a civilization that was not only capturing all the energy of a star but a significant fraction of the energy of a galaxy.

Jacob: You would build a structure around a galaxy and capture energy from multiple stars? Is that the idea?

Jocelyn: Or maybe individual structures around a significant fraction of the stars in a galaxy.

Jacob: Uhhuh.

Jocelyn: So you look at galaxies in the nearby universe and you try and find ones that look redder than they should be and that would be evidence of this kind of type 3 Kardashev civilization is one that is in possession of energy on the scale of it's own galaxy.

Mur: What would type 1 and type 2 be?

Jocelyn: So a type 1 is what you can do just absorbing all the solar energy that would hit Earth. So, we're not at type 1 yet. We're sort of approaching, we're below type 1. And then type 2 is the Dyson Sphere, so that's all the energy of a star and then type 3 is all the energy of a galaxy.

Mur: Wow.

Jocelyn: But, yeah, so you start thinking about space structures and the next thing you know you're looking for red galaxies to see if there's some enormous galaxy spanning civilization very far away.

Ben: Yeah. I've got one more factoid about Dyson Spheres if you'd like to hear it?

Mur: Sure.

Ben: Alright, so the idea here is that there is a symmetry that exists in gravity which is that if you're on the inside of a big hollow, perfectly shaped sphere, you can't feel the effects of the gravity from the mass that was used to create that sphere. A classic example is if I dug a hole to the very center of the Earth, when I was at the center of the Earth I'd feel weightless because the gravity pulling me is from one side, you know, of the sphere mass on my left would cancel out the pull from the sphere the right. And anywhere you go on the inside of a big hollow sphere you can't feel any gravitational attraction.

[31:47]

Jocelyn: It always just cancels out like the near side and the far side, they always cancel out so you just float around inside the sphere without any gravitational pull that signifies that there's this massive thing of matter surrounding you.

Ben: So, the deal is if you have a Dyson Sphere it's a big hollow sphere and while you're constructing it the components making up your sphere, the different panels, spherical panels that you're putting in place will all feel gravitationally attracted to the sun. But once you've attached them together in a big hollow sphere all of their gravitational attraction towards the sun will kind of cancel out and so the sphere won't feel any gravity from the sun and the sun itself won't feel any gravitational attraction towards the sphere. And so the sphere is no longer anything like being in orbit around the sun. They'll decouple from one another so if you had a Dyson Sphere and a comet came in and it wanged against the Dyson Sphere, maybe knocking it a little bit towards the sun then the Dyson Sphere would drift closer and closer and closer to the sun. There are no really gravitational forces keeping the sun at the center of the Dyson Sphere.

Jocelyn: It's unstable.

Ben: It's unstable. Your gravity, your sphere will end up hitting the surface of the sun and melting and then everything will go bad!

Jocelyn: Yeah. So not only do you have to build this hypothetically huge megastructure then you also have to actively keep it from going unstable. So, maybe that's why we haven't seen them because whenever advanced civilizations build them they crash into the sun and exploded.

Ben: Alright, that was fun! So, thank you Jocelyn, thank you Jacob. You've pleased me, your efforts have born fruit and that fruit is sweet. Jocelyn you get a banana.

Jocelyn: Nom, nom, nom.

Ben: And Jacob you get a cantaloupe because it's shaped like a Dyson Sphere.

Jacob: Nom nom nom.

Ben: I'd like to thank my guest, Mur Lafferty. Mur, thanks for being on today.

Mur: Thank you guys I learned a lot.

Ben: Hurray! Alright, Ti-Phyters, remember her book *The Shambling Guide to New York City* is now in book stores or on the Internet. You should probably go check it out.

Ben: Incidentally, Ti-Phyters, listen, I love the show and I love hearing from you. Let's suppose you want to interact with us? Why not follow us on Twitter at @titaniumphysics or you can join our Facebook group. And if you'd like to hang out with us and socialize why not join our online forum the Brachioboard is a fun place where fans of the BrachioMedia Network gather to chat about science and things. If you want to send me an email directly to ask a question or propose a topic you can email me at barn@titaniumphysics.com or if you'd like to tell me nice things email at the fan email thing tiphyter@titatiumphysics.com. I'm always happy to hear nice things. Okay, that's it for the main part of the show. Remember if you like listening to scientists talk about science in their own words you might also want to listen to other shows on the BrachioMedia Network like the Weekly Weinersmith where Kelly and Zack Weinersmith talk to academics about their research or Science Sort Of where we talk about science in the news or, our new baby brother podcast, Technically Speaking! It's Jacob's show!

Jacob: Yayyyyy!

Ben: Alright, they talk about engineering. So, editing support for the Titanium Physicists Podcast is provided by a gentleman named John Heath, thanks John! The intro song to our show is by Ted Leo and the Pharmacists and the end song is by John Vanderslice. Until next time my friends, good evening and remember to keep science in your hearts.

[36:40]

Jacob: Yeah. I think I can give a generic statement as to why we haven't seen massive advancements in space technology in the past few decades and that's that as the 20th century turned into the 21st century our technology got more and more complex. It had more and more subsystems to build a single system and when it gets to a certain point where something is so complex that a single person can't hold all of the details in their head that we have to develop different ways of thinking about those systems in order to truly understand them and control them. Really the forefathers of this kind of thinking were Wernher von Braun when he worked on the Apollo program because the system of the Saturn V rocket was so complex that not even he who was the designer and really project leader, understood everything about it. He had to have other people that were focused on smaller aspects of it. But he had a top down view to make sure that everybody else was doing their job and then assumed that everybody else knew what they were doing. And so that's what's really happened with a lot of areas of technology. I mean with aircraft in particular and spacecraft, we're making less and less different kinds of aircraft and single aircraft that can do more things. So where we used to, during World War II have a fighter aircraft and a bomber aircraft and a reconnaissance aircraft and maybe three different types of each of those. Now we have a single aircraft that is a fighter, bomber, reconnaissance mixed. And really, the amount of work that it takes to create that complex combination is greater than the sum of the three individuals. Because now you have to worry about the complex interactions between the two. And with space elevators and sky hooks and launch loops. They are very complex systems because on a simple conceptual basis all it is is an iron rope that's 2,000 miles long and while that's something that maybe we haven't made yet it's certainly not crazy to think that we could, it just would be really expensive and who's going to pay for it. But the systems that would be required to make it safe and reusable and consistent are things that we haven't yet developed and things that are two complex for one person to understand.

[39:07]

Jacob: So, that's the basic idea.

Jocelyn: Do you actually like, I mean, you still have to get the rocket, the energy to get the rockets going up there to begin with. For the amount of energy that, to get the inertia going so do you actually win out in the end once you factor in how much energy it took to get the thing going.

Jacob: Ah, well, it's a relatively reusable system so theoretically as long as you get a lot of use out of it then you might be able to make the life cycle cost win out in the end. But you're right it's going to require a huge initial energy investment.

Jocelyn: Yeah. I guess you could also refuse whenever one of the stations is low so you get some advantage.

Jacob: Uh huh. Yeah. You could even put a mass driver on the moon and shoot, you could have, you could have the moon shoot out some pieces of moon ore and just smack the bolo every once in the while to keep - you wouldn't even need rocket fuel.

Ben: Okay.

[40:27]

Jacob: Thousands of individual strands of carbon nanotubes would have to be combined in order to make it an inch or two thick.

Jocelyn: Is it only thousands?

Jacob: Ahhh. I don't know. That's just a guess.

Jocelyn: Nanotube width...

Ben: Millions isn't it? Nano is E^{-6}

Jacob: Well.

Jocelyn: Nano is E^{-9}.

Ben: Nine, okay. So, tens of millions to get it a centimeter.

Jacob: Is that, but, is that how big an actual carbon nanotube actually is? Like, what's the actual width of a carbon nanotube?

Jocelyn: Right, well, it would be a few, a few... A few, it would be maybe tens of nanometers... Or.... Hundreds? I'm guessing.

Ben: Yeah, they're pretty small.

Jacob: The diameter of an ideal nanotube can be calculated as follows, ah, blah, blah, blah, blah, blah blahhhhh.

Laughter.

Jacob: It's, it looks like it's... Well, 4.3 angstroms in diameter. What is that little a with the little funny symbol.

Jocelyn: Angstroms, that's 10^{-7} I believe. So...

Jacob: A bunch of them. You need a bunch of them, how about that? Does that work?

Jocelyn: You need like millions of them. Probably. Close to a million.

Jacob: Yeah. Cool.

Jocelyn: How many, probably in labs we're building like, I don't know, what, probably I'm guessing right now like tens at a time or hundreds at a time.

Jacob: Um, there's actually the one lab that's produced, I don't know, kind of like a weird liquid powder mixture where you can extract nanotubes by literally pulling them out and they kind of like form on themselves. Like, they self coalesce and they attach to each other and it forms a visible, a visible string. Um, but just barely visible, I mean like smaller than the thinnest fishing wire you've ever seen. I can't remember, you know, what the other details of it . Oh, there it is. The process was developed by Richard Smalley and his co-workers at Rice University. So.