Episode 60, "Meters of Interference"
Dramatis personae:
- Ben Acker
- Sabrina Stierwalt
- Rupinder Brar
- Ben Tippett

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Ben T: Never be afraid. There's nothing which is known which can't be understood. There's nothing which is understood which can't be explained. For over 50 episodes now, my team and I have brought you to the very frontier of knowledge in physics and astronomy. And still our mission goes on. To present you with your birthright: an understanding of the Universe. I've traveled the world seeking out a certain type of genius. Masters of not only their academic disciplines but also at explaining their research in understandable ways. And I've bestowed upon these women and men the title of Titanium Physicists. You're listening to the Titanium Physicists Podcast and I'm Ben Tippett. And now... allez physique!

01:11

[Intro song; *Tell Balgeary, Balgury Is Dead* by Ted Leo and the Pharmacists]

01:46

Ben T: I'm really bad at archery. About this time last year my wife and I decided to start learning archery so we bought a couple of recurve bows at the archery shop and they gave us a free half hour lesson and then we just started attending biweekly archery nights at our local fish and game club. Anyway, like I said, I'm kind of bad at it. Here's the thing: when I pull back an arrow and let it go, it won't always go in the direction I've aimed the bow. And that's because I have bad technique. So yeah, little things, like how I'm holding the string, how I line up the shot, how I let go of the string, how I hold the bow, they're all slightly different each time and these differences add up. So, the arrow mostly goes in the direction I point it - give or take - but that means that after I've shot a couple arrows they all are kind of spread out on the target around near the point I aimed at. So why do I care? Well, suppose I go blind and decide to suddenly start sensing the world around me by shooting arrows at things and listening to the sounds they make when the arrows hit them. You know, I'd aim the arrow to the left and let it fly and then I'd hear a quack and then I'm like "Yes, there's a duck over there to the left". And I aim an arrow to the right and I let it fly - bonk - okay, it's concrete wall over there, okay? So, the bad archery technique would present a problem with this plan, because the arrows aren't necessarily going where I aim the bow. I don't know if the duck I heard quack was exactly where I aimed it at or off to the left or right or above it. I only have a vague sense of where these things lie. And this is relevant when we want to talk about looking at stuff. Those of you who are nearsighted, now's a good time to take off your glasses to see what I mean. Unless you're driving - hold on - then pull over and take off your glasses. There are different aspects to seeing things. Sure, recognizing color's a part of it, detecting light is a part of it but one big thing that's super desirable when you're looking at things is the capacity to be able to differentiate between an object and the stuff you see around it. The reason you shouldn't drive with your glasses off is because the light is no longer properly focused in your eyes and the shape of everything becomes blurred and you can no longer tell where an oncoming car ends and the road begins. So even though you see the lights from their oncoming headlights, you can't quite tell where it's coming from. It the same problem as the one with the bad archery. So the issue here is called angular resolution. If you're to put protractor up to your eyes you could be able to describe the limits of your capacity to see things in terms of how many degrees wide the smallest things you can see are. I'm nearsighted but with glasses I've got pretty good angular resolution. I can see the details of the craters on the Moon and I can see the silhouettes of trees on the faraway mountains but without my glasses I can't distinguish between the hairs on my arm, for instance. Now, okay, okay. So the reason I'm going on and on about this and it's really neat. There are fundamental limits to a lens' angular resolution. Even if the lens in my eye is perfect and I don't need glasses, there are still limits to how far away I can see. And the basic limit is this: the smaller the diameter of the lens, the smaller its angular resolution is gonna be. And the less detail it's able to resolve. This has to do with the wave nature of light and interference but the limit is actually the ratio between the width of the lens and the wavelength of the light. Now, big lenses offer two benefits. First, they catch a lot of light. That's why fish at the bottom of the ocean have really big eyes. And that's why telescopes and binoculars have such wide lenses. Fewer photons means that you need a really wide net to catch it off to make an image. But the second is that the wider a lens you have, the better the angular resolution it offers. So the smaller your eye's diameter is, the less detail you can see. Antlions are a type of bug that eat ants. They don't look like lions but to ants, they're lions. These have really, really little eyes. And as a result their angular resolution is only about 5 to 10 degrees and that's enough only to see an ant that's maybe a centimeter away from it. Which does its job, I mean it's not gonna jump on an ant that's 2 centimeters away from it but it's absolutely crazy! They're super blind. And not because their eyes are bad, just because their eyes are too small! Okay. So, telescopes. This is/ get back to telescopes. You point your telescope in a certain direction and you see some light. The angular resolution of the telescope tells you whether the light you detected is really coming from the direction you pointed the telescope or off to the side somewhere. Radio telescopes have a really, really bad angular resolution. This is because radio waves are so long. This is why radio telescopes need to be so wide. And I'm sure you're familiar with the Arecibo telescope in Puerto Rico. It's this huge one from the movie Contact and the James Bond movie and the episode from the X-Files. And it's 300 meters wide. And compare that to my eye, which is about 2 cm wide. The Arecibo telescope is 15 thousand times wider than my eye. But, the radio waves it receives have a wavelength that are like 6 thousand times wider than the visible light that my eye's receiving. And that means that, as big as it is, the Arecibo telescope has a worse angular resolution than my eye. If it looked at the Moon, it couldn't see all the details. It couldn't see the craters or the man on the moon because as a lens, the radio telescope is too small, even though it's 300 meters wide. So, so here's the thing. Astronomers have figured out a trick to let them get beyond this limit. And harnessing this trick, we've been able to use radio telescopes to see the finest details in the Universe. Today on the Titanium Physicists Podcast we're gonna be talking about radio interferometry. So, speaking of radio, a particular very influential format of radio show has really fallen out of favor in this day and age. Well, before this day and age broadcast television killed it, the way the Internet is killing broadcast television. I'm talking about the serial radio drama. I'm talking about the golden age of radio, I'm talking about the Red Ryder, Flash Gordon, I'm talking about Superman and Lights Out and The Whistler and The Shadow, I'm talking about Foley artists making sound effects of opening and closing doors and people walking across floors. Oh man! Fun times. Just because the radio no longer plays clever serial drama, doesn't mean that the format is dead. No, no, no. It's found a huge audience on the Internet. The Thrilling Adventure Hour's one of the most creative podcasts ever, featuring talents like Paul F. Tompkins, the Thrilling Adventure Hour's a podcast that takes all those old-timey tropes and shuffles them together in new and fun way. Amelia Earhart fights Nazis through times, Sparks Nevada is a marshal on Mars, Frank and Sadie Doyle are alcoholics socialites who help ghosts solve their personal problems. The Thrilling Adventure Hour was produced for over 10 years and it ended just this autumn. But the WorkJuice theatre's doing show at San Francisco Sketchfest, January 9th today. My guest is one of the two co-authors of the Thrilling Adventure Hour. It's Ben Acker! Hello, Ben!

Ben A: Well, hello.

Ben T: For you today I've got two fantastic titanium physicists. Arise, Doctor Rupinder Brar!

Rupinder: Zzzzzzrrr

Ben T: Dr Rupinder did his PhD at Queens University and he's currently a senior lecturer of physics and astronomy at the University of Ontario Institute of Technology. In 2010 he won TV Ontario's award for best lecturer in the world! Now arise, Doctor Sabrina Stierwalt!

Sabrina: [ping]

Ben T: Dr Sabrina did her PhD at Cornell. And she's currently a staff scientist at the National Radio Astronomy Observatory. In 2014 she was a L'Oréal for Women in Science Fellow and she has a podcast called Everyday Einstein with quick and dirty tips series. Alright everybody, let's start talking about radio interferometry.

09:24

Rupinder: So, Ben. Let's just say you wanted to watch a movie, right? And let's say you wanted to watch Contact. Have you seen this movie Contact, by any chance?

Ben A: I have not.

Rupinder: Okay, but let's say you were gonna choose to watch Contact. Would you rather watch it on Blu-ray or on VHS?

Ben A: Oh man, I'll rather watch it on Blu-ray. Did I walk right into your trap?

Rupinder: No, no. You're totally right. You're totally right. And so the biggest difference between those formats is exactly what we're talking about today. It's the resolution, right? You want to see the details of Jodie Foster's science as much as possible and you're gonna do that with a high resolution TV, coupled with a Blu-ray player, getting as fine a detail of those lovely radio telescopes that she uses. That is until the 4K version comes out, which I'm hoping is sometime soon. And so just like TV, we keep making higher and higher resolution televisions, we want higher and higher resolution telescopes. There's really just two things that a telescope does. It makes dim things brighter and it makes small things - that's not quite the right word. Not small things bigger, 'cause that's just zooming. That's not what we're looking for. We want to be able to resolve smaller details. And so the bigger the telescope, the dimmer the object we can see and the higher the resolution of the picture that we can make.

10:51

Ben T: The contrast here is, like, normal resolution television - old fashion television - you get really close to the screen and you see big pixels, right? The higher definition ones, you can get much closer and still see little background details and the pores in people's skin and stuff. And that's essentially the advantage that Rupinder's talking about. The bigger the telescope is, the more resolution we get, the more the finer details we can make out.

Rupinder: And it's super important in astronomy because everything is really far away. Sure, the things in our Solar System are relatively close but even just looking at the surface of a star, which sounds like sort of a basic thing astronomy should be able to do, is actually really, really tough. Stars are so far away that resolving a star beyond just a pinpoint of light to actually seeing the disk of the star is really quite a challenge.

Ben A: Agreed.

Rupinder: [laughs]

Sabrina: So you would think that we can just keep making our telescopes bigger and bigger, right? If we wanna get more light, we wanna get better resolution, we wanna get better sensitivity, you can just keep building bigger and bigger telescopes. Until a certain point. You get to a point where that's just not structurally feasible. So/

Ben A: The telescope would fall right over, right?

Sabrina: Well, yeah. So, well first, Ben mentioned the Arecibo telescope. 300 meters in diameter. But it sits in a sinkhole in Arecibo. So, they were gonna build this big dish, they said let's just put it where there's already a hole in the ground. So there was a sinkhole in Puerto Rico where they've built this dish and that means they can't steer it. So it just sits like a big old bowl and you can't steer it around. I believe in Goldeneye they flushed it like a big toilet. They acted like it was under water. It's not actually under water. But you can't steer it so you're just forced to look at whatever goes overhead, basically, to some extent. So, we built the Green Bank Telescope which is the largest steerable man-made device. So they build this huge telescope in the radio quiet zone in West Virginia but the problem with that telescope was they made it so big that it fell over the first time. And they thought "Hey, we're building this engineering marvel, this biggest steerable device, let's put it right over the place where the operator sits". And so - sure enough - this huge steerable telescope fell down, crushing the operator's desk but I'm laughing because the operator actually had been sitting there all night but in these 5 minutes decided to take a break and head to the shitter and was saved. So, nobody was hurt in the falling over of the Green Bank Telescope because of a very fortunately timed bathroom break. But the moral of the story is not only go to bathroom when you need to go but also just we can't just keep building bigger and bigger telescopes because we hit a limit where it's just not structurally feasible anymore and so we have to come up with a different technique and that's where interferometry comes in.

13:58

Ben T: So as it stands, the bigger telescope, the better but I'm not sure if you've noticed. There's different types of telescopes out there. There are the ones that look like tubes or like big mirrors - they're optical telescopes. Like, the ones on Hawaii, I'm sure you've seen. There's an observatory in LA that's an optical observatory and it's just like a traditional telescope.

Ben A: Classic telescope business.

Rupinder: Yeah. And they’re usually like, about you know, 5 to 12 meters in diameter, just a single mirror bouncing light to a secondary mirror and then to a CCD. Standard telescope stuff.

Ben A: Textbook telescopes.

Rupinder: Exactly.

Ben T: I wanna tell you about those weird, giant space-looking telescopes. The ones that look like big satellite dishes.

Ben A: Okay.

Ben T: Okay.

Ben A: Let's get into that.

Ben T: You're familiar with those ones. They're usually out in the desert somewhere and they're huge. They're like the width of a building and they're big, bowl-shaped, they look like satellite dishes. For a good reason - they essentially do that. You're familiar with those ones?

Ben A: I'm unfamiliar but I trust you.

Ben T: Unfamiliar? Hm. I guarantee that you know what shape they're in though.

Ben A: Oh yeah, no I'm familiar with shapes.

Ben T: Okay, you just/

Ben A: Just not those telescopes.

15:09

Ben T: So they're just big, wide bowls and they're usually kind of tilted off to an angle and you can make them point in different directions.

Rupinder: Yeah, I mean they look basically like your standard satellite dish that you probably had on your house in 1995, getting signals from some satellite but instead they're much larger, reading similar signals from deep space.

Ben T: So, they're radio telescopes. The reason they aren't mirrored like a mirror, they're not shiny, is because radio waves are so wide that they bounce off just pieces of metal. So you don't even neeed a sheer piece of metal that's shiny, you can use kind of a grating like a barbecue grate and they'll bounce off. So they're cheap to make, because you know, a grating doesn't have much mass, you don't need much supporting understructure to keep it in place and you can make them really, really, really big and the tolerances of them are pretty/ Like, if you grind a mirror, an optical mirror, and you're off by like a couple microns, everything's done. It's over, right? It won't focus the image properly. But because the wavelength of radio waves are so wide, the tolerances on building one of those things are much more forgiving. And so you can make them really, really big and they have. This is why they can't make a mirror the size of a building for an optical telescope - because it's too big, it'll be too heavy - but you can make an underlying understructure holding up one of this building-sized radio telescopes just fine. And so they do. They're essentially/ they work on the same principle as your parabolic reflecting telescopes/

16:42

Sabrina: Yeah, so the Arecibo dish isn't actually solid, like you were saying. And when people go out to fine-tune it and turn all the screws every now and then they have to wear these special shoes that have like basically huge flat pieces and then you strap your foot into them and then you can walk around, like, with these big massive feet so that you don't fall through.

Ben A: Cool.

Ben T: It works in the same type of way as an optical telescope. Only it's cheaper to build and you can build really, really, really big ones. And it detects radio waves instead of light.

Rupinder: And we should mention, like, what is radio wave. Like, are we listening for music from gas cloud in space? No. Radio light - we can call it radio light because really it's just identical to the light that we can see it's just a different size, that's it. So, light or electromagnetic radiation, comes in all different sizes, all the way from the very, very small - like gamma rays, X-rays, UV light - to the very big. So, beyond the optical we've got microwave and then eventually radio. But essentially there's nothing different about it. It's just that when we think of light, we think of the light that our eyes are sensitive to as being something special. But astronomically, there's nothing special about it. Biologically, sure, it's special to us. But black holes and neutron stars and cool things in space don't really care that we can see in this tiny, tiny little part of the electromagnetic spectrum. The Universe is cool at all wavelengths, at all sizes of light and so if we can observe at different wavelengths, you know, we want to.

18:28

Ben A: You just blew my mind.

Rupinder: And one other thing is that like living here on Earth, which you know, it's a total bummer, right?

Ben A: We're best planet. Come on, best planet.

Sabrina: [laughs]

Rupinder: Here's the problem with the Earth, though. It's got this thing called atmosphere which sure is great for/

Ben A: Ugh. Atmosphere.

Rupinder: Yeah, exactly. For biological light, it protects us from, like, radiation and other/

Ben A: Yeah.

Rupinder: /things in space it only allows two tiny, tiny little portions of that giant electromagnetic spectrum. It allows in visible light - which is great for us to see into space - and radio light. Those are the only two that actually make it all the way to the surface of the Earth. And that's why radio astronomy is sort of like the - you know - little brother of visual light astronomy. Because we can look into the outer space just by creating some kind of device that's sensitive to this radio light coming from space.

19:23

Sabrina: Right, but where the optical astronomy has been around since - you know - the 15-16 hundreds, Galileo. Radio astronomy has only really been developed since about World War 2. So, we're just hitting our stride figuring out what sort of radio emissions are coming from stars, galaxies, black holes, like Rupinder said, whereas we've been looking at the stuff for many more hundreds of years in the optical.

Ben T: Now, before we go on, we should maybe talk about the angular resolution stuff I started the show with. Because radio telescopes have really bad angular resolution. But to get into that we have to talk about what the light's doing and why the telescope is bowl-shaped, okay? So, it's not just bowl-shaped. It has a very specific curvature to it, called parabolic curvature. It's shaped like a parabola, which is a geometric shape that isn't round like a sphere but it's also not flat like a piece of paper. It's curved in a very specific way. And the specific way it's curved has very desirable geometric properties. These properties are often described in terms of focusing rays of light. And so the idea here - I'm sure you've seen one of these diagrams is - the light comes in, there's multiple parallel rays coming in like laser beams from something. So, they'll come in, parallel to each other, straight down, and then they'll bounce off the mirror and when they bounce, they'll all bounce off in different directions but they'll all end up crossing at one specific point. And that point is called a focal point. Are you vaguely familiar with this mental image that I'm trying to draw?

Ben A: Yes.

21:08

Ben T: Okay. So, the deal is with one of these telescopes is, you take a big mirror and then you point it at the star you want to look at and then you take your little camera and put it in your focal point. And then all the light from that star comes in and it bounces off the mirror and goes into your camera at the focal point. And it's like you've got great big eye the size of the mirror instead of an eye the size of your camera. So, there are various benefits to this but before we go on I want to talk about another way to introduce how this thing works. It doesn't just amplify the light because all the light comes in and bounces off and gets collected together at a point, there's also a really neat element to this that involves the timing of when the signal comes in and how it's collected. It has to do with the wave nature of light. So I'm sure you've heard that light is a wave, right? You've heard it, everybody's heard it.

Ben A: My favorite song.

22:07

Ben T: Yeah, so one way to imagine it is you're sitting on a beach and there are waves coming towards you. Each of these waves is essentially one big long hill, right?

Ben A: Mhm.

Ben T: The points on the hill are all getting closer to the beach at the same time. It's a big flat wave, right? That's what we're going to start imagining. So, we can talk about what happens when two waves cross one another, okay? If two waves cross each other, they'll just pass through each other. And so overall, if I was standing on a jet ski or something and two waves were to pass under me at the same time, the change in height that I would feel would be the combination of the two waves. So, if both peaks were passing under me, I'd be really high up. And if both troughs were passing under me, I'd be really low down. And if the peak of one was passing while the trough of other was passing, they would kind of cancel out, okay?

Ben A: Got it.

Ben T: So this fact that how they add together causes a cancellation in height, they can cancel one another out or they amplify each other. This is called interference. And I'm sure that you've heard of this - it's really popular with sound - you've had noise-cancelling headphones before, right?

Ben A: Let's say yes.

23:20

Ben T: Yes, we'll presume that you're rich enough to own noise-cancelling headphones. Like the ones they sell in Sky Mall, right?

Ben A: Mhm.

Ben T: So what those do is/ sound is a type of wave, they're pressure waves. There's a little speaker inside the noise-cancelling headphones and what they do is they listen to the sound coming in towards your ears and they produce the same sound but offset by a little bit. So it produces its own wave that partially cancels out the wave that's coming in. And so in the end you hear less noise. So it's not just muffling out the sound, it's actively cancelling it, using interference.

Ben A: So much science in your earholes.

Ben T: I know, it's crazy. What happens when a wave hits one of these big curved telescopes? Essentially what'll happen is as the wave hits the telescope, it'll hit different parts of the surface of the telescope at different times. Just like imagine a big wave washing up into an inlet. It touches the inlet at different times, depending on how deep the wave has penetrated into the inlet, right?

Ben A: Mhm.

24:24

Ben T: Okay. So, same thing happens in your telescope. And every time the wave edge hits the edge of the telescope it's gonna reflect a little bit of wave in just random directions, okay?

Ben A: Wait, what?

Ben T: It's gonna bounce off, it's gonna generate its own wave.

Ben A: So, bouncing off a thing with a thing.

Ben T: Yeah. So, it generates kind of a new wave. The wave just bounces off. And so the wave that bounces off will interfere with the rest of the wave, it'll bounce off it'll do its own thing. The easiest way to think about this is to imagine/ think about a gymnasium, okay? You're a gym teacher and you've decided to make all of the stupid kids race. You're like "Okay, you stupid kids. You're gonna race, we're gonna see which one of you is fastest". But here's the thing: you know beforehand that all of them run at exactly the same speed, right?

Ben A: What?

Ben T: You're at a very dull school where none of them are fast, they're all just running at the same speed.

Ben A: No wonder this gym teacher hates his job.

Ben T: Yeah, right. I know. You want to (...)

Ben A: Don't blame on the kids, though, gym teacher. Look inward. Look inward.

Sabrina: [laughs]

Ben T: So the gym teacher goes and he lines them up all against a line on the back of the gymnasium and then he goes "You gotta cross this tape. Whoever crosses this tape first, wins". And so he puts a little X on the ground. And he goes "Okay, cross it". And who wins? The one closest to the tape, right?

Ben A: Mhm

25:47

Ben T: So, the parents phone in, they complain. They're like "Well, Johnny runs just as fast as Susan but Susan won the race and you gave her the chocolates and we disagree. She shouldn't get an A, everybody should get the same grade. We know this kids run at the same speed". So the gym teacher decides to make a slightly different test. So what the gym teacher does, he goes "okay, I'm going to take a piece of tape and around this little point I'm going to draw a U shape that faces outwards towards the back end of the gymnasium", okay? So, all the kids are lined up along the line at the north end of the gymnasium and then there's the target point that's in the middle of the basketball key, right in the middle. And then around that, kind of facing the kids, he's drawn a big U shape in tape. Okay? And he says to the kids "Okay, so what you're gonna do is you're gonna run straight towards the other end of the gymnasium, you're at the north side, you're gonna run straight south and then, when you reach this tape U that I've drawn, you’re gonna touch the ground and then you're gonna run to this dot". The kids go "Yeah, okay, this seems arbitrary". And he's like "whatever, they're wind sprints. You just gotta/ it’s important to run".

Ben A: Mhm.

Ben T: The idea is that you can design the U shape tape so that it has a really specific shape, this parabolic shape, where kids will run in, touch that U shape and then run towards the middle, and if the U is shaped like a parabola, what'll happen is - because the kids all run at the same speed - they'll all arrive at that X at the same time. The idea is they're all travelling on different paths, some of them hit the tape early and then have to turn and run towards the X, some of them hit the tape really late and they have to run to the back of the gym, touch the ground on the U and then run around. They all run different paths but, because of great geometry, we know that it's gonna take them all the same amount of time to arrive at the X. Now, if we're gonna talk about waves, if we're gonna break the wave front, as in terms of these little kids all running forward, bouncing off the mirror, running towards the X, what it means is all of those rebounded wave fronts that bounce off the mirror are all going to arrive at the focal point at the same time.

27:59

Ben A: That was well explained.

Ben T: Oh, thanks. So they all arrive at the same time and we talked about how the waves add together, right? And so what'll happen is all those waves will add together at the same point at the same time and you'll get a really big wave. They'll all add together, you get a huge amplification at that point. And that's essentially how these telescopes work. It's that the light comes in and this wave of light will get bounced off this parabolic shape in a way that causes it to have a huge amplification right at the focus because it takes the light the same amount of time to bounce off the mirror and arrive at the focus.

Ben A: Yeah, thanks to a gym class of well-meaning same-running children.

Ben T: That's right. So, one other particular aspect of this is that: suppose you're in a gym class of running children and they set up the U and they did the thing and then it's a substitute teacher's day to come in and run the children. And the substitute teacher doesn't know where to start the children lining up.

Ben A: Oh no.

Ben T: So the substitute teacher takes another piece of tape and runs a line across the gym where all the kids line up but it's not parallel to the baseline of the basketball court. It's kind of at an angle.

Ben A: Mhm. Mhm. Mhm.

Ben T: And then he starts the children running. What'll happen is they won't all touch the U and arrive at the focus at the same time. The only way they all arrive at the focal point at the same time is if they start running on a line parallel to the baseline of the basketball court. Any other configuration, they won't all arrive at the same time.

Ben A: It's not their fault.

29:25

Ben T: It's not their fault. It has to do with how they started out. But in telescopes this means something absolutely crazy. It means that if I take a telescope and I point it straight up, then light from a star coming straight down at me will get amplified at the focal point. On the other hand, light coming from an angle that's just a little bit off straight up vertical, it'll be moving in a way that the light won't bounce off the mirror and amplify itself at the focal point. When the light reaches the focal point in that case, it'll be partially cancelled out - it will be a weaker signal than it should be.

Ben A: Mhm.

Ben T: So this parabolic mirror gives us the advantage that not only can we amplify the light that's coming in from straight above but it also kind of unamplifies, it makes the signal weaker, coming from directions that are off axis. And so this is useful. It's kind of like that archery thing I started with. What you can do is you can use this to figure out exactly where these stars are because you can tweak the direction of the telescope and depending on where pointing the telescope, you get the strongest signal, that's the direction it lies. It kind of reminds me of when I was a kid, I went to a science camp where - you know how they put radio tracking collars on bears?

Ben A: Mhm.

30:35

Ben T: Yeah, so essentially it's like finding the direction of the bear. So essentially the radio tracking collar is making a ticking sound and you have got an antenna and it's directional and you can twist it around and figure out which direction the loudest signal is coming from. And that's the direction of your bear. Similarly we can take those radio telescopes and twist them around, tilt them in different directions and we know that wherever it's loudest, that's where the source is of where the radio emissions are coming from. So it's helpful. Because we can't see with our eyes where all the radio stars are or anything. All we have is a machine that tells us if it's getting a loud signal or a quiet signal. So we can use pointing it in different directions to figure out where the loud things are, loud structures

Ben A: Oh man, so you're using audio words for visual things. I get it, I get it. But I was just getting on board with the idea that there's visual stuff you can't see and now you're talking about loud instead of bright. It's fine, it's fine. Term of art.

31:38

Ben T: Okay, so the deal is: it's like we said. We point the telescope in a particular direction and it's loud, we know that there's something in that direction that's making those radio waves. Maybe it's a weird star, maybe it's an alien artifact - who knows. But because of the wave nature of light, there's a weakness to this. Which is to say that we don't know exactly which direction it's coming from. We just have kind of a cone that we know that it's coming from, right? There's some angular error involved in it. It might be a little bit to the left of it, it might be a little bit to the right of it. We know the general direction. And the thing with radio - like I said at the start of the show - is that radio has really, really long wavelengths. And this translates to essentially all these great things like that the atmosphere is transparent to radio, it has other benefits, right? But one of the weaknesses is, because it has such a long wavelength, the error on which direction we think the thing is coming from, those error bars are really big. So we're not sure whether it comes from a lot to the left or a lot to the right. And even really, really big telescopes like Arecibo, which is absolutely huge, you can walk around inside of it, you could live in it if you wanted to.

Ben A: Pass.

Ben T: If you want to live inside a bowl for some reason. Even Arecibo doesn't have all that great angular resolution. Like I said, our eyes have better angular resolution. Our eyes can see finer detail than Arecibo telescope. So, they've figured out a trick called radio interferometry that lets us see everything in finer detail. Okay, so interferometry is kind/

Ben A: They call it the cleverest trick the devil ever played, right?

33:24

Ben T: That's right. The easiest way to explain it is: so, the wider the telescope is, the better the angular resolution, the more detail we can see, right? And you need like a kilometers wide telescope to see really fine angular resolution in radio just because radio waves have such a long wavelength. So, the argument goes like this: imagine you had a radio telescope that was kilometers wide. Why don't we build one? And the answer is engineering-wise it's too much.

Ben A: It's gonna fall on somebody's desk.

Ben T: Yeah, it's/ they're just too big, right?

Ben A: Yeah. Come on, it's ridiculous.

Ben T: You're not gonna build something kilometers wide that's U-shaped because the sides would have to be really tall. So we need to do something/

Ben A: Let's do it, yeah. Whatever that is.

Ben T: Let's do it. So imagine that we did have one of these.

Ben A: Yeah, that'll solve the problem.

Ben T: And that we cover it with a tarp.

Ben A: Oh, with a tarp? Magic tarp theory.

Ben T: Imagine it was kilometer wide, you cover it with a tarp/

Ben A: Yeah, let's cover it with tarp. That'll do.

Ben T: /but then we cut holes in it. Imagine you cut three holes in it. One near the edge, one near the center, one somewhere in the middle. Just little, you know, 200 meter wide holes.

Ben A: This telescope is dressed like a ghost now. A Halloween ghost.

Rupinder, Sabrina: [laugh]

Ben A: Okay, alright, perfect. I don't see any structural issues now that it has a tarp on it with three holes in it.

34:37

Ben T: Even with the two or three holes in it, it would still have the angular resolution of the kilometer wide telescope.

Ben A: Okay, alright, I see.

Ben T: It would just not receive as much light, so the light would be dimmer because it only lets through at three places but it would still have this angular resolution. So, effectively what we do is we set up multiple small telescopes in a way that gives us essentially the same thing. We add up their signal in such a way that it acts like a kilometer wide telescope, only with a few holes drilled in it.

Ben A: You win this round.

Rupinder: So basically, at its core, a radio interferometer could have like 20 dishes, 30 dishes, each one itself is a telescope but really they're just one telescope, each dish giving us part of the picture in a way, right? And so overall if we, say, have 30 dishes and they're spread across 5 km, it's the equivalent of having a single telescope that has a dish 5 km across. It's equivalent for resolution it's just not equivalent for the amount of light I collect. I won't get as dim a picture as I would if I had one giant telescope but I should get just about as good a high definition picture as if I had one giant telescope.

36:00

Sabrina: Right, so basically some of that light is gonna fall in between the cracks of your telescopes because you don't have a uniform piece. You're getting the same high resolution image but you're missing some of the light that falls in between the telescopes.

Ben A: You're getting the same image but you're not getting the same light? Or are you getting an image with holes in it?

Ben T: You're getting the same angular resolution image.

Ben A: Okay, alright.

Rupinder: Imagine this like this. Let's say that you were watching a nice HD movie on your laptop or something and then you start turning the dimness down on your computer screen. You still have the resolution that you had originally but maybe you're starting to miss things because the screen's just not as bright as it was otherwise. That's what it's like.

Ben A: Gotcha.

Sabrina: So you end up missing things that are more spread out because those tend to be fainter. You can't pick those things up. So you're getting denser stuff that's brighter as you can see a lot more detail but things that are sort of diffuse and spread out you miss with this, with interferometry.

Ben A: Alright, I'll take it though. Sounds like the best option.

37:05

Ben T: The way interferometry works isn't that you have a 10 km wide telescope with holes/

Ben A: No, that would be crazy

Ben T: /covered with a tarp with holes drilled in the tarp. What happens is, it's like you had individual telescopes that are placed where the holes would be. They collect the signal coming in from space and then we know at what time each signal was received by the various telescopes. We essentially plug them all in - using wires - to a computer that's collecting all the information (...) maybe we put atomic clocks in each one so that we know exactly what time each of the light waves was received but what we can do is we can essentially combine it in the same way. We can say "okay, this one would this take this much time to get to the focus point, this particular wave would take this much time to get to the focus point and using the timing information of the 3 telescopes we can combine essentially the signal we would've gotten if it was a 10 km wide tarp-covered telescope. Essentially, the argument is the same. We're looking at how the signals from each of these telescopes add together.

38:09

Rupinder: So let me ask you a question then, Ben Acker, instead of you asking us. How big can you imagine an interferometry getting? If you could build one at any size and all you have to do is take little telescopes and make them work together. How big can your imagination get?

Ben A: Oh, I got a pretty sweet imagination.

Rupinder: Alright.

Ben A: Like, professional grade.

Rupinder: [laughs]

Ben A: You know, so like it's just a bunch of these things that add up to a whole picture, right? So you can have a limitless amount. You can put some on the goddamn Moon, I don't care.

Rupinder: Nice, there you go.

Ben A: Yes. Right? If you could float them on Saturn, do that, right? Yeah.

Sabrina: So, one of the things that limits how many dishes we can throw in is that you have to do something called cross-correlation. So/

Ben A: I didn't think of cross-correlation.

Sabrina: [laughs] Right, it/

Ben A: Oh, my stupid imagination.

Rupinder: No, don't blame yourself.

Ben A: (...) Terrible. Just talk about the gym class. I got those guys.

39:18

Rupinder: [laughs]

Sabrina: So Ben as talking about measuring the delays between the signals that you're getting from each one of these dishes and that means that you have to look at antenna one and compare it to antenna two, the signals that you're getting. And then you have to look at antenna one compared to antenna three and then compare it to antenna four and then you have to start comparing antenna two to every other antenna and that adds up pretty quickly in terms of how many calculations you have to do.

Ben A: You do this on a computer, right?

Sabrina: Yes.

Ben A: Like, this isn't somebody with a gridded notebooks. Writing all/

Sabrina: Just like a big switchboard?

Ben A: Yeah, it's like, you know, ENIAC, a two inch tall ENIAC or whatever.

Sabrina: Yeah. But our computers are still only so good. And so that's one of things that limits how many antennas you can throw into the mix. One of our biggest baddest interferometers it has a 17 petaflop correlator. So that peta- is 10^{15}, so 15 zeros. And that's how many calculations it does per second.

Ben A: Okay. That seems like plenty. Is it a Mac? You wanna get a Mac.

Rupinder, Sabrina: [laugh]

40:22

Sabrina: So that interferometer has 66 antennas. 66 dishes.

Ben A: Alright. Then that's how many. 66. Right, the biggest number? Oh is that the biggest?

Sabrina: It's the biggest where it's all in one spot. So you hit on something else that is a super neat trick. Which is having dishes that maybe aren't all in the right spot but are all spread out all over the world. And so we do that too. We have something called Very Long Baseline [Array] Astronomy where we have telescopes in Alaska and then one in St. Croix.

Ben A: Is that/ did a British person name that?

Sabrina: St. Croix, yes.

Ben A: No, no, no. Not St. Croix and Alaska. Very Long Baseline sounds so... respectful and simple and, like, this is what it is. Very Long Baseline. You're coming from a place where you're saying "interferometer" a lot. And then you're like "And then we have one called the Very Long Version".

Rupinder: [laughs]

Sabrina: Oh, you would be surprised. We also have/ we have the Very Large Array.

Ben A: [laughs] I love it.

Sabrina: So, Large Array wasn't taken but I guess they decided that let's just go for "very" right off the bat.

41:25

Ben A: Yeah, right? It goes to eleven. This array goes to eleven.

Sabrina: And there's also in optical, there's the Very Large Telescope. So I guess we're just not that creative, I guess that's the problem.

Rupinder: Yeah. There's one in India that I've used called the Giant Meterwave Radio Telescope.

Ben A: Mm-mmm.

Rupinder: Yeah, so they're like "Very sounds big but Giant sounds even bigger".

41:45

Ben A: Yeah, but the gigantic one dwarfs the giant one.

Rupinder: Oh man, but they'd be the same acronym how could you do that? [laughs]

Ben A: Oh man, you're gonna make our robots brain explode.

Ben T: Maybe you can just spell it with bigger letters.

Rupinder, Sabrina: [laugh]

Ben A: Yes, font based, yeah.

Ben T: So, Sabrina would you keep rattling off about these big crazy facilities? 'Cause there's one that correlates all of them across like continents, right?

Sabrina: Yeah, so the Very Long Baseline Array. And so it's a kind of very long baseline interferometry, it's what it's called. But yeah, these telescopes are spread out all over the world. Within reason. You can't have too many that are too far north versus too far south because when you're in the northern hemisphere versus the southern hemisphere you can see different parts of the sky because the Earth is a ball, you may know. So, they're mostly spread out in the northern hemisphere, this VLBA, this Very Long Baseline Array. And you can get very, very exquisite detail because you have these telescopes spread out. And so it's used for things like the Navy uses it to monitor the positions of distant, distant galaxies that are super bright called quasars. And the Navy's interest in this is that in case the enemy ever shoots down our GPS satellites, we still know where we're going because, you know, the enemy can never shoot down the quasars, I guess. They can't shoot down the distant galaxies but they can take out our GPS satellites and this way at least in North America we'll still know where we're going.

Ben A: (...) You're daring enemies to shoot down out quasars.

Rupinder, Sabrina: [laugh]

Ben A: Nothing could possibly happen to our quasars. I'd defy the gods to prove me wrong.

Sabrina: [laughs] Well, yes, so another thing you can use this VLBA antennas, these radio telescopes, for is you can use them in reverse and the whole point is to look at detailed images of the sky based on the difference, the time delay in the signals you get so how long it takes for a signal in space to get to each telescope. You add up the delays and that gives you information about the position of what you're looking at in space. But you can use it backwards and you can study the plate tectonics on Earth. Because the plates on Earth shift over time, right? So this is plate tectonics, we get earthquakes and all that good stuff. So, we can actually measure very precisely the different distances between these telescopes that are spread out over the northern hemisphere and get/ they shift on something like a millimeter each year. And we can actually measure that tiny, tiny difference and it tells us where the plates on Earth are moving. So you can use it/

Ben A: You're so smart.

Sabrina: I know.

Ben A: [laughs] You said that like I was sad about it.

44:45

Ben T, Sabrina: [laugh]

Ben T: So, moral of the story is: interferometry is essentially when we ask the telescopes involved to take account of when they received each of the signals so that we can recreate essentially a really, really big large telescope by combining their signals in different ways. And the important thing here is that doing so gives us stronger angular resolutions. So we have a better sense of which directions precisely the signal's coming in from. So adding 17 more telescopes in conjunction doesn't produce a brighter signal, we don't receive more photons than each of the 17 telescopes acquire but it does let us say "yes, that particular radio source is really, really tiny and it's coming from exactly that direction in the sky. And this one is coming from exactly that direction in the sky. It's essentially giving us a stronger ability to pinpoint different sources of radio and to image different sources of radio. So how does it get used, you guys?

Ben A: Haunted houses.

Rupinder: [laughs]

Ben T: Haunted houses. What else?

Ben A: Surprise parties.

Rupinder, Ben T: [laugh]

Ben A: I didn't know is this a time segment? Is this a lightning round?

Ben T: Yeah.

Ben A: Pass. What do you guys think?

46:08

Rupinder: So well a couple of things that we wanna do with radio astronomy in general and with interferometers in particular is to compare what we see in those wavelengths of light vs what we're already seeing in the optical part of the spectrum. And sometimes it's pretty crazy. Like, you could look at a galaxy in the optical, like you're just taking regular visual picture with a regular old reflecting telescope and the galaxy will look just like your typical spiral galaxy and suddenly you look at in the radio part of the spectrum and it has these two giant jets of something coming out of them perpendicular to the direction of the galaxy at speeds approaching the speed of light and suddenly you're like "wow, that normal looking galaxy actually has a supermassive black hole in the middle of it that's like ejecting matter out at crazy speeds at huge, huge distances. We wouldn't have discovered so many things without looking at different wavelengths of light and radio astronomy in particular.

47:14

Sabrina: Yeah, so one of the things that I use radio interferometry for is looking at how stars form. This is actually something we don't understand the process very well and part of it is because stars form when you take clouds of gas and you collapse them down eventually things get hot and dense enough so that you get hydrogen fusion which starts a star. But this is all happening enshrouded in dust and gas and all of this space junk and optical light doesn't make it out. And so without radio wavelengths, without longer wavelengths that can make it out of these clouds to tell us what's going on inside them, much like only the radio wavelengths are getting through some of our atmosphere. Here even optical light isn't getting out then we can tell more about this process and then stars do crazy stuff, like, once they form, they'll fuse other elements and then when they die, they explode and send those elements back out into this gas and dust called the interstellar medium and this process is called feedback where you're getting/ stars are giving back to their environments and we don't understand the interplay between stars living their lives and the gas around them very well. Just because we've never been able to penetrate these areas with the resolution that we now are just starting to be able to do with radio interferometry.

48:42

Rupinder: So, Ben Acker, I think there's probably like a question you might have right now. Let me help you state it.

Ben A: Yeah, yeah.

Rupinder: Like, now that we've created interferometry for radio telescopes, you might be asking yourself why don't we do it for other telescopes? If those other telescopes already have better resolution, wouldn't an interferometer in, say, the optical part be like a crazy crazy high resolution telescope? And the answer is yes but overall it's just harder to do. And so we've just started to sort of scratch the surface on taking this technique that you know, we're pros at in the radio part of the spectrum and use it on smaller and smaller wavelengths. And just recently a brand new telescope, I would argue maybe the best telescope in the entire world right now, opened up, called ALMA. It's in Chile, it's called Atacama Large Millimeter Array and it's really just begun but it's going to revolutionize our understanding of so many processes including a lot of the ones that Sabrina was talking about.

49:51

Sabrina: Yeah, so ALMA is actually the telescope that has the 17 petaflop correlator.

Rupinder: Oh, that was the one you were talking about?

Sabrina: Yeah. So ALMA is badass. Not only because it has this great resolution sensitivity but it also is opening up frequency space. So new wavelengths of light that we haven't really been able to look at before. And so it's showing us a lot of different molecules in space, in other galaxies that we haven't seen before and so these different molecules, you can look at interacting galaxies for example. So when two galaxies slam into each other, you get all sorts of shockwaves going off that produce extreme environments for star formation and this can produce a lot of different molecules that we don't see normally in other places until ALMA. One of the things ALMA's doing is looking at these different environments and looking at these new molecules so there's this whole area of astrochemistry that is really taking off right now because of what ALMA can do.

50:54

Ben A: So, when you guys talk about, like among yourselves, seeing molecules in other galaxies. Like, that's the thing you just said we can do, right?

Sabrina: Yes.

Ben A: So does your brain basically go bananas? Are you like "man, we can see molecules in other galaxies, science is awesome" and, like, high five each other in the halls of the science building or are you like "yeah, yeah; we can see molecules in other galaxies but what we're really interested in is something even cooler and more per my interest" or something like that? Like, are you just constantly in a state of, like, "whoa; things are awesome 'cause science".

Rupinder: That's a great question. Like, for me personally sometimes I do find, like, in science meetings and stuff like that that it does get sort of blasé but the great part for me is sharing it with students, you know, like when we talk to people who, you know, aren't blasé about/ who have, you know for the very first time understanding what we're doing, that's when I realize "Oh my God, this is incredible. We are/" And again with this podcast, same sort of thing where it's just/ sometimes you begin to get a larger picture of the enormity of some of the things that we're able to do as opposed to, you know, worrying about the error or the dirtiness of your data and all that minutiae stuff that gets in the way of the bigger/

Ben A: Your bottom line, your monthly bottom line, your boss is on your ass about how many articles/

Rupinder: Totals

Ben A: You've got to clear these to get better telescopes to Glengarry telescopes, we can work this out.

52:29

Rupinder: Right.

Ben A: It's great that you've found a way to be blown away by it so regularly.

Rupinder: Yeah.

Sabrina: So, when we're talking about these antennas, these multiple different dishes, so ALMA has 66 dishes. Well, it will when it's completed, that's still in the process. But we don't just put these antennas out there and then sit them. We move them constantly in and out. So they're closer together and then further apart. Because we were talking about as you spread them out, that gives you the benefit of this better resolution but you're still making bigger and bigger cracks that light can fall through, right? So sometimes you want them spread out as far as we can to get the best resolution but sometimes we want them closer in so we sacrifice a little bit in our ability to pick up that detail but in exchange we get a better filling in, something called longer spatial scale, so we can see more spread out stuff. And so we wanna be a able to go back and forth between these modes to get the most of our telescopes, so each one of the dishes for ALMA is a 100 tons and so you have to be able to move a 100 ton thing and then place it and the placement where you put them has to be right to within a few millimeters. So you have to have something that can transport these things pretty constantly and also be able to place it within a few millimeters of where you actually want it, so that you can get it into the right spot. So they had to build these special transporters in order to do this. So they only have two, 'cause they're super specialized and expensive, as you can imagine. They've named them Otto and Lore because, you know, we're fond of them. But these transporters have something like 28 or 30 tires each and they're like 6 meters high, 20 meters around and they also have to be able to work at elevation. So ALMA is up in the Atacama desert which is at elevation, it's at about 5000 meters up. So, also machinery doesn't like to work as well up there. So they just had to make these super specialized transporters and it's really cool to see them in action, although I recommend/ they have videos of them online but you should watch it in speed-up mode 'cause they can't go over, like, 20 km per hour. So they're really really slow but they're super amazing that they've had to build these special transporters just to move these dishes around.

55:00

Ben A: In the Pixar movie, would the transporters be blue collar and ALMA be like a fancy lady?

Sabrina: Yes.

Ben A: There would be like a snobs versus slobs situation?

Sabrina: Sure, sure.

Ben A: Don't placate me. I'm curious.

Sabrina: [laughs] Well, so the guy that drives the transporters/

Ben A: Oh, there's a guy that drives it?

Sabrina: Yeah, well, so you can remote control it but for when the guy wants to get in, they have to make a special seat - the driver seat has like this pouch, this indent in the back for his oxygen tank.

Ben A: Woah.

Sabrina: Because it's so high up/

Ben A: What kind of guy is he? Is he a scientist? Or is he like a jock? Well like thousand things like, is this a guy who is driving transports and it's just one on his list? Who's this guy? That's my question. Who's this guy?

Sabrina: Well, I'm pretty sure that they're generally not scientists. I'm pretty sure I couldn't go up there and be like "hey guys, could I move this dish a little bit? Because it's a little bit off." I'm pretty sure they wouldn't let me as a scientist just hop in there and use their/

Ben T: They're technicians, though, right? Not like groundskeepers.

Sabrina: It takes skill, for sure.

56:10

Ben A: But like, so there's a union guy driving the truck? Right? Like a teamster?

Sabrina: Right. I mean, you've gotta be somewhere high up on the pay scale if they're letting you move this really expensive dish. On a really expensive transporter.

Ben A: Yeah. What does he do the rest of the time? Is he like Indiana Jones? Like "Uh, I move this transporter for science and stuff, 'cause yeah, science now I got to go swing on thing and punch a Nazi". How do I punch a Nazi?

Ben T: [laughs]

Ben A: But like, you guys, you don't know the inner life of the guy who the drives the transporter?

Sabrina: I do not.

Ben A: Alright.

Sabrina: I'll try to set up a pen pal situation with him and get back at you.

Ben A: I appreciate it. I thought this was a comprehensive podcast. I guess I'm mistaken.

Rupinder: And so like we talked a lot about angular resolution and things like that but maybe we don't really understand how accurate we can actually be. The smallest I've seen in interferometer apparently work it was the equivalent of being able to see the head of the screw 300 kilometers away. Just to give you an idea what kind of tiny, tiny sizes we're talking about.

Ben A: We can see a molecule in another galaxy, though. Right?

57:20

Ben T: Yeah, when we say we see a molecule in another galaxy, we should add a little addendum. We can't resolve the molecule. Different materials emit different colored light and so the deal is if you can recognize those types of light, you can recognize/ you can identify what material or what chemical's emitting the light. And so what they're saying is now this thing is so sweet that it can see frequencies of radio that we hadn't previously been able to measure and we can use those to detect chemical signatures that we weren't able to see before.

Ben A: Alright. I think that's probably still impressive.

Ben T: It's still impressive, yeah.

Ben A: Yeah, yeah, yeah. Guys, don't get down on yourselves.

Rupinder, Sabrina: [laugh]

Rupinder: Oh.

Ben A: No, keep high fives

Sabrina: We've done it before.

Ben A: Always, for science. Yeah, right? There it is, find the silver lining.

Ben T: I don't know. Is anything really crazy in the radio that we've discovered that's/ Well, pulsars.

58:18

Sabrina: So, in a start, a normal star it is fusing elements which creates photons, it emits this light out and it prevents the gravitational collapse of the star. So basically the star starts from this collapsing cloud but eventually something starts fighting back against that collapse and that's when fusion happens, it starts emitting all these photons, all this light that has some sort of radiation pressure that fights back. But eventually it's gonna run out of material to fuse through and burn in the core and then that gravitational collapse is going to win out. And depending on how big the star was to start with, you can end up with different things. Like, something like our Sun, a star the size of our Sun is turn into something called a white dwarf which is basically a bunch of electrons packed together and then slightly bigger stars will end up in something called a neutron star, so this is something that's held together by something called neutron degeneracy pressure which basically says neutrons can't get any closer together. Quantum mechanics sets a limit and these neutrons, as there's nothing fighting back against gravitational collapse, eventually the neutrons are like "okay, no more, we will not be crushed any closer together" and that can support the star for a while. But it does this weird thing to emissions from a star that are left over in the core making their way out where it gets beamed at either direction so rather than emitting light at all of around, like an orb, like the Sun, instead you get this sort of beamed emission out either pole. And if this and this star, it rotates if it's pointed the right way, we fall in the path of this beam and we can see it. And it's/ that's why they're called pulsars because we see a pulsing and we can find millisecond pulsars, meaning we can see pulses on order/ happening every millisecond. So these are really really fast spinning stars. And where we detect these emissions is in the radio wavelengths, so we can see that these stars are out there, pulsing and so it tells us a lot about our understanding of what happens to stars when they die, our understanding of what happens in the presence of a strong gravitational field. 'Cause neutron stars are super, super dense objects. I think it's like taking the mass of the Sun and cramming it into something the size of Manhattan. So it's like super, super dense and so this creates crazy physics around the object because the gravity is so strong and so they tell us also about that physics, general relativity, stuff like that.

61:18

Ben T: Okay, yeah, but you missed the crazy part which is they're detected in 60s and they thought it was aliens. So they had this radio telescope and they were just kind of poking around with it and then they got a signal that was [starts snapping fingers] regular, it was like beep-beep-beep-beep-beep-beep and they were like "what could be making that pulse? Cause it's totally regular". And they were like "oh, must be aliens". But then it wasn't, it was this spinning neutron stars, which are fascinating but, you know, if you ever think astronomers aren't immediately about to say "Oh, it was aliens", you are wrong. Because they've heard this and they were like "yeah, it's probably aliens".

Ben A: Wasn't there aliens like six months ago, three months ago? Something like that?

Sabrina: The alien megastructure?

Ben A: Mhm.

Ben T: Oh, yeah. Yeah, yeah. Astronomers were like

Sabrina: "Probably aliens".

Ben T: "When we get interviewed we have to say that it's probably not aliens to keep people from panicking but it's probably aliens". And then it's not and they're disappointed but astronomers are a hardy bunch. Rupinder, what are we gonna say about Jocelyn Bell?

62:14

Rupinder: Yeah, so if I'm not mistaken, wasn't it Jocelyn Bell who made the original observation for the pulsars?

Sabrina: Right, but she didn't get credit.

Rupinder: Right, she had one of those supervisors.

Ben A: Ugh.

Sabrina: So, her supervisor got the Nobel Prize.

Ben A: What?!

Rupinder: And he was also the guy that was all like "Hmm, looks like aliens". I feel like he was/ I think we've discovered something great here and he's all like "probably aliens".

Ben A: Oh, I would watch this show.

Rupinder: Yup.

Sabrina: Her being a woman was no small part in that either.

Rupinder: Yeah, I know, it was all because of that, I think. At that time she was definitely a pioneer and did not get due credit for one of the most important astronomical discoveries of the 1900s.

Ben T: Well that was fun. Thank you Rupinder, thank you Sabrina. You've pleased me. Your efforts have borne fruit and that fruit is sweet. Here's some fruit, Rupinder you get a mango.

Rupinder: Oh, yeah. Om nom nom nom.

Ben T: And Sabrina, you get a grape.

Sabrina: [chomping sounds]

Ben T: I'd like to thank my guest, Ben Acker, thank you Ben, remember if you want to hear the WorkJuice Theater, it's doing a show in San Francisco at Sketchfest in January.

Ben A: And all of our podcasts are on iTunes and nerdist and everywhere podcasts are cast, pod wise. And always will be.

Ben T: Go enjoy those lovely podcasts. And comic books and stuff.

Ben A: Yeah, right. Thanks, thanks for having me. You are lovely host and I feel like I learned at least three things today.

Ben T: That's good.

63:40

Ben T: Oh wow, that was fun. Okay, so now it's announcement time. First, I was thinking that around this time of the year people go poking around for new podcasts to listen to on their fancy new devices while they sit in the airport or on the bus or on that long car trips to visit their great-aunts or get away from their great-aunts, in fact. Now, I was thinking it might be time to remind the world that we exist. So, if you'd like to help us promote ourselves, you can give us an iTunes review. ITunes Ranks their shows according to how many reviews they're getting each month and so we have our review numbers go up just a little bit, more people will see us and more people will try us and more people will learn lovely fantastic physics explained by brilliant people to clever, clever laypeople. Okay, now, in other news, transcriptions are firing on all cylinders. We've got a dozen done, more are on the way. Email me if you're interested in trying your hand in transcribing an episode and we'll talk about the details. And on that note, we're still humbly soliciting your donations. Your donations are going to paying for our server fees and our ambitious project to get all the episodes transcribed. This particular episode of the Titanium Physicists has been sponsored by a collection of generous, generous people. I'd like to thank the generosity of Seth Rogen, I'd also like to thank Melissa Burk, Yaseen Owarzazee, Spider Rougue, Insanity Orbits, Robin Johnson, madam Sandra Johnson, Mr. Jacob Wick, Mr. John Keese, a Mr. Victor C., Ryan Close, Peter Clipsham, Mr. Robert Halpen, Elizabetha Theresa, and Paul Carr. A Mr. Ryan Noule, Mr. Adam K, Thomas Sharay and Mr. Jacob S. A gentleman named Brett Evans, a lady named Jill, a gentleman named Greg, thanks Steve, Mr. James Clawson, Mr. Devin North, a gentleman named Scott, Ed Lowlington, Kelly Wienersmith, Jocelyn Read, a Mr. S. Hatcher, Mr. Rob Aberzado and Mr. Robert Stietka. So, that's it for Titanium Physicists this time. Remember that if you like listening to scientists talk about science in their own words, there are lots and lots of other lovely shows on the Brachiolope Media Network. The intro song to our show is by Ted Leo and the Pharmacists and the end song is by John Vanderslice. So good day, my friends, and until next time, remember to keep science in your hearts.

66:03

[Outro song; *Angela* by John Vanderslice]

67:02

Ben A: Okay, wait. This is, I'm following but I'm getting distracted. Rupinder, do you have a planet you like better than Earth?

Rupinder, Sabrina: [laugh]

Ben A: Sabrina, you're next. And Ben, everybody, what's your favorite planet?

Rupinder: Probably my favorite planet/

Ben A: Earth is your favorite planet?

Rupinder: To be honest, Earth is my favorite planet.

Ben A: Yeah. Earth, it's great. We're from here.

Rupinder: It's where I keep all my stuff, it's true.

Ben A: Yeah. Alright. Sabrina?

Sabrina: [laughs] Earth is definitely my favorite planet, 'cause I have a very narrow range of temperatures at which I am comfortable so here it is.

Ben A: Regular Earth stuff. Alright, great. Ben?

Ben T: I'm gonna say Saturn.

Ben A: [exasperated sigh] There's always one.

Ben T: I'd liked it and it's got a ring on it so/

Ben A: Blugh

Sabrina: And it would float in a bathtub.

Ben T: It would float in a bathtub. It's fun all the time.

Rupinder: [laughs]

Ben A: Oh, that sounds like another podcast.

Ben T: [laughs]

Ben A: You're not gonna tell me why it would float in a bathtub, are ya?

Sabrina: It's just less dense than water, so it would float even though it's super, super massive. If you could get a bathtub that could fit Saturn, it would float.

Ben T: It's very fluffy.

Ben A: I'm sure. If I get a bathtub bigger than Saturn, man, I'd be set.

Ben T, Sabrina: [laugh]

Ben A: You'd all see. You'd see.

Sabrina: You could prove me right or wrong.

Ben A: Well no, yeah. But it wouldn't be about that. It would be like "that's a guy that can get bathtub bigger than Saturn".

Rupinder: [laughs]

Ben A: "I wonder what kind of car he drives. I wonder what planet it's bigger than", you know. Anyway, you were saying about this (...). Oh but first of all

Ben T: Yes.

Ben A: Yay Earth! Good job, guys. Except for you, Ben.

Ben T: Sorry.

Rupinder: [laughs]

Ben A: Hate Earth. You should get a teacher.

Rupinder: Love it or leave it, Ben.

Ben A: Yeah.

Sabrina: Love it or leave it [laughs]

Ben A: Yeah, that's a (...) all Trump on you.

Ben T, Sabrina: [laugh]

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Sabrina: Also something they use radio interferometry for is, I don't know if we wanna talk about this but for SETI. For the Search for ExtraTerrestial [Intelligence] life. Because if you were to fly over our solar system, no offense to Saturn, but you would know right away that Earth is where all the intelligent life action is because we're emitting tons of radio emissions so all our communications, you know, cell phones, cable TV. We do a lot of stuff in the radio regime and so all of this is just, you know, shooting off like crazy off Earth and so you can tell that there's intelligent life here because of the radio emissions. So, some astronomers think that if we look long enough in radio waves, we can/ and search enough of the Universe, we can find other intelligent life like ourselves.

69:46

Ben T: Hey, incidentally, you know how in Lord of the Rings movie, how/

Ben A: Nope. Never seen it.

Ben T: /how Legolas looks like a hundred kilometers away and tells them how many horses there are and stuff?

Ben A: No. I mean, I trust that it happened.

Ben T: I'm just wondering how big his eyes would actually need to be to be able to resolve that distance.

Rupinder: He's got big eyes.

Sabrina: It's elven powers.

Ben T: Yeah, but he must have big eyes, right? Like I know that they had to find the handsomest person to play him in the movie but he has to have/

Rupinder: They succeeded, right?

Ben T: /really big eyes, right?

Ben A: Yeah, I know, she's real pretty.

Ben T: Like anime eyes.

Ben A: Yeah, if it's not about saving Christmas, elves need to shut up. That's my thing. Like, I can't take an elf that takes himself seriously seriously. So, like people love it, it's fine, go ahead, like that stuff but it's not my thing.

Rupinder: But you're down with, like, trolls and stuff, right?

Ben A: I'm sorry? No,

Rupinder: You're down with, like, trolls.

Ben A: No, like it's all of a piece. Like, I'm not much of a fantasy, swords and sorcery guy. I'm much more robots and time-travelling Nazis.

Rupinder: You're in the right place, I think.

Ben A: Yeah, yeah, yeah. I'm just saying, like, I feel bad that I should be down with your Lord of the Rings thing but I'm not.

Ben T: It's okay. When one writes long essays at the start of these things, one thinks about strange things.

Ben A: Sure, yeah. No, it's an apt illustration, I think.

Ben T: I bet Rupinder would know the answer to this.

Ben A: Yeah, yeah and while you've got him, you gotta ask him. It's not (...) my appreciation for just the latter works of Peter Jackson.

Ben T: Maybe if he did know it, you'd be really impressed. It was a long gamble.

Ben A: Yeah, that one dude, the computer generated Elijah Wood guy, Gollum.

Ben T: Yeah.

Ben A: Giant eyes.

Ben T: It's true, 'cause he lived in the dark.

Ben A: And Elijah Wood, also giant eyes.

Ben T: Right. Maybe they can see really far.

Ben A: Elijah Wood can see more heads of screws than me.

Rupinder, Ben T: [laugh]

Ben A: 'Cause he's like, his head is like two thirds eyes probably. Is that helpful? Do you wanna take this whole thing back?

Ben T: That is helpful, I'm gonna write that down.

Ben A: [laughs]

Rupinder: Well, if we wanted to talk a little bit about it, it's kinda cool too. It's like our atmosphere only lets in light from space, including the Sun, in the visible part of the spectrum, the part we can see, and the radio part of the spectrum. And so a long, long time ago before there was such a thing as sight, evolution sort of decided that we were going to develop these things that were sensitive to this light that was present on Earth but imagine some kind of biological organism that was sensitive to radio light. Their eyeballs would be these meters large. It would be disgusting.

Ben T: Yeah, what trees can see in radio? 'Cause about the right width. What if they're talking to each other about us in radio?

Rupinder: We would have heard that, right Sabrina?

Sabrina: Yes. If this is if a tree falls in the forest...

Ben A: No, this is if the tree gossips about you. You go and you cut that tree down because "shut up".

Sabrina: Can you locate which tree was the gossip?

Ben T: Yeah. Is Arecibo wide enough to figure out which tree was talking stuff about us?

Ben A: Or a bunch of trees all gossip Spartacuses.

Ben T, Rupinder: [laugh]

Ben A: Which tree said that thing about my fat ankles? "I'll never tell". "I said it". "No, I said it". Alright.

Ben T: [laughs]

Ben A: Nature's gossips.