Episode 43: Approaching Singularity
Dramatis Personae:

- Ben Tippett
- Jocelyn Read
- Katie Mack
- Jesse Moynihan

The Titanium Physicists Podcast
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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 phenomenon, science will never lose its romance. Over the years, I've traveled the world indulging in my fascination in physics. And now, I find that a new hunger has woken within me, a fiery need to share these great ideas with the people around me. And so, I've assembled a team of some of the greatest, most lucid, most creative minds I encountered in my travels. And I call them, my Titanium Physicists. You're listing to the Titanium Physicists Podcast, and I'm Ben Tippett. And now… allez physique!

01:15

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

01:52

Ben: *[singing]* Far far above, time standing still, memories are one, same space, same will, now move along, light speed divides, rips all from one, it blows my eye holes and fills me with real power, fills me real power power power power.

Everything has edges. Points past which we don't understand. Desks have edges. Lives have edges. Even a mathematical understanding of the universe has edges. These edges in physics often show up as infinity. A point, for instance, where the energy density become infinite. A point where we definitely don't know what's going on. And we call these points singularities. Before we go on, the word singularity is a misleading one. A single of something is just one unit after all. A single serving of bread. A single serving of cheese. A single serving of disappointment. But the word singular in case, doesn't refer to the quantity, it refers to the singular uniqueness of the point. It's a point where our theories stop applying. The singularities represent the edge of our understanding. Today on the Titanium Physicists Podcast, we are talking about singularities. Speaking about the edge of understanding, today's guest is an expert at the boundary. He is an American artist, composer, and director and he is writer and artist on the show Adventure Time and is responsible for some of my favorite episodes, including the episodes "Wizards only Fools" and "the Great Bird Man". He is also the author of a crazy awesome web comic called "Forming" and Forming volume 2 is coming out in stores this spring. Welcome to my show Jesse Moynihan.

Jesse: Thanks man.

Ben: Oh man, I'm so excited to have you on. This is going to be fun.
Jesse: I'm glad that that song resonated with you. Okay.

Ben: So Jesse. For you today I've assembled two of the best titanium physicists in the world. Arise Dr. Jocelyn Read

Jocelyn: [Roar]

Ben: Dr. Jocelyn did her undergraduate at UBC, her PhD at university of Wisconsin Milwaukee and she is currently faculty at the physics department at Cal State Fullerton. She's specialist in neutron starts. Now arise Dr. Katie Mack

Katie: Ta Da!

Ben: Dr. Katie did her PhD at Princeton University in astrophysical sciences. She's currently at the University of Melborne in Australia where she's a post doc and Discovery Early Career Research award holder. She studies theoretical cosmology. Alright everybody, let's talk about singularities.

04:31

Joselyn: Okay. The first we wanted to do was say the word singularity gets used a lot in different places and sometimes it's used sort of haphazardly but it's got kind of a mathematical meaning which is that things blow up. But mean we means this in a precise way, tight. So one of the simplest things is if you think of about what happens if you just try and look at the function 1/X. When X is 2, it's a half. When X is 4, it's a quarter. As X gets bigger, it gets smaller. But the opposite happens as X gets smaller, so at a half, 1/X is 2 and at a quarter, 1/X is 4. And then as you get closer and closer to zero, it gets bigger and bigger to infinity. So there at zero is the singularity, we say it's not defined precisely, it blows up, and well we can handle that in math, the idea's people have often thought if your physical theory of the universe has a singularity, and that then something is going wrong.

Jesse: Does that have to do with that paradox, where you walk half way to a wall?

05:40

Ben: Yeah, oh, that's a great example. Let me rephrase what Joselyn said. Those are Xeno's paradoxes, right.

Jesse: Yes, Xeno's paradox.

Ben: Yeah. So Xeno's paradox was all about motion.

Jesse: Okay.

Ben: Philosophically, Xeno didn't think that anything changed because to change something you would have to change it a little bit. And to change that a little bit, you'd have to change it an even smaller amount and he was against the whole idea. And so he came up with these paradoxes, and Isaac Newton took Xeno's paradoxes and turned them into math, and he then crushed them.

[Laughing]

But the deal with Xeno's paradoxes is a wonderful example. I want you to imagine that you're on the periphery of a big circle, on the street, somebody has drawn a big circle. So they put an X right in the middle, and you stand on the edge. And the game goes like this. Every time you go half way between where you're currently standing and the center of the circle, you get a cookie.

Jesse: Right.

Ben: You know, you walk half way to the center of the circle and then the guy next to you gives you a cookie. And then you walk another half way, but this other half way is a quarter the distance to the center. And then you get another cookie. And then you go an eighth distance to the center, and then you get a cookie. And then you go 1/16 to the distance to the center, and you get another cookie.

Jesse: Yeah.

Ben: Okay. So how many cookies do you get by the time you get to the middle of the circle.

Jesse: Like infinity cookies.

Ben: You get infin… yeah. That's what we mean by the singularities. This is essentially what Joselyn was describing.

06:50

Jocelyn: The neat thing about singularities is some things are perfectly well described, like, we can measure lengths to the center of the circle and be totally tappy talking about them. And then other things that depend on that length behave in weird ways, like giving you infinite cookies. So a lot of this is trying to reconcile the things that behave in ways that are easy to understand with the things that don't. And, I mean, length as it turns out, even though Xeno was like, we'll never get to center, it turns out that you can take effectively an infinite number of infinitely tiny steps in a finite time. So it turns out not to be a problem because of calculus, basically. But other things don't go away with calculus. So there're singularities that remain, even when we do all the tricks.

Jesse: Okay.

Ben: I mean, Xeno's paradox is kind of resolved. You play the same cookie game, and this time, when you go the first time you go half way to the center of the cookie, he gives you half a cookie. And then the next step when you go, you know, a quarter to the center, he gives a quarter of the cookie. And then as you go an eighths to the center, he gives you an eighth of the cookie. And so the process of him giving you cookies, he'll do it an infinite number of times, by the time you reach the center of the cookie, you...you'll only have one cookie instead of an infinite number of cookies.

Jesse: I understand what you are talking about, but I also feel like there is this other you know… Say in the big bang, right. When everything started from the single unit…

Ben: Yeah.

Jesse: And then exploded into infinite space time. So that that action, the big bang action. So everything before we formed into, and this has to do with that {xergiox huh} before we formed into individual pieces, like definable matter I guess or whatever…

Ben: Yeah.

Jesse: When we exploded from that single point, everything was the same energy junk, right?

Jocelyn: Yeah, I mean there is a precise way that our model of the universe has a singularity. And it's a similar idea, except now if you try and go back in time and you look earlier and earlier, everything gets closer and closer together.

Jesse: Yeah.

Jocelyn: Until at sort of a finite time ago, at the big bang that started the universe, the entire universe was all together in a single point.

Katie: So that singularity, the big bang singularity, means we can't look beyond the beginning of the universe. You know, farther back, because space time comes into being at the singularity if that's the model you are using. But we also can't see the singularity. I mean, we can't go back to that point with our physical models either because quantum gravity becomes important when you get to things being dense enough that you're at this stage where we can't just use gravity and quantum mechanics as separate things anymore. Everything is so dense and so packed close together at such high energy densities that you need to have a unification of quantum mechanics and gravity, and we don't have that at the moment. So even before you reach the singularity, we still can't deal with that with our current understanding of physics.

Jesse: Right.

Ben: Let's get back to singularities, because you were talking about the big bang, and the big bang singularity is actually fascinating,

Jesse: Yeah.

Ben: But to understand it, you have to kind of understand the singularities at the hearts of black holes. Because they are very similar things.

10:09

Katie: Yeah, so black hole singularities are and inevitable consequence of gravitational collapse. So what happens is you have the star, and normally, a star is kind of held up by the nuclear reactions happening inside the star. So you have a whole bunch of material and you're creating nuclear reactions in the center that's burning usually hydrogen into helium or something. And that's creating a pressure that pushes the outer bits of the star out and keeps it in this vaguely spherical shape. And the star has a lot of gravity that's pulling it in and then it has this pressure that is pushing it out and so it's in equilibrium and it's stable. And what happens with a star is that eventually it runs out of fuel and various things happen with blowing off layers and supernova and stuff like that but some point you get to a point where you don't have any more fuel to push the layers out and you have nothing to keep the star from collapsing under its own gravity. And there are a number of phases you go through with different kinds of exoctic matter that different kinds of pressure but can keep the star up for a while. But at some point you have so much matter in such a small space cause you've run out of processes that can hold it up and then the collapse becomes inevitable and there are no physical processes that can keep this from happening. And when that happens, the star collapses in upon itself and the gravitational field becomes more and more intense at the center and you have this process by which you're basically warping space-time by having so much gravity in one place. And that's what creates a black hole. So anytime you have matter in space-time, then that matter is creating a gravitational field and that gravitational field can be thought of as curvature of space-time. So the more mass something has, the more strongly it is curving space-time, or the more dense something is, the more strongly it is curving space-time. And so black holes are when you have something curving space-time so much that it's basically becoming infinitely curved at the center. And that's the singularity.

Jesse: Okay.

Katie: And the, you know, defining feature of a black hole, I guess, is the event horizon, which you might have heard of. Which is where the curvature of space-time becomes so intense at the event horizon that light can't escape out of the black hole. So people talk about it as the place where the escape velocity, the speed at which you need to be going to escape from that gravitational field is higher than the speed of light.

Jocelyn: And so one of the things about this collapse story turns out to be that if you have your collapsing star and it's just getting denser and denser and more concentrated and if it falls so that all the mass is past the horizon, there is nothing left that can keep it from going to the very central point. Everything is just going to keep falling. You know, stars can have different properties and structures and things, but a black hole is just all the matter, every kind of stuff is all just at one point in the middle of it.

Katie: And in a sense, you still have the same amount of mass if you are looking at it from far away. But basically all that matter is sort of converted into space-time curvature because it doesn't have any properties anymore. It's just become this space-time funnel. And all its doing is collapsing into the center and making this sort of pinch in space-time where the curvature of space-time is really high, and it all goes to the central point, the singularity.

13:43

Ben: Okay, so there's two things I want to emphasize about the collapse into a black hole that are actually pretty neat. And the first is that it's a type of runaway collapse. An example of runaway effects are greenhouse gas. People talk about it being a runaway thing, like global warming. The idea that things get out of hand. The more it warms, the more CO_2 emitting things will happen and the faster it will warm and the faster warming will cause more CO_2s and back and forth. Right?

Jesse: Yeah.

Ben: So what happens is – let's imaging yourself on the moon, okay? And imagine I've made a machine that stretch or shrink the moon's radius to any size I want, right. So I can make the moon really wide, I can make it really small. But the mass has to stay the same.

Jesse: Okay.

Ben: So gravity depends on the distance from the center

Jesse: Okay.

Ben: And it also depends on the total mass. And so if I doubled the mass, that would double the amount of force that you feel toward the center.

Jocelyn: So you'd notice that you'd weight twice as much.

Ben: Yeah. But if I halved the distance, if I halved the radius of the planet, if I shrunk the moon down to half its width, then you would, on the surface of the planet, feel four times as much force pushing you towards the center.

Jesse: Okay. Yeah.

Ben: So shrinking down is a very effective way on make this force stronger and stronger and stronger.

Jesse: Wait wait. Shrinking down, and the mass stays the same?

Ben: Yeah. So even though the mass is the same, you're much closer to the center of mass if you shrunk down the object to a smaller size, and so gravity is stronger.

Jocelyn: You're making it denser and more concentrated.

Ben: It's kind of like, you know, the earth, people go up into space. If you are really far away from the earth in space, the gravity pulling you towards the earth decreases, the force of gravity, right.

Jesse: Yeah.

Ben: The closer you get to the surface of the earth, the stronger the gravity you feel. So the same thing happens in this collapsing object, right. So you imagine you are standing on the surface of the star as it's shrinking. As it's shrinking the force causing it to contract is increasing dramatically

15:32

Jesse: Yeah. Yeah.

Ben: So the acceleration ramps up. Once the radius of the object is smaller than the event horizon, things become unreal. In terms of our regular intuition, the force pulling it together becomes unreal. To the point that nothing can stop it from crunching down to a point. So effective, it goes *[growls]*, kind of fights its way down to the size of the event horizon. Once it's under the event horizon, there's nothing that can stop it, it just goes *[whoosh]* down to a point…

[Laughter]

Ben: accelerating collapse. Because the smaller it gets, the denser it gets, and the denser it gets, the stronger the forces are going to get. Okay, there was a second thing I wanted to emphasis here with black hole. It has to do with kind of the nature of the black hole. The idea is that if you look at a model of a black hole, everywhere you go in it, there's no matter. You feel the force of gravity kind of pulling you towards the center of the system, but if you had a big net, you can waive the net anywhere you want, and it wouldn't scoop up anything. Even if you fell inside the black hole, you still wouldn't scoop up anything. It's a vacuum solution. Everywhere you go, there's nothing except for, at the very center, there is this place where the curvature is infinite. And so… but it's just one point. In fact, you can't even talk about it a point. It's… it's… it's kind of like a time. Because everything on the inside of the black hole is going to hit, it's more like an inevitability in time than it is a location in place. Your question: Why do we think that our theories can get to the point where we say "Yes this place or time, or this inevitability of this crunchy singularity at the center of the black hole, will definitely happen." It's an interesting question because there was a time when we didn't think that it was going to happen. Jocelyn mentioned that the theories, when they first came out with black hole model, everybody was like "No, this can't work because it's full of singularities." Because there's this second type of singularity that happens at a wider radius. That happens at the event horizon.

Jesse: Okay.

Ben: Something crazy happens at the event horizon, we keep saying the event horizon of a black hole, time can't escape.

Katie: Light can't escape. Sorry.

17:29

Ben: Yeah. That does something totally bananas to the mathematics of the thing. And so everybody, when they originally came up with it said, "You know what, stuff is probably going to come in and hit the event horizon and there's a singularity there. And that it's going to disappear or something. Who cares what happens on the inside? The event horizon has a singularity too." But it was an interesting example of why people need to be careful with singularities. And it's interesting because the deal is that sometimes singularities show up in the mathematics, and they're not actual real singularities, it's just an artifact of the mathematics.

Jocelyn: So you've seen this if you've ever looked at a globe.

Ben: Yeah. Yeah yeah. Okay. So we can talk about the latitude and longitude, right.

Jesse: Okay.

Ben: So latitude is the height away from the equator and longitude is the distance around, like clockwise around the world, right.

Jesse: Right.

Ben: So you can talk about traveling a distance with a constant latitude but a changing longitude, right. You are essentially staying the same distance away from the equator moving around the world, right.

Jesse: Uh huh.

Ben: This system kind of breaks down when you are at the North Pole.

Katie: And the…and the South Pole.

Ben: And the South Pole, yeah. There's two of them on the world, right. So when you're at the North Pole, you have a latitude, right. It's at the North Pole. What's your longitude? And the deal is that you're every longitude at once, right.

Jesse: Right.

Jocelyn: So you can say I'm going along all these longitudes and I'm not actually traveling. It's sort of a form of singularity. It's a…the problem is with your coordinates.

Katie: Or you can think about you're increasing your latitude, and then at some point you can't increase your latitude because every direction you go is decreasing your latitude, and so it's like where have you gone, you know. Like where do you go from there?

Jesse: Right. But it's just a math problem. It's not a physical problem.

Katie: Yeah.

Ben: Yeah. Right. So in general relativity, in this type of physics, it's very mathematical. And so it's really difficult because the singularity that happens at the event horizon of a black hole, it's called a traversable singularity. It's like the North Pole. So there's nothing strange about the North Pole. You can go the North Pole, and you can wander around it. And you …maybe if you take sextant, you might feel like... and measure the stars, you'd be like "Oh, things are weird here." But just in everyday usage, there's nothing strange about the North Pole. Very cold, but, you know, polar bears. Fine.

Jocelyn: And it took people about 20 years to figure out which of the singularities in the back black hole were just because it's hard to talk about the coordinates and which were real physical singularities.

Jesse: Yeah.

Ben: So the deal is that they thought that… originally they thought that they maybe everything would crush up against the event horizon, but it turns out everything just passes through it.

Jesse: Okay.

Ben: But then, the runaway collapse is the reason we know that there's got to be something crazy going on right in the middle of the black hole. Right at the singularity. Because you can't resist it. There's no way, once it's inside the event horizon, for the collapsing star to stop at some radius. In fact, its collapse is a matter of time instead of space, it's kind of like, there aren't any rockets we can use that can keep today from turning into tomorrow. There's no rockets we can use to keep…

Jocelyn: [Laughing]

Ben: You know… no matter how the rocket pushes, you can't hold a second still. And once you're inside the black hole, because… it's a mathematical thing, this inevitable crush is so strong that staying at a constant radius is exactly the same as staying at 10:00 pm, which is crazy.

Jocelyn and Katie: [Laughing]

Ben: So yeah, runaway collapse. The point is, yeah, we're pretty sure, at least in canonical general relativity… this … this… this type of physics that Einstein invented, that everything in the black hole is just at the center. There's nothing anywhere else. Once you're inside the event horizon, you fall right down to the middle.

21:23

Jesse: Okay. What's there? Like, you know, if it's sucking all this matter inside of it…

Ben: Yeah.

Jesse: And then, it gets crushed and chills in there?

Katie: The matter kind of ceases to exist as a physical thing. I mean, it turns into pure space-time curvature. It doesn't have properties anymore. I mean, it doesn't have atomic structure. That all gets crushed. It doesn't have color or anything like that. It just goes into the singularity and it's hard to define.

Ben: Yeah, mathematically the singularity is literally the end of the universe.

Jocelyn: This is also what we take now as a hint that our description breaks down right at the densest point.

Ben: Oh, yeah yeah. Yeah. Steven Hawking. You know who Steven Hawking is right.

Jesse: Oh, yeah.

Ben: So Steven Hawking is like… everybody knows his name and thinks he's a great guy. And the reason everyone knows his name and thinks he's a great guys isn't because of all those books he wrote. It's not because he's in a wheelchair, although that's part of the reason he's so fantastic. The reason everybody knows his name is because in the 60s, he came up with a mathematical proof showing that general relativity, our psychical model of gravity, is inconsistent at the singularity. So literally, somewhere on the singularity, our laws of physics can't be consistent. They have to break down.

Jesse: Do they break down into a new set of laws, or do they break down into just gobbledygook.

Ben: Well, their inconsistent. All we know is that they're inconsistent.

Jocelyn: So our philosophy is that there should be a new set of laws there. But there is more an aesthetic faith that we can describe the universe in a consistent way. And we don't know the description right now. It's a mystery.

Katie: It's kind of like what I was saying, that the big bang singularity, before you even get to the singularity, looking back in time, you have to deal with quantum mechanics and gravity working together, and we don't know how to do that. Um.. same way we don't know. Um.. the same way we don't know how to reconcile the physics at the black hole singularity.

Jesse: Yeah.

Ben: So the deal is now that we've talked about the black hole singularity, now we can start talking about the big bang singularity. Because their stories are very similar.

Jesse: Um hum.

Katie: So we know the universe is expanding. We can measure that expansion and we know that it's been expanding for a long time. And if you, kind of, dial that back in time, then things must have been closer together. And if you dial that back farther and father in time, you get that at some point, basically everything would have been at a single point. And we know that we can't really, within our understanding of physical laws, we can't really extrapolate back that far. Because then you get to densities that we don't know how to deal with general relativity by itself. But the upshot is that at a finite time in the past, we suppose that the universe was itself a singularity. That every point in the universe was sort of singular or in one singularity. So that's called the big bang singularity. But it's actually… one of the things that comes up a lot if you are a cosmologist like me and you talk to the public, when I talk about the big bang, in cosmology, er, sort of like with my colleagues or whatever, I'm not usually talking about the singularity. I'm talking about the hot big bang, which is just… this sort of… idea that in the past the universe was smaller and denser and hotter. And so that's something that you can observe with the cosmic microwave background, the leftover light from the big bang. This hot big bang, not singularity, but hot big bang like fireball. That we know the universe must have been in at some point. And we can see evidence for that. And so knowing that big bang happened in terms of everything was hotter and denser and smaller in the past and it's been expanding, that's totally observational cosmology at this point. But extrapolating, back to the big bang singularity, to saying that the big bang being the expansion from a singular point to everything we have, that's kind of a different issue and that's something we can't observe directly because we can't get to that point observationally. We can't see back to the big bang singularity, if it was s singularity. If it did all come from a single point. There sort of a complicated things that might have happened between the hot big bang and the singularity. Like something like inflation where you had the universe expanding exponentially fast for a while that made the universe way way bigger and way more stretched out and there's ideas to think that might have happened to solve various problems of cosmology. So, getting back to the big bang singularity is actually really difficult with the sort of observational tools because there are a couple of, sort of, observational issues with trying to get to that, and theoretical issues with things like trying to have a understanding of quantum gravity to… to be able to deal with those extreme densities. So, you know, the big bang singularity is something that we often talk about as a possibility, but it's not sort of as clear as the black hole singularity in terms of that has to have happened. Black hole singularities I think are much more inevitable.

Jocelyn: But even, like, there is sort of an analogy with the black hole. That when I say we see black holes, we never see past the event horizon. There's actually a theory that you can never have a naked singularity.

Katie: Yeah

26:42

Jocelyn: It's always cloaked by the event horizon, which shields it from view.

Ben: Except the big bang singularity, which isn't behind an event horizon.

Jesse: Why can't see past the event horizon?

Jocelyn: Because no light can get out from there.

Jesse: Oh. Right. Haha.

Jocelyn: So… so… you know… to see something, you need a messenger to tell you what's happening and all the messengers got crushed to the center.

Jesse: Right. So, could I ask more questions about the sing…big bang singularity versus the hot big bang?

Katie: Yeah.

Jesse: So one is… the hot big bang… let me… I'm just trying to understand this… the hot big bang is the thing that we can observe because there's evidence of it. Like physical evidence. Right?

Katie: Yeah, we see the afterglow, in what we call the cosmic microwave background.

Jesse: And then the…the singularity big bang is basically number crunching that we've…

Katie: It's just that if you take the expansion that we can observe and dial that back, you get to everything being at a single point, and that's the big bang singularity.

Jesse: But you think of those two things as totally separate.

Katie: Yeah, because you can mess around with early universe theories and not have a big bang singularity. Weird things could have happened beyond the point where we can do any observation because you know it's within that, sort of, fireball time that we can't see past, and or it's in this sort of quantum gravity regime that we can't really deal with. There're a lot of ways to… to have not have been an actual big bang singularity. But we know the hot big bang happened because we see the light that's left over from it.

Ben: So, everything Katie said is right, before I say anything. We really don't know what happened before this observable epoch. And we can mess around with the models in ways that what I'm about to say isn't inevitable.

Jesse: Uh huh.

Ben: But let me just tell you the canonically simplest model so that you'll get a sense that this big bang singularity is a little bit more inevitable than it sounds. You have to do some pretty heroic work to get rid of it. So first off, it's inevitable because of gravitational collapse…is what happens. Um… so… what I'm going to take you is a mirror image in time to our universe, but one played in reverse time, where everything is collapsing in on itself instead of expanding out. But before then, did you know that the universe is infinitely large?

28:50

Jesse: Uh, yeah. That's what everyone tells me, yes.

Ben: Okay. And did you know that the universe is infinitely regular. No matter where you go in it, even if I could teleport a hundred trillion billion light years away in one direction, the density of matter and the composition of matter would be about the same as it right here, give or take. You know, if you average out the density of a cluster of galaxies, it's about…

Jocelyn: You have to be bigger than a galaxy for everything…

Ben: You have to be pretty big to talk about the scales. But on the scales that drive the dynamics of the expanding universe, no matter where you go, the density is about the same. It's called the Copernican principal, named after Copernicus who was like "Hey, there's nothing special about the earth. It's not the center of the universe." Right.

Katie: Can I just jump in real quick with a bit of pedantry.

Ben: Yes, you'll like…

Katie: We don't…so… what we can do is talk about the observable universe which is as far out as we can observe, um, and within that region everything looks Copernican. And, you know, it all looks good. But we don't actually know that the universe is infinite. That's a good assumption. But we can't observe beyond the edge of the observable universe.

Ben: Of course.

Katie: And so…

Jesse: But that's where the underverse is, according to Riddick.

Ben: Right, I mean, so, of course.

[Laughing]

Ben: Everything Katie said is right. We might be in some weird…you know… all sorts of more complicated things could be happening at larger scales, and of course, modern physics is…is playing with different ideas to take into account. I'm just talking about the very simplest assumption because the simplest assumption makes the math a lot simpler. And so these were the first ones introduced, it's… it's the assumptions that everything else is based on and also the assumptions that we're testing and playing with when we're building new theories. Not wrong at all Katie Mack.

30:40

[Laughing].

Ben: Anyway, assume she's wrong.

[Laughing].

Ben: Everywhere you go, it's the same. Of course, un-testable because I can't teleport a hundred trillion billion light years in any direction. I can't see for myself that everything looks the same. But like I said, it's named after Copernicus for good cause. There's no reason to suggest that there's anything special about our particular patch of the universe. And certainly every direction we look, things seem to look the same. And so it's an assumption people thinks are pretty good. That said, it is a crazy assumption. The universe is infinite and everywhere you go, it has the same density. It's reasonable in its simplicity, but also extravagant in its assumption. Okay, so the universe is infinite, but what happens though is that even though it is infinite, it can expand and contract. And the way we see it expanding and contracting is in stuff moving away from each other. It is if you zoom in really close. But in essence, the way you describe it expanding and contracting is in terms of density. So if the university is expanding, even though it is infinitely large, the density decreases. And if it's contracting, the density increases.

Jesse: Yeah.

Ben: And this system, even though it's infinitely large, it still gravitates. It still has some gravitation to it. And you describe it's gravitation using Einstein's Theory of General Relativity. And the deal is, I want you to imagine this universe is full of stuff, everywhere you go, it is the same. As it contracts, it's not contracting to a point. We're just talking about the density increasing. Since it's gravitating, it's kind of… it's actually exactly numerically like the inside of a black hole. All the matter collapsing down to a point. Can you imagine our universe collapsing down to a point? What happens is the denser it gets, the stronger the force of gravity gets, the more inevitable the collapse gets. So it gets denser and denser, and it starts to increase the speed in which its density is increasing. You get a runaway contraction. It gets denser. So even though until the very last moment mathematically, the universe is infinitely large. And it's not collapsing down on a point, it's just that the density skyrockets and becomes infinite. and of course, the moment the density become infinite, the math stops working, and we call that a big crunch singularity. And if you play it backwards, universe stays infinite, but starts out infinitely dense, and then it starts expanding outwards, that's the big bang singularity.

32:43

Jesse: Okay. Say if we do a big crunch, right. If the universe eventually does a big crunch and collapses in on itself, maybe again or whatever, right. Is there a reason why it'd want to expand again?

Ben: Okay, so the devil's in the details. And so what happens is, there might be physical effects that are too subtle for us to know about right now that become very strong and very important when the universe is really really really dense and hot. It's kind of like the strong nuclear force and the weak nuclear forces only happen inside the atom. They don't happen outside. So there might be effects that only start to dominate when things get really really dense. And what happens is it might be those effects act kind of like a spring. What happens is that the density gets so strong that those effects start to play in, and those effects say "Hey guys, we can't keep collapsing. We're… we're running out of steam." And it causes… it's called a cosmological bounce. It causes everything to stop contracting. The density stops getting denser and it starts to expand. Density starts getting….

Jesse: But that wouldn't happen to a black hole though.

Ben: Well, nobody's sure.

Jocelyn: But we see what looks astrophysically like black holes.

Ben: Yeah.

Jocelyn: They haven't bounced back into our universe, at least. The idea is maybe the center kind of inches off into another universe. But that's totally beyond anything we can observe or…

Ben: Yeah, these things happen inside black holes, sometimes too mathematically.

Jesse: Now a long time ago, I heard about one of the universe models being like a static universe or something. That there was no big bang. That the universe always just existed infinitely.

Joselyn: That's what sort of what Einstein tried to do when he was first coming up with GR because that's sort of the picture people had about the universe. That it was sort of eternal. But then there was… there's various paradoxes that arise if you think about the universe that way and…

Katie: And we also discovered expansion. And so, that made it clear that the universe is changing and not static.

Ben: It's funny. All these things are coming together with that question, because Einstein… you asked: "Could there be something… what could cause it to bounce." And Einstein introduced a term into his equations so that he could build a model of the universe that could sit still. Because he was like "Finally, thing sit still." And then immediately after, Hubble put out a paper saying "Oh look, it looks like the universe is expanding. Einstein was right the first time." And he refers to that as his biggest blunder. But it turns out the constant that he added into the equations, he did by hand, but since then mathematicians have gone through the his work and said actually, maybe that term is reasonable to include in his equations. But it's possible that that it could contribute to a universe that starts out collapsing, and then bounces instead of big crunching. And it's also possible that you can make it if it has a certain parameter, you can use it to cause the accelerating expansion, the dark energy that we see today. So, it might be in there, but it certainly is not causing the universe to stand still. So Einstein might have been extra accidently double right.

[Laughing]

Ben: Well that was wonderful. Thank you, Jocelyn. Thank you, Katie. You've pleased me. Your efforts have borne fruit, and that fruit is sweet. Here's some fruit. Jocelyn, you get some guava.

Jocelyn: [Chewing]

Ben: And Katie, you get a watermelon.

Katie: Num Num Num.

[Laughing]

Ben: Ah ha. I'd like to thank my guest Jesse Moynihan. Thanks, Jesse.

Jesse: Yeah, thank you man.

Ben: I hope you had fun.

Jesse: Yeah, I did have fun.

Ben: Alright, so listen TI Phyghters. Some of you might want to support our show financially, and that's understandable. We've got a couple ways to do it. If you want to support us, firstly, you can download a podcast app called Podiversity for the Android phone. It's a subscription for content based app. Kind of like Netflix, only for Podcasts. And they only have a few podcasts, and their all science podcasts, but they pay us cash money for downloading episodes. So if you get the app and listen to our show, cha-ching, we're in the money. Secondly, T-Shirts. Go to our store at the TI Phy website and buy yourself a sweet shirt. Some of them were designed by brilliant designer Chelsea Addison. Are the shirts kind of expensive? – Yes. They are kind of. I'm sorry about that. But TI Phy gets a cut of each shirt sold, and they're really really good quality and they look fantastic. And Bethany bought one two years ago and she's worn it every day since… well, at least twice a week since then, and it still hasn't worn out. The t-shirts are very high quality and very nice. So have a look at them.

So that's it for the main part of today's show. If you keep listening past this, you'll hear some ridiculously fun conversations. Remember that if you like listening to scientists talk about science in their own words, you might want to listen to other shows on the Brachiolope Media Network. I'm talking about Astrarium about Astronomy, Science Sort of about science and science culture, the Weekly Weinersmith where they do science interviews, Technically Speaking where they talk about engineering. 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 day, and remember to keep science in your hearts.

37:22

[Outro song: Angela by John Vanderclice.]

38.24

Jesse: If you guys could help me out a little bit, there might be like a lot of leeway as to how popular culture understands the meaning of singularity. Cause there's… ah… like… people talk a lot about the internet singularity. You know.

Jocelyn: The… the technological singularity is that the idea of the rate of change of technological advancement by whatever measure is… the rate of change is increasing in a way that it's going to go infinitely fast at some finite time in the future.

Jesse: Yeah.

Jocelyn: So that's the same idea that we were talking about. This idea that you can go... you're looking forward in time, something is basically going to blow up.

Katie: That's basically the point at which computers are replicating themselves and making themselves more advanced.

Ben: Yeah. That's when like computers start designing themselves and they're going to do it better than we can. And so past that. So originally, at that start of the show, singularities are kind of sometimes used in science language when we mean that the boundary between where we will be able to understand and we won't be able to understand what's going on. And in this sense, so once computers start designing themselves, who knows how fast they'll be able to advance. And then after that, they're probably going to all take care of us, and we'll all live in computer paradise.

[Laughing]

Jesse: Or they'll do… did you see Her?

[Laughing].

Jesse: Did you see that movie Her?

Katie: Yeah, yeah.

Jocelyn: I did see that movie.

Ben: Isn't it like a guy making out with a monitor or something like that? He falls in love with…

Jocelyn: No no. It's a phone. It's a phone.

Ben: He falls in love with his phone?

Katie: But no spoilers.

Jesse: But she… oh, no spoilers. I'm sorry. But it has to do with what we're talking about, where the computers advance beyond human production and intellectual modes, you know.

Jocelyn: In a general term, a singularity is when… a singularity is when you're ability to predict what's going on stops working, right. Whatever model your using just is breaking down at that point. So you need something else to predict what the computer will do.

Ben: [Laughing]

Jesse: Does that have to do with the singularity, that singularity principle. Like how you're defining it because I think, I think sing… the word singularity gets thrown around a lot.

Ben: Yeah.

Jesse: Umm…

40:45

Jesse: Does that understanding of that big bang singularity… Does that apply to… you know… I've done a little bit of reading about quantum physics … just on the toilet.

[Laughing]

Joselyn: As one does.

Jesse: You know that idea that one particle is in communication with another particle faster than the speed of light. So one particle one side of the universe can affect another one.

Jocelyn: So that's the idea of entanglement which…

Jesse: Right. Entanglement.

Jocelyn: I don't think actually involves any singularities.

Jesse: Oh, okay.

Jocelyn: So that turns out just to be straight quantum physics. One thing is that even though the particles… They're entangled, so they talk to each other. There's no way to transmit information faster than the speed of light.

Jesse: Okay.

Jocelyn: So it's… its sort of consistent with our regular picture, even though it's really non intuitive.

Jesse: Do you see any potential use for the principle of, like, quantum entanglement? Like is there any…

Ben: Oh my, we just did a show on this. Yeah. You can do all sorts of neat things with it, for communication things. Like you can use it to come with a way to encode messages that is completely secure. The short answer is when two people are trying to communicate with one another using a code, you have to get the code to the other person so they can decode what you are saying. And the process of getting the code to the other person is, itself, requires some security, right. Because somebody can stop and you know, beat up the person with… with the suitcase full of codes, and then they can hack into all your codes. So what they do is entangle two particles, and then one person looks at the particle, and they way he looks at it will change how the other person's particle reads. So if one person looks at the particle and it's a… its…a particle point up, the other person's particle, because it's entangled, will be pointing down. And so there's this way… there's…

there's no information being transmitted, but there's a coherent sense of what's going on on the other end. And it's not hackable. You can't intercept that. And so you can make essentially…you can come up with a scheme for making one time pads, it's called. In… ways to encode information. So you never actually have to go down the street with a… with a list of numbers that somebody can beat you with a blackjack and steal…

Jesse: To get your key.

Ben: Yeah yeah.

Jesse: That's cool.

Ben: But…

43.08

Jesse: Now someone offered you a chance to go into spacesuit and cross the event horizon, would you do it?

Katie: No, no no.

[Laughing]

Katie: That would be a really bad idea. So…

Ben: I'd do it

Katie: So the reason it would be a really bad idea, for one thing you could never like… you couldn't like write home and tell people about it, which would kind of suck. So, it would be like, you know, nobody would… would ever know that… that… what happened, but the other reason is because of something called spaghettification. Which is the technical term for what happens when you have so much more gravity at your feet than at your head. That your body is stretched out into spaghetti. And that… and that would be really unpleasant.

Jocelyn: It's like a really extreme form of tides.

Katie: Yeah.

Jocelyn: The way the earth gets tides on either sides of it. You're… you would be totally stretched and in an extreme way.

Jesse: And so you would die before…

Jocelyn: Before encountering the singularity. Or getting to answer deep philospophical questions. You would… you would… you wouldn't get a chance to do that. You would just get torn apart.

Ben: It'd still be pretty cool.

Jocelyn: It'd probably be pretty cool, but only for a while. And you couldn't tell anyone about how cool it was.

Ben: [Laughing]

44:29

Jesse: Okay, so Jupiter's gravity is less than earths?

Ben: Umm… okay. Well, okay. So the question… when… when some… when you ask how much the force of gravity is, you want to know how much it weighs and also how far you are from the center of it.

Jocelyn: Right. That's the… that's the question…

Ben: So…so…

Jocelyn: Because Jupiter's so big. But Jupiter's also much more massive than earth.

Ben: So yeah, depends on where you're standing.

Jocelyn: So… so… so Jupiter has about twice the surface gravity of earth.

Jesse: Okay.

Jocelyn: So it's just the way that the size and the mass balance out it's… it's…like… I don' t know… it's way way way more massive, like, I think, hundreds of times or something .

Ben: Yeah.

Jocelyn: But because it's so much bigger, it's…you only get twice the gravity on the surface.

Jesse: Okay.

Ben: And there's no surface to Jupiter.

Jocelyn: Well, yeah…

Jesse: Well… that's like… it's not… that's why I was asking. Because it's not dense, right. It's just…

Ben: Yeah. It's like gas.

Jesse: It's a gas.

Katie: Yeah, I mean, there's a difference between sort of density and compactness that… that's… a little bit subtle with that I guess because some black holes, if you measure them by, you know, the… the size of the event horizon and the amount of mass in them, they're not that dense, on average.

Ben: Um hmm.

Katie: But something becomes a black hole… when it's got more mass within its Schwarzschild radius, which is the radius of the event horizon, than…than a certain limit. So it's… So it's the compactness as defined by kind of the amount of mass within a certain radius that's defined based on its mass rather than density per se.

Jocelyn: Right, like if…if you look at say the super massive black hole at the center of the galaxy…

Jesse: Um hmm.

Jocelyn: Umm… so, that the mean... What's the mass of that?

Katie: It's about, ah, million solar masses. It's on order of a million solar masses. I don't remember the number exactly.

Jesse: That's at the very center of our galaxy… is a huge black hole?

Katie: Yeah.

Jocelyn: Yup.

Jesse: I didn't know that.

Katie: Yeah.

Ben: Do you feel a little bit more doomed?

[Laughing]

Jesse: I don't know.

Jocelyn: But but…no… you but the… the other thing that we talked about is that away from the black hole, it just behaves like a mass like anything else. If we took the sun away, and… and instantaneously put in a solar mass black hole, same mass, earth would just go around in its normal orbit.

Jesse: Right

Katie: Yeah.

Jocelyn: So… so…

Katie: We'd all… we'd all die, obviously, because we didn't have the sun anymore. But we wouldn't be sucked in or anything.

Jesse: Right.

Ben: The… the…the reason that black holes are so sucky isn't that they're force of gravity is… is… is really big itself. It's that you can access regions of the space where the gravity is really really strong, that would otherwise be occupied by the star.

Jocelyn: They only suck when you're inside the horizon.

Ben: Yeah. They only suck when you get too close.

Jesse: It's at the center of the galaxy. So our…uh… solar system is being affected by it? Its being… it's rotating around it, right?

Katie: We're rotating around because of all the mass between us and the center of the galaxy, not just the black hole. But um...

Jesse: It's cumulative.

Katie: Yeah, yeah. But the… I mean the… the black hole is sort of the point around which all of the mass of the galaxy is rotating.

Jesse: I see.

47:30

Jesse: So in our daily life, right…

Ben: Yeah.

Jesse: You exist on the planet, right. You're walking around… and you learn the violin or whatever… [Laughing]

Ben: Uh huh.

Jesse: And everything you're interacting with exists like makes sense within our idea… our common idea of time, you know. Like everything that we do is… I wake up at 9. I… if I drop a ball, it's going to fall on the ground.

Ben: Um hmm.

Jesse: It's not going to fall on the ground first and then I'm going to drop the ball, you know what I mean?

Ben: Yeah.

Jesse: I'm not going to be able to drop a ball into… so why do you think that something physical exists that's so outside of our common experience. Why do you think that in order to explain something that we observe, our black hole observations, it has to be so abstract?

Katie: I mean that I think that the big difference is that our daily lives exist in a regime where space-time is reasonably well behaved. So, we can think of space-time as being, you know, really fairly boring and flat. And it's just that around black holes or inside black holes, space time gets really really warped and really messed up. And so because space and time are inextricably entwined in, you know, our ideas about general relativity and stuff and special relativity, then you get these really freaky effects where space and time become really complicated. And the way that things happen and the way that, you know, space and time are affecting each other are change a lot, in those regimes. And so it's because we're… I mean, you know, we're on a planet, so our space-time is curved in the sense that we have… we're in a gravitational field, but it's a pretty mild curvature and so it doesn't create, you know, sort of, screwy effects.

Jocelyn: We see hints of the whole space time curvature thing in our day to day lives, right Your GPS needs to account for the curvature of space time around the earth to get the timing right with the satellites.

Katie: And it has to account for the fact that time moves more slowly when you're moving very quickly. That's a special relativistic effect. It has to take that into account as well.

Jesse: Oh. I didn't know that.

Jocelyn: If you look past the sun when there's an eclipse, you see the positions of the stars behind the sun move a little bit because the sun is bending their paths. So, you know, our day to day lives, we don't really feel these things. But we've been able to measure all sorts of little things, like the orbit of mercury kind of loops around in a faster way than it would without space-time curvature. So you sort of see all these things, and you extrapolate, and you say wow, there's weird stuff that exists in reality.

Jesse: Yeah.

Jocelyn: And, you know, when Einstein originally proposed the theory, like, they'll use these singularities as evidence that it was a bad theory.

Jesse: Um hmm.

Jocelyn: But it turns out that actually it's still the best description that we have and that the singularities… we do observe their affects. So we observe stars orbiting black holes at the center of our galaxy. We observe hot gas falling into other black holes. So it's this weird abstract thing that has physical consequences.

Jesse: Can you imagine like a civilization that existed where space-time was more, like, less consistent or less… uh…

Jocelyn: What I was going to say, there's a book by Greg Egan called *The Clockwork Rocket* about universe where light has a different speed and things behave differently.

Jesse: Oh, okay.

Jocelyn: So I mean, people do imagine like what if this behaved differently but you still… This idea consistency we… we're pretty sure that everything should fit together in the end of things.

Katie: I mean by the time you're in a region of space-time that's curved enough to give you sort of noticeably freaky time effects, the gravitational field is so high, you're not going to be able to do a whole lot.

Jesse: Can you imagine like a life form exist… I mean like this is like sci-fi but… a life form existing within a heavily curved... inside the… isn't effected by the mass of gravity of a black hole. So there could be planet inside a black hole.

Jocelyn: We don't know anything that's not affected by gravity.

Katie: I mean, everything exists within space time. And everything is affected by space-time. Even, I mean…light doesn't have mass the way we think of it, but light travels through space-time, and the path of light is bent by the bending of space-time. So really, everything has to follow those rules.

Jesse: Did you see that move The Black Hole?

Ben: Yeah!! I loved that movie.

Katie: I didn't see it.

Jocelyn: I haven't seen it.

Ben: It came out when we were like one. It was like 1979, right.

Jesse: It's a Disney movie.

Ben: Yeah. With the robots. And they fall into the black hole in the end. And it's really trippy.

Jesse: They built a ship that could withstand the crush of the gravity of a black hole.

Ben: Yeah. So yeah… in real life, if they tried that, the ship… the ship might be able to survive longer than the people inside it, because it would crush the people inside it just as well.

Jesse: Oh…

Katie: It would spaghettify people.

Ben: So it's actually interesting…

52:55

Jesse: So if you saw, say, gas getting sucked towards a black hole, right. And you saw it reach, not quite yet the event horizon, but then you see it cross the threshold, right. I understand that it would disappear. You wouldn't see it anymore, right.

Ben: Yeah

Jesse: And that because it just has entered into a zone with no light.

Katie: We don't really see it cross the event horizon. We would kind of see it freeze on the event horizon and fade away. Because once it gets to the event horizon whatever light it's producing won't get to us. It'll go into the black hole. So like let's say you're shining a flashlight out from inside the black hole. The light from that flashlight will turn around and come back to you, if you're inside the event horizon.

Jesse: … will never reach the person on the outside observing.

Katie: Yeah. And so if you're right on the event horizon, then the light from that flashlight kind of stays at the event horizon surface but if you're outside the event horizon the light from that flashlight can get out, but it'll be shifted to the red part of the spectrum which is another…

Jocelyn: it'll be all stretched out.

Katie: It'll be all stretched out and it'll take a really long time.

54:08

Jesse: But that wouldn't happen if there was a big crunch.

Jocelyn: Well actually, we should say that our observations of the universe suggest that it's actually not going to crunch back down it's actually accelerating to get bigger faster.

Jesse: Oh, okay.

Katie: Yeah, so there's different kinds of big crunch kind of things as well. I mean, there's a model called the ecpirotic universe where you have a big bang big crunch cycle. And that it's a cyclic model, but you have sort of extra dimensional things happening. You do get this expansion that we see now, but you're collapsing in a different dimension also. And then you get the bounce happening. So you can do weird stuff with other dimensions and still get big bang big crunch kind of things. But basically, the classical idea that they crunch where the universe gets more and more dense and collapses into a singularity that's, as far as we can tell, that's not going to happen in our universe. Because we have something going on now where the universe is expanding and it's accelerating and its expansion is due to something called dark energy and we have no idea what that is. But whatever dark energy is, it's causing the expansion to go faster, it's kind of pushing everything out. And so what we think is going to happen in the distant future is that everything is going to get more and more spaced out, everything is going to get less and less dense and the universe is going to sort of become more empty according to what we can see, and, you know, the stars will die out and everything will get cold and dark and… umm… and lonely and it'll be extremely depressing.

Jesse: Yeah. So depressing.

[Laughing]

56:00

Jesse: There's no reason to believe that, according to Copernicus… is there reason to believe that it would be any different anywhere else? You know what I mean. And that made me think about that… uh… that made me think about that story of Flatland and… you know, the two dimensional beings interacting with three dimensional beings interacting with four dimensional beings. You know. And that our methods of observation are limited in our way, so we find some new way of observing.

Ben: Oh yeah. Indeed. In fact, there are models of the universe that have more than three spacial dimensions. There're models for universal acceleration, expansion, dynamics of the universe that take into account the possibility of larger geometries beyond the ones which our universe exists on. The Copernican assumption is audacious in some ways, entirely reasonable in other ways.

Jesse: Right. But it's a good place to start.

Ben: Yeah. That's right. That's the idea.

Jocelyn: So you can have the sort of the base level of Copernicus, which is we're not special, without also saying that and we see everything about what's in our neighborhood.

Jesse: Right. Sure. Okay.

Ben: But yeah… so… so… but, you know, if there were four dimensions, if there were six spacial dimensions, you'd say but why are we stuck on four… three dimensions. What special about those three dimensions. So its… its… I mean at some point in time, it just becomes a philosophy of science stuff. Where you're like "You can't assume that you know everything" and it's just like "Yeah, but the math works better this way." And so, you know. You do what you can in the short time you have in front of the chalkboard.

57.25

Jesse: Right. And you were saying that the way we measure expansion is though the density and not through distance, right.

Ben: Yeah.

Katie: Well, I mean…

Ben: Yeah yeah yeah. Hold on. Yeah. So in the bottle, it's preferable to talk about density instead of distance. But when we observe it astronomically, we're looking at long distances. And seeing how light changes over them.

Katie: We're seeing things become more distant.

Ben: Yeah.

Jocelyn: It's kind of funny, we were talking before that you have to choose the coordinates, right?

Jesse: Yeah.

Jocelyn: To describe things. And when you're talking about the universe, you can choose coordinates that sort of expand with the universe or you can have sort of coordinates that stay fixed and have the universe expanding against them.

Jesse: Yeah.

Jocelyn: So depending on what you mean… what you… what you mean by "our lengths getting bigger." So…so like the distances between things are getting bigger, and you can think of it in different ways.

Jesse: Because depending on like where you at, it might not, it'll seem different. Depending on where you're measuring from. Is that …

Jocelyn: Well, we measure galaxies by their Doppler shift…

Jesse: Okay.

Jocelyn: And we can see that as the galaxies are all flying away from us…

Jesse: Yeah.

Jocelyn: Or we can that as actually the light from the galaxies is getting stretched out by space expanding.

Jesse: Right.

Jocelyn: And it's the same thing.

Jesse: But some of them…but some of them are not getting further away. Because we're like moving with some of them, right. Or…

Jocelyn: Right, it's…

Katie: Yeah, so the nearby ones are not moving farther away, but as you go farther out, where… where the other galaxies are not affected by our gravitational fields or we're not affected by theirs, those are all moving away from us.

Jesse: Right, right.

Jocelyn: It's like if you have a river, you can have little eddies and currents and things, but as a whole, things tend to be going in one direction.

Jesse: Yeah.

59.26

Jesse: Is unified field a scientific term or is that a new age term?

Jocelyn: It can be a scientific term.

Jesse: Oh, okay.

Katie: Yeah, I mean, people… there's things called grand unified field theories. Grand Unified Theories. Usually abbreviated to GUT. Grand Unified Theory. And it's a… it's a… the name for a kind of theory that unifies the forces of nature to like one major… like… you know… one single theory that includes all the forces. Because right now, we can… we can unify certain forces pretty easily. So we can unify electricity and magnetism into electro-magnetism. And we… and that's that's all very easy. And you can unify electro-magnetism and the weak force – electro-weak unification. And that happens at high energies, high temperatures, um, unifying. Then you have to… when you want to unify electro-weak and the strong force, that's where you… that's where grand unified theories come in. We think that that happens in the early universe when everything was really really dense. We think that there was a time when you had the GUT era. So when… when you had grand unification of those forces. And then bringing in gravity, that's sort of beyond grand unification, that's quantum gravity. And that the next step that we really don't know how to do yet.

Ben: In what sense have you heard the phrase "unified field"?

Jesse: Oh yeah, that gets thrown around in new age… new age circles.

Ben: Are they like "We're all connected with a unified field."

Jesse: Yeah.

Ben: Yeah, I great. So… [laughing]

Katie: Oh, yeah, that's bad.

[laughing]

Katie: Yeah, we don't like that.

Jocelyn: It's not physically meaningful.

Ben: I can see the indigo children through the unified field.

Jesse: Right…

Katie: I mean, there's quantum field theory and there's effective field theories, and there's grand unified theories, but… and those are all physically meaningful, but unified field is not physically meaningful, as far as I'm aware.

Jesse: Okay. My question a lot of the times is… out of the hot big bang, what made up the building block material of the universe? Is just that energy or whatever eventually like separated itself into different …

Jocelyn: It separated into, like, electrons and neutrons and the things we day to day today.

Jesse: Right. Yeah yeah. I mean that stuff is all still there, right? I mean, that stuff, the original building block materials is all still what it was when it first exploded, right?

Katie: Well, no, it's like… it's stuff that sort of condensed out of that matter-energy stuff that was the beginning. So, it's like you know how with stuff like particle accelerators, so like the Large Hadrons Collider at CERN. What they do is they take two protons and they… and they smash them together and create this really high density high energy collision. And then particles come out of that and they get all sorts of different particles even though the particles they put in were protons which are made of quarks. They get lots of different kinds of particles out of it because they've recreated some of the primordial soup of... just like… energy density and the lots of different kinds of particles can condense out of that. And that's kind of what happened in the early universe is that you had this energy density and particles came out of that.

Jesse: I see.

Ben: The word condensation is actually delightfully vivid. Kind of like how water condenses. Like so if you have an enclosed chamber, it's got water in it and you heat it up to the degree that water can't stablely exist as a liquid. What happens is water droplets come into being, but because everything is so violent inside your hot hot box, it'll turn back into vapor, right?

Jesse: Yeah.

Ben: And then if you cool it, as it cools, suddenly there gets to be a point in time where a water droplet might form, and it can stick around.

Jesse: Yeah.

Ben: So there are all these fields, electrons and quarks and thingy… photons and they can all… they're all interacting when it's really really hot, but as the universe cools, as it expands, as it becomes less dense, suddenly an electron can form and stick around in current form. And uh…

Jesse: Right. But why would it form? Why would that soup that you were talking about… why would it form discernible tangible objects?

Jocelyn: So one of the things we can say is that you know we see matter around us and all sorts of different forms that look very different. But if you go down to the smallest components, every electron looks like every other electron and every proton looks like every other proton. They're identical. They don't have any difference between them.

Jesse: Right.

Jocelyn: And so when you have this sort of mass-energy, the stuff that comes out… just sort of by quantum probabilities are just this various spectrum of fundamental particles that can later arrange themselves into the things you see in your day to day lives.

Jesse: Why did they arrange themselves that way?

Katie: Each Particle creation is kind of a probabilistic event. And it's sort of going to a lower energy state, so having this hot primordial soup is… is kind of higher energy and then as the universe expands a little bit, it's less energy. And then you create particles and they're kind of an easier state for that energy to be in is the particle. And which particles are created are sort of a quantum mechanical probabilistic thing.

Jesse: Um hmm.

Jocelyn: Getting from there to what you see today, we don't really know the why, but we know how that happened. We know that once there were enough electrons and protons and neutrons floating around, they started forming hydrogen. And once you had a cloud of hydrogen gas, some of them started collapsing in on themselves and forming starts.

Jesse: Wow.

Jocelyn: And then once you have st… you know, the structure of the universe… and you know we don't know all the details, but in general, we know how that turned into stars that exploded and formed other elements and formed new stars and formed discs that have planets and then all the building blocks just sort of came together because of this dance of gravity and stars that are just fundament physical things.

Jesse: Yeah. Umm… That's cool.

[Laughing]

END.