Episode 33: His Dark Materials
Physicists: Rupinder Brar, Vicky Scowcroft
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Transcribed by Denny Henke

Ben: Oh. Hello old friend, it's good to see you. Let's talk about this word facination. It describes an unquenchable urge which compels our hearts to quest and be captivated. As long as there are elegant explanations to complicated phenomena science will never lose its romance. Over the years I've traveled the world indulging in my fascination with physics and now I find that a new hunger has woken within me a fiery need to share these great ideas with the people around me so I have assembled a team of some of the greatest most lucid most creative minds I have encountered in my travels and I call them my Titanium Physicists. You're listening to the Titanium Physicists Podcast and I'm Ben Tippett, and now allez physique!

[1:48]

Ben: One of Carl Sagan's most popular sayings is that "Extraordinary claims require extraordinary evidence." So, what if someone were to tell you that 70% of the world's food was eaten by ghosts? And then if you ask, well, have you ever seen a ghost eating 70% of the world's food? They'd go, well, no, but they're ghosts, no one's ever seen them eating food because they're ghosts but the food is missing. This would probably start a pretty incredulous discussion about the evidence which led to the claim. Now, a lot of people have responded, fairly reasonably I think, to the claim that 70% of the mass in the Universe is generated by strange, mysterious invisible type of matter we ominously call dark energy. We've never seen it but we know it's there and we know it's huge and it's massive and it's ever present. Today we're talking about dark energy. You know what else is huge and massive and ever present? It's Ben Caplan, his beard, his voice, his glasses. Ben Caplan is an indy rock musician and he's based out of Halifax and he tours internationally, he sings songs that are rollicking and are raucous and has like a gypsy pirate music. Aw wow, hey Ben, welcome to the show.

Ben C: Hello.

Ben: So, you can find more about him on his website bencaplan.ca or you can follow him on twitter, @bencaplanmusic. You can find those links on our website. So Ben's the brother of a good friend of mine and I've been looking forward to inviting him on the show for awhile now so when I finally got around to introducing myself to him I asked what he'd like to learn about and he said dark energy. So, anyway, here we are. So, Ben, for you today, I've assembled two fantastic Titanium Physicists, arise Dr. Rupinder Brar. Dr. Rupinder is one of the friendliest people I know. He's so good at making science fun that in 2010 he won TV Ontario's lecturer of the year award. He got his PHD at Queen's University and he's currently a senior lecturer at the University of Ontario Institute of Technology. Now arise Vicky Scowcroft. Dr. Vicky got her PHD from Liverpool John Moores in the U.K. She's currently a post-doc at Carnegie Observatories where she works on the Carnegie Hubble Problem. She even has a new knitting podcast called One Starry Knit, I'll link to it on our website as well if you want to find it. Alright, let's start talking about dark energy.

[4:12]

Rupinder: Let's put the problem in context. Let's start in the early 1900's. So, it's almost like the debate that's going on right now happened in a sort of different way about a hundred years ago. A hundred years ago theoretical physicists were debating, is the Universe itself, static, like non-changing, infinite or is it something that changes with time? And basically we were able to solve this question through one of the greatest observational astronomers of all time, Edwin Hubble. And basically what Edwin Hubble did was, he measured the distances and what we call redshifts of galaxies and basically redshift just means that he's able to figure out how fast these galaxies are going. So these are distant galaxies, he can now measure their distances but also, not only how fast they are going but which direction they are going and the big discovery was that all distant galaxies are moving away from us and essentially what this showed was, in fact, that the Universe itself is expanding. So we're living in an expanding Universe where essentially space itself the distance between distant objects is getting larger and larger. And this is the Universe I grew up in, right, this is the Universe we were raised on and it sort of sets the picture for what comes next.

Ben: So, what's the relationship between Hubble and doppler, it's called the doppler effect right?

Rupinder: That's absolutely right, so this idea of redshift is just another way of saying the doppler effect, right, and so light coming from distant objects is going to be, what we call, either red shifted or blue shifted through the doppler process and so if it's coming towards us it's going to be blue shifted. If it's going away from us it's going to be red shifted and so if you imagine a Universe of randomness, of non-changiness pretty much half the galaxies should be moving toward us and half the galaxies should be moving away from us. So, you've got to imagine the surprise and the shock really of when Hubble did this experiment a hundred years ago and figured out that all galaxies, other than the few that are really, really close to us that are gravitationally interacting with the Milky Way, but all other galaxies are moving away from us. The only explanation could be, in fact, that the Universe itself is expanding. There are other possible explanations but the thing is the further the galaxy is the faster it's going, that's the key. So, the further you are away from us the faster you're moving away from us and that definitely translates into an expanding Universe.

Ben: Beautiful. You know, have you ever heard of Einstein calling something his biggest blunder?

Ben C: I haven't heard about that.

Ben: Okay, so there's a story. So this whole red shifting, blue shifting, doppler shifting thing is interesting because mathematically red shift isn't a doppler shift, it's an analog to doppler shifts. Doppler shifts happen in sound, ah, red shifting and blue shifting happens to the color of light so something that puts out white light, if it's moving away from you really quickly that white light will be shifted and we'll see it as red light just like how the pitch changes in doppler shifting. So we usually explain red shifting and blue shifting processes in terms of a doppler shift analogs. But all this doppler shifting comes from Einstein like he was the guy who predicted it when he invented Special Relativity. So, in 1916 Einstein produced his theory of General Relativity and it's the theory of gravity so it's theory that talks about black holes and it also talks about the Universe expanding. And the thing about Einstein's theory of gravity is that it imagines that everything in the Universe lives on a, it's a four dimensional sheet called spacetime, you've probably heard of the spacetime continuum, that's what they're referring to. So, right after the First World War, people were playing with different models for gravity, so one of the models they came up with is, essentially, the black hole solution. And another other model, it has some simple assumptions built into it, so you take these equations and you say how am I going to simplify these equations and come up with a model and the simplifying assumptions were pretty neat. They said so what if everywhere in the Universe is like everywhere else? It's called the Copernican assumption, it's based off Copernicus was the guy who said what if the Sun doesn't go around the Earth, what if there's nothing special about the Earth and everything in the solar system is going around the Sun? So Copernicus was like, there's nothing special about the Earth and so this Copernican principle says well what if there's nothing special about anywhere? What if everywhere is essentially the same and it's a lovely set of assumptions because the equations become very simple and what it ends up describing is a Universe that's expanding or contracting, but this contraction or expansion happens everywhere at the same time. So, it's kind of like, anywhere you go in the Universe you'll see the Universe expanding in the same way, so there's no center of attraction. It's not like an explosion where everything explodes out from a single point. Instead its kind of like, we often describe it in terms of, if you take ants and put them on the surface of a balloon and then start inflating the balloon, the distances on the balloon will start increasing but technically speaking there's no center on the balloon that everything is being attracted or repelled from.

[9:33]

Vicky: And the ants don't get any bigger.

Ben: The ants don't get any bigger.

Rupinder: Right. It's uniform space.

Ben: Right. So, Rupinder was saying, people at this time were really conflicted because you know, philosophy had been around for several thousands of years and what philosophers decided was that the Universe should either exist forever or maybe built the Universe at some time, but there's no reason the Universe should have a beginning or an end or anything like that.

Rupinder: Interestingly enough, I think Einstein was part of that school too.

Ben: Yeah, that's right. So Einstein bought into this and he looked at his equations and his equations said the Universe can either be shrinking or it can be expanding and it can't do neither, it can't just sit still. And so Einstein said, well, let me add a term here and he added this term called the Cosmological Constant to it which is just, it's a constant that you just stamp into the equations and what the constant does is it has the capacity to make spacetime solutions that don't expand or contract, they just stay the same.

Ben C:Does the constant have a physical relationship or conceptual relationship to any force or any ratio within the Universe.

Ben: That's a good question. So at the time it didn't, at the time he just inserted it by hand and mathematically since then people have justified him doing so. We think that it's not mathematically flawed to add a constant where he did, but he did it because he wanted a cosmology that didn't change.

Ben C: So he figured out how to solve the equation to exactly what he wanted it to.

Ben: Yeah, but he had to add a little term in there to his original equations. So, since then mathematicians have said oh, maybe that constant should be in the equation but Einstein just put it in, he found it aesthetically appealing right, the solution he got from it. But then immediately after that Hubble came out with his finding that said Oh, hey, look, the Universe is expanding which is what Einstein's theory originally predicted which is why he said oh, this is my biggest blunder, why did I go out on a limb and say that there was this constant that everything still, so wrong, right.

[11:29]

Rupinder: One more thing we should mention about the Hubble observation before we go onto this new dark energy observation is that finding the velocity of these distant galaxies is actually really easy, the hard part is finding the distances. The distances to far away objects is one of the most challenging things in observational astronomy and the only way he was able to do it was because of this type of star called a Cepheid variable star and so a Cepheid variable star is a specific star that basically gets brighter and less bright, brighter and less bright, very, very regularly. And, the period of that brightening and dimming is directly related to it's actual luminosity, that is its intrinsic brightness and so, by, basically, measuring the period you know how bright that star is. And by comparing how bright it actually is to how bright it looks through your telescope you can use that relationship to figure out distances and that's what Hubble did and theres a very…

Vicky: It's what we still do today. Like, this is what I do all day. Like, we're using exactly the same technique that he used a hundred years ago because it's still the easiest way to do it. It's still hard but it's still the easiest way to do these things.

Rupinder: And yet…

Ben C: So, what is it that's causing the change in luminosity of the star.

Vicky: So, it's got Helium in the atmosphere of the star and as it gets hotter, the heat like, can knock of electrons and ionize the Helium but that changes the chemistry inside the star so the radiation starts to get trapped so as it gets trapped it makes the pressure go up which then pushes the star out and makes it bigger and that changes the brightness but then eventually it goes too far and then it cools down because it's got bigger and then it starts to shrink back in on itself. And it just keeps doing that and doing that but it's really regular because it's basically just like a sound wave propagating through the star so you can predict really simply what it's going to do.

Ben C: Would you describe it as frequencies?

Vicky: Yeah, we use period or frequency. We tend to use period because the period is typically like a few days but theres another type of star that we use for distances of closer things where the period is like a few hours but the Cepheids are what we use for the nearby and quite far away galaxies.

Ben C: So what is the process for using the change in the light, that's still a bit unclear to me, the way in which the light changes, how does that allow you to pinpoint the distance? How do you transform that period into a measurement of space?

Vicky: From the period and from what we already know about these types of stars we can work out how bright it really is and then you take an image of the star and measure how bright it looks to you and then you take the difference of those two numbers. It's like if you had a hundred watt light bulb and I held it right in front of your face you would be blind and also, it would be really bright but if I moved it to the other side of the room it would look fainter and you know that the amount it gets fainter is proportional to how far away it is so you can work out by how much fainter it looks how far away it is.

[14:24]

Ben C: Yeah at first I thought you were using the change in the light to determine what the true brightness is but you are using a calculation based on the period of the light to figure out the true luminosity…

Vicky: Yes

Ben C: Not by direct observation but through calculation of the change

Vicky: So we have a relationship, there's like a well defined relationship between the period of the change and how bright the star really is, so we have a few stars nearby that we can directly measure the distance of by seeing how they move with parallax, like when you close one eye and then close the other eye things tend to move, we do the same thing with these stars using observations in, like January and July or whatever, so we do the same thing with ones that are really close and then use that to calibrate out.

Ben C: When you say January and July, you're measuring the parallax by using your knowledge of where the Earth is in relation to Sun and using the widest point possible to triangulate the distance

Vicky: Yes. Yeah, that's exactly it.

Ben C: Gotchya.

Rupinder: So basically for the next hundred years, till 1998, we're living in a Universe that we know is expanding, so basically what scientists are trying to figure out now for the next hundred years is what's eventually going to happen to our Universe. Are we living in a Universe that will collapse back on itself in this sort of big crunch, will the expansion reverse, will it sort of come to some beautiful equilibrium and just stop or will it expand forever but sort of slow down as it goes and the answer to that is no.

Ben C: I'm not clear, what was the no to? No to that it can't expand forever?

Rupinder: No on all of those. All three of those turned out to not be valid in fact due to these brand new observations that we'll talk about.

Vicky: Yeah, so there was three. It could either expand for awhile and then run out of energy and then collapse back in or it could keep expanding and eventually slow down and then just carry on going but at like a really slow rate or it could just keep going forever and… so, okay, we wanted to look at these different types of expansion so they looked at stars called super novae which are kinda like Cepheids, like we know exactly what brightness they should be so if we observe them we can work out how far away they are so they were looking at really distant super novae, like, as far away as we could observe and they found that these super novae all looked too faint from what you would expect them to be so that either means that there's something wrong with our super novae model or the super novae are further away than we're expecting to be. So, there were like two groups that discovered the same result at the same time and for a little while neither of them published because they were like, oh we must have messed something up here, this is just like insane. And eventually both of them did publish it and they realize that they were both seeing the same thing but from different observations.

Ben C: Is the reason they were afraid to publish is because they were afraid that the findings are challenging the present model or just or…

Vicky: No it wasn't that, they were't sure if they were right. They wanted to be really sure that they were right. Once they'd convinced themselves of this then they did publish. So they publish, saying that the supernovae were too faint and the explanation for that is that the expansion of the Universe is actually accelerating. So it's not just that the things are further away from us are moving faster, but they are getting faster and faster all the time as you get further and further away.

Ben: So right after the Big Bang, the Universe was expanding, the spacetime itself had a kind of momentum that was pulling all the objects in the Universe apart, it was adding volume to itself, it was getting bigger and bigger like the surface of a balloon. And what happens is, before this discovery, Vicky was talking about, we expected that initial momentum to be essentially, all the Universe had driving the expansion, right. We know, based on what Hubble discovered, that the Universe is expanding currently and then we expected the matter in the Universe to kind of slow the expansion of the Universe down. So in this case there are three possibilities. One of them is that it keeps on expanding forever, just like, you know how the Earth has an escape velocity, so if I take a ball and I throw it faster than the escape velocity the ball will keep on going forever.

Ben C:Yup, that's how rockets get up into the sky.

Ben: That's right, we kind of imagine the Universe doing that, you know, it was possible if the Universe had enough velocity, right at the get go that all of the deceleration caused by the gravitational attraction of all the dust and planets and stars in the Universe would cause the Universe to slow down but it could be that the initial velocity of the Universe was so fast that it blew past that limitation and we just keep on expanding forever and then we have nothing. Everything would be so diffuse the Universe would be empty. And another model said that we would have less than the escape velocity of the Universe and the pull of gravity would cause the Universe to re-collapse. It's expanding right now but maybe in a few million years it would begin re-collapsing down in on itself and you get a big crunch. Now, this discovery that Vicky was talking about said that the Universe isn't decelerating, the way we would expect it to decelerate from the attraction of all the objects in it, it's accelerating. So, things aren't just getting farther apart, they're getting farther apart faster and faster.

Ben C: I guess that means that the analog of throwing a ball and being able to predict what's going to happen falls apart because apparently it's more and more complex forces at work than we had initially anticipated?

Ben: It's kinda like the ball was actually a rocket and after it left it's hand…

Ben C: No one knew the ball had a rocket built in.

Ben: Yeah

[19:27]

Ben C: What's the evidence that everything is accelerating and how recent has that been confirmed by observation?

Vicky: So, the original evidence from the supernovae was in 1998 and the people who discovered that won a Nobel prize two years ago. But it's been confirmed in other ways now, there's a satellite called Planck which has just released its results recently and that was one of the ones that's confirmed it and what it does is it measures all, like, the radiation left over from the Big Bang called the Cosmic Microwave Background, and it measures the sizes of all the fluctuations in the background. But what it does is it measures all these sizes of these different fluctuations and measures how many of each one there are and from that it can work out what the Universe is made of like how much of it is dark matter and how much of it is regular matter and how much is dark energy. And they work out that that 70% of the Universe must be dark energy and you're like, why would it be that? But if you take that, with the supernovae as well and you say, well how much dark energy must there be in the Universe for those supernovae to look like they do? It's 70% as well. So now we have two different things that are saying like 70% of the Universe was eaten by ghosts.

Ben C: So, this 70%, is it based on observation. Is…

Vicky: Yeah

Ben C: So, dark matter, can we say it is analogous to a vacuum or is it something radically different than the absence of matter?

Vicky: So, dark matter, its just like regular matter but we can't see it. So it behaves, gravitationally, in the same way.

Ben: So, there's two things at play here. So, when everybody made their ridiculous announcements, they said that there was dramatic evidence for two things that we can't see. Dark matter and dark energy. So, dark matter is a type of matter so it's planets that aren't shiny count as dark matter and so what you can do is you look at galaxies and galaxies are rotating so everything in a galaxy is twirling, like stuff around a drain, and the thing that makes our Sun orbit the galaxy is, essentially, the gravity of everything inside it's orbit, all that matter, so you can figure out, based on looking at how fast, all of the stars are as you move from the center of the galaxy out to the edge, you can figure out how much mass is contained from the inside to the outside of the galaxy and you find that there is way more matter in a galaxy, in terms of the velocity of the things that are orbiting than there is stars. And so, all the other stuff must be there, but isn't shining like a star we'll call that dark matter. So, we've known about the existence of dark matter for awhile now, but in addition to it all of these cosmological dynamics, tests that Vicky was talking about, confirm the existence of dark matter so now we have two big demonstrations that dark matter exists but in addition to that there's this weird dark energy thing and nobody knows what causes that.

Rupinder: These names are unfortunate, dark matter, dark energy, the reason we call them these things is we have no idea what they are, that's really what it comes down to. There's nobody…

Ben: You could replace dark with mysterious.

Vicky: We call it dark because everything we do in astronomy is looking at light. We can't go out there, we use the telescope to look at the light and this is something we can't see so it must be dark. That's it. It's simple.

Ben C: So, go on, tell me more about how dark energy relates to the problem of an accelerating Universe.

Ben: Ok, so it's like this, when you're talking about the dynamics of the Universe as it expands, the deal is that the more concentrated the matter is the more potent it is gravitationally so most matter like your beard, if you stretch out your beard, it becomes more diffuse right, it's density decreases. So, usually what would happen is as the Universe expands normal matter like the distribution of galaxies becomes more diffuse so the overall effect of the matter becomes less potent on how the Universe evolves, right? So to make the Universe accelerate what you need as a special type of matter because if the Universe is accelerating it means that whatever is driving that acceleration is getting more and more potent

Ben C: I see

Ben: So, somehow the larger the Universe gets the more of this dark energy there has to be.

Ben C: So, let's say a sandbox had a certain amount of sand in it…

Ben: Yeah

Ben C: and the walls were moveable but then the sand would become less voluminous, there'd be less density of sand within the sandbox, and we would expect it to slow down but instead it's like more sand is just appearing out of no where that continues to push the sandbox wider.

Ben: That's exactly what it's like.

Vicky: Yes.

Ben: Very good

Ben C: Great

[23:47]

Ben: Let’s suppose you had a box that was empty, it had nothing in it. Vacuum. And you doubled the size of the box, would the density of the vacuum increase or decrease.

Ben C: Well I suppose if it’s a vacuum its already, by nature, not possible that it increase or decrease, it’s already nothing.

Ben: Very good, I mean it’s just as nothing as it was before. It’s just like you said. So the deal is that one of the possible candidates is a type of energy, it’s a type of gravitational effect that’s constant, it’s like the vacuum, it’s ever present, it’s everywhere and so just like the vacuum, if you double the size of the Universe, it will keep the density the same. Just like that. So, there’s one thing that works just like that and we’ve talked about it already. It was called Einstein’s biggest blunder, that constant that he added in to his equations in order to make the Universe stand still, you can choose a constant for that constant that makes the Universe expand and accelerate and it’s called the cosmological constant and it’s one of the candidates for why the Universe is accelerating. So, the deal is, it’s not becoming more potent as the Universe accelerates, it’s just as potent throughout it’s life, but the thing about the cosmological constant is all the rest of the matter in the Universe is getting more and more diffuse so, in comparison to the regular matter, the cosmological constant, if that’s what’s causing the expansion, gets more and more dominant over the regular matter and so it’s driving the accelerating expansion. So, in the end it might have been Einstein’s greatest move ever in that he predicted this thing a hundred years earlier except nobody knows if thats it.

Ben C: This cosmological constant that’s now driving the bus as it were, is there any sort of analogy of how it exists spatially or temporally within the Universe?

Ben: So, there’s two different explanations, depending on whether you're coming from my point of view which is just as a parameter, so, the way I would imagine it is, all gravity is caused by curvature, so what we call gravity is actually the effect of curvature on spacetime so in my picture the cosmological constant is kind of like, imagine you're trying to tile a basement, you're trying to build something out of a bunch of tiles, you open up your box of tiles and each of them was kind of smushed, you know, they're still rectangular but they’re kind of curved like Pringles, you can make them meet edge to edge but if you did it so you would end up with a large, weird curved shape instead of a nice flat shape. So, in essence, the way I understand this cosmological constant is it’s kind of like that, it’s kind of a four dimensional spacetime curvature that each of the points in the spacetime kinda has just like each of these tiles do. So, your spacetime inherently has a curve to it and that curve is being exposed as the matter is becoming more and more diffuse. But there’s another, that people explain this curvature and its through something called vacuum energy. Have you ever heard of vacuum energy before?

Ben C: Never heard of vacuum energy.

Ben: In quantum mechanics all systems are imagined kind of like guitar strings and what they say is, they talk about exciting a system the way you would excite a guitar string by plucking it and they say at the smallest levels things are quantified. You can only add very discrete packets of energy to it, it’s like saying that a guitar string can oscillate at one decibel or 1.5 decibels but it can’t oscillate at 1.4 decibels, there’s no intermediate states. So, then the mathematics of quantum mechanics say that at its lowest state, once you’ve extracted all the possible energy out of an object its still got a little bit of vibration to it.

Ben C: Because the lowest possible state is not zero.

Ben: Yeah, effectively you treat it like it's a vacuum. It's got no more energy to give so in some sense it's a vacuum on the other hand, it's got a little bit of energy to it so quantum mechanics as it started was very well behaved and before too long people started applying quantum mechanics to more than just particles. We started talking about quantum mechanics about electromagnetic fields, these larger systems, and what happens is if you break down these more universal fields in terms of quantum mechanics you see these vacuum energies popping up. They're times when like an electromagnetic field will have no excited state, there won't be any photons in it but it will still have some inherent energy to it.

[27:44]

Ben C: So even though it seems like the field is not active or present in any way it still acts.

Ben: Yeah, and the thing is when you add that to gravity you'll say okay, each of those little motes of vacuum energy are going to add up and that means that the field will have some mass and when you add up that mass you usually get infinity. So they do a couple tricks with the math to get not infinity. They can predict how much mass this vacuum energy is going to have and then they can compare the predicted theoretical vacuum energy mass to the measured vacuum energy mass and it is 120 orders of magnitude too high. Some people call it the worst prediction from science ever.

Ben C: So, not off, but like waaaaayyyy off.

Vicky: Yeah

Ben: It's called the cosmological constant problem and nobody knows how to resolve it.

Vicky: We have an issue

Ben: Nobody knows whether that vacuum energy is gravitating or whether it's just a thing that lives in the mathematics. Nobody knows if it might exist but somehow there's some other secret field that's canceling out the energy so that you end up with a fairly low number. So, nobody knows whether this prediction is true or not but it's possible. This vacuum energy might be the thing that's driving the accelerated expansion of the Universe.

Vicky: The weirdest problem is, it's the same problem we have with dark matter. We can like infer that dark energy is there because we see its effect and we can infer that dark matter is there because it messes up what galaxies look like but we can't find it, we can't go out and, like, get some or say, oh this is a dark matter particle or this is what dark energy is. We're still guessing right now.

Ben C: So it seems as though the visible forces of the Universe are nested somehow inside invisible forces that we can't really see.

Ben: Yeah, for us to have the Universe that we observe to be consistent with the theories that we have we need a whole bunch of invisible players behind the scene pushing things around.

Rupinder: And to be honest I think the theoreticians are definitely behind here, no offense Ben, like…

Vicky: We've done our job so…

Rupinder: Yeah, we've got a couple possibilities and stuff but the real answer to what dark energy is probably I don't think we've come up with it yet. And one thing that maybe we'll mention just briefly since we have been talking about dark matter as well is there's always sort of the concept that maybe something we do know about we just don't know about to the proper degree like say the concept of gravity or general relativity could there be something more complex about it that when we get to larger and larger scales we honestly just don't have a proper theory for how gravity or general relativity works and thats how the properties that we now call dark matter and maybe eventually call dark energy could those be described by a more complete theory of gravity? I'm not proposing that that's true but it's certainly something that smart people are thinking about.

[30:38]

Vicky: So, one of the interesting things that has come out recently with Planck is that, so they measure the fraction of dark energy and dark matter and regular matter and other things like the rate of expansion of the Universe and one way they measure it with the microwave background and there's another group of people including me who measure it by measuring distances to very nearby galaxies instead of the really far away microwave background and we get different answers so right now we have no idea why we get different answers so it's entirely possible that there's something we just don't quite get yet. So, it's an exciting thing to work on because we have no idea what we're doing. It's great.

Ben C: Sounds so exciting.

Ben: It's kind of frustrating, its frustrating, because I mean Rupinder said that there's a whole bunch of alternative explanations and there are but the problem is that we don't know enough. We're getting enough information that we know that the Universe, as we understood it back in Hubble and Einstein's time, isn't right. we know that the Universe is accelerating and we know how much it's accelerating by kind of, we know a few more parameters but we're not, there aren't all that many and so what happens is you can make a lot of different theories of gravity that account for the differences, like technically speaking adding a cosmological constant to Einstein's theory of gravity is technically a different type of gravity I mean, it's a matter, it's really an academic thing, it's like arguing whether Han Solo shot first. I mean its like, because it's so trivial, and because Einstein added the term on his own but people do much more ridiculous things. Some people are arguing that Einstein's theory of gravity should have additional terms where Einstein's theory of gravity is just a simplest approximation to how the Universe really works and that there should be, curvature should play a much higher role in affecting matter and nobody knows whether that's true or not but people are playing with it, they're called f(R) theories of gravity. They're really neat, some of them predict the dark matter, some of the account for mass having a bigger vote the farther away you get from it which would account for why galaxies spiral the way they do. Others of them predict accelerating expansion like our Universe and it's lots of fun

Ben C: So it seems like physics right now, to me it sounds analogous to the state of astronomy of the 15th, 16th century where you're adding circles upon circles upon circles, each orbit has another orbit and you're tinkering with this model of the solar system until it's so insanely complex and ugly and so we've got these models, we're adding rules, we're adding formulas and different principles and different ways of looking at things and brining new things into the model, you know, with Galileo the moves is to more beautiful, easier to understand model that is radically different and has different underlying principles at it's core, so perhaps the dark energy situation predicts that a new model, I guess a unified theory, would replace the old model entirely.

Ben: Yeah, that's certainly possible.

Vicky: Yeah

Rupinder: For sure.

Ben:Um, it's exactly like that. We've got a theory that doesn't fit. Einstein's original theory of gravity doesn't fit. We know that a small tweak that's mathematically correct can allow for the Universe to increase in size the same way but just like when we saw the stars doing their retrograde motion and we couldn't predict it and astronomers started adding these circles we don't know which theory is right and you can modify the theory, you can make new theories that all predict the same type of expansion.

Ben C: You know the retrograde motions, the models were insanely complex…

Ben: Yes

Vicky: But maybe we really just need to switch around the way we're thinking about it.

Ben: Yeah, that's right. I mean, right now there's a plethora of explanations. They do all sorts of things. It's actually fantastic, it's like a golden age for theory because there's enough data to justify changing the orthodox theory, but not enough data to choose which of these potential candidates for the successor is the correct one.

[34:22]

Rupinder: But what needs to happen… Any sort of scientific method is going to be for these new theories to make predictions for the observers. Now we need to see the theoreticians and computational physicists and all these guys to be all like look if this specific theory is correct then you should be able to observe this specific thing and then we'll go out there and we'll see if we do see it. That's the only way we're going to progress in this different scenario.

Vicky: One of the things to remember about this, it's easy to forget like dark energy, that was 1998, that was less that 20 years ago. We've come all this way in just a short amount of time but what we need to do now is like, we have, like the satellite experiments, measure one set of parameters and when they measure these numbers they can't always disentangle them, they're like, they're measuring one thing but it's kind of linked to another number and they're not getting any unique answer so you need different types of experiment to be able to say that we can definitely split up these values and we can measure how much dark energy there is and completely disconnect that from a different parameter about the Universe and right now we can't do that so we have to think of different ways to look at it. Hopefully we'll get there soon but…

Ben: One of the things that theorists do, we don't just dream up new theories but one of the things that we spend a lot of fun time doing is when somebody proposes a new theory, it's usually fairly simple, they say hey, why don't we just do this and they'll add a new term and it will throw something up and we'll say oh, okay, hmm, is that right? In addition to looking for things we can test just like Rupinder says, one thing theorists do is we look for inconsistencies, and so one of the problems various modified gravity theories is they'll explain dark matter but they can't explain dark energy or alternatively you can tune them to explain dark energy but they won't be able to explain dark matter. So, it's a pretty fun time these days because there's lots and lots and lots of explanations for why the Universe is expanding the way it is but we're not sure which is right. We're in the wild west.

Ben C: Well, I'm going to stop playing music and start studying physics.

Ben: Well, if you want to you're welcome.

Vicky: Come and join us!

Ben C: This thing, I mean, I don't know, it's not nearly as exciting as all this physics.

Ben: Well, I don't know… you're pretty good at it.

Ben C: Maybe I'll keep up with what I'm doing… but it's fascinating, it's an exciting time.

Ben: So, thank you Rupinder, thank you Vicky, that was great, you've pleased me very much. Your efforts have born fruit and that fruit… here is some fruit. Vicky, you get a pear and Rupinder, here's a mango for you. Alright, I'd like to thank my guest, Ben Caplan, the clever indy rocker with a beard that just won't quit. More information is on his website at bencaplan.ca and if you want to follow him at twitter go to @bencaplanmusic. Thanks Ben!

Ben C: Thank you!

Ben: Did you have fun?

Ben C: I sure did Ben.

Ben: Hurray! So, my Ti-Phi-ters, I love this show and I hope you do to but for every listener to the show I know that there are a hundred other people who would love to listen to the show but they just don't know how. So, I want you to spread the word and there are three ways you can do this. The first is iTunes. It's still the biggest place to go to find new podcasts so most frequently rated shows are at the front where everybody can see them so, if you've got a minute give us an iTunes review. It will increase our rank and more people will see us. The second is to teach people how to listen to podcasts which is funny, but everybody you know has a smart phone or tablet these days and a very low percentage of these people know how to listen to podcasts so if you know somebody who would like to listen to the show ask them if they know how to listen to podcasts and if they don't point them to the Stitcher app and I don't say this lightly but the Stitcher app useful, it's easy to use and it works on almost every hand held device so whether they're working with an Apple or a Blackberry, they can still listen to Stitcher. Do it, your grandmother will thank you for it! The third way to talk about our show is to tell people online about us. The internet is full of explanations about physics. If you see someone on the internet talking about a topic one of our episodes covered or maybe a new story post a comment at the bottom telling them about the show. Alright, that's it, I hope you'll help us out and point new listeners in our direction, so thanks. So, that's it for the main part of the show, remember if you like to listen to scientists talk about science in their own words you might also want to listen to other shows on the BrachioMedia Network like the Weekly Weinersmith where Kelly and Zach Weinersmith talk to academics about their research or Science Sort of where we talk about science in the news. So, editing support for the Titanium Physicists podcast is provided by a gentleman named John Heath - thanks John you're the reason we sound so good lately. 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 have a good day and remember to keep science in your hearts.

After end song:

[39:53]

Ben: Okay.

Ben C: But then you'd expect the vacuum itself to limit the size of the container

Ben: Oh, yeah, well if you're in the atmosphere you're pulling against the atmosphere and then you need really big arms like a musician… yeah, so you're right.

Vicky: But in space I wouldn't worry about that.

Ben: In space… playing the accordion would be very easy.

Vicky: Yeah.

Ben C: Right, because there's no vacuum, there's no there's no pressure on the outside the vacuum that limits the vacuum.

Ben: Yeah, that's right.

Vicky: Yeah, so you're just making your box twice as big and still having…

Ben C: So, spacetime is curved in my mind, the way I understand it, and then everything in spacetime if you imagine like, imagine like three kids in a skateboard park ok and they're all on their skateboards and they all, they're standing right next to each other in a line and they all, they all, what's the verb for scooting on your skateboard?

Vicky: Skating?

Ben C: They all start skating in one direction so there are three of them side by side but then skateparks usually have bumps and curvature to them and so it won't be long before all three of them are moving on entirely different trajectories, one might be going up and the other might be going to the left and the other one might be going to the right and they'll skew their direction so effectively that's what we interpret as gravity when we say everything, gravity causes matter to collapse, what we're actually describing is how the curvature of spacetime messes up with the trajectory of all the objects in the universe to kind of, skews things.

Ben: There's another way to make dark energy though. Have you ever heard of a big rip?

Ben C: No

Ben: The characteristic of this dark energy is that something that doesn't get less potent the more you stretch it out. A cosmological constant it would stay the same no matter how much you stretch it, it's like a box with nothing in it, you can make the box bigger, the amount of nothing hasn't increased. But, you can invent other types of theoretical matter that get more gravitationally potent the more you stretch them out.

Ben C: It's almost as though there's a kind of antigravity, the laws of gravity are reversed.

Ben: Yeah, kind of, it's the laws of conservation of matter kind of, that are reversed. It's kind of negative accounting. If you imagine your sandbox example, you stretch your sandbox to twice the size and suddenly there's four times the sand that was in it before and the sand gets denser and denser the bigger your thing increases, it's very weird stuff. Now, if the Universe has stuff like this in it, it's called phantom energy, if you stretch out this phantom energy it gets denser and denser the more you stretch it and what this will cause is the Universe will get bigger and get more dense and get bigger and get more dense and get even bigger and get more dense and the more dense it gets the faster it gets bigger and so it will cause a run-away expansion of the Universe so the Universe will start expanding faster and faster and faster and faster and we can talk about physics in terms of domains because we know that if you're really large, if you're the size of groups of galaxies you'll feel the tug of the Universe expanding but at Solar System level we can't feel the tug of the Universe expanding on us the force of gravity by the Sun, the force, the electromagnetic force of the atoms binding our skin together are all much stronger than the force of gravity of the Universe expanding so it's negligible on Earth but the thing is if you get this weird run away expansion, the force of expansion everywhere in the Universe will get stronger and stronger and stronger you know, suddenly, maybe, the tug of the Sun on Pluto won't be enough to hold it in its orbit because the acceleration of gravity will be too fast and then maybe, as the Universe gets faster and more dense with this phantom energy the tug of the Sun on Jupiter won't be strong enough to hold Jupiter in it's orbit anymore because the Universe is pulling out on Jupiter so hard.

Ben C: So if the Universe keeps expanding the whole Universe will basically get ripped apart by this force as it continues to accelerate.

Ben: Thats right and it will accelerate all up to a point so it won't happen gradually it will zoom in all of the sudden, suddenly the stars will blink out and then we'll lose all the planets and then the Sun will go dark as the Earth is pulled away from the Sun and then we'll get pulled off the Earth and then our bodies will get ripped apart. It's called the big rip because it rips everything apart.

Ben C: Let me ask you a question then, how does this expansion and increase in velocity I guess, how does all that relate to the speed of light? I would think that the speed of light would be the fastest that these forces could travel at but, I guess not, does the speed of light itself increase?

Ben: Well, that's a good question. So the speed of light is constant, just imagine a balloon and there's a guy under blowing in the balloon so the balloon is steadily increasing in size and instead of the speed of light we'll talk about the speed of ants. So you have ants and lets suppose that the ants all move 1 centimeter per second, they're kind of speedy ants so the deal is lets suppose you have two ants, one at the equator of the balloon and one at the top of the balloon. The ant at the equator wants to walk to the north pole there are occasions where the guy blowing air into the balloon is blowing air fast enough the surface of the balloon will be expanding so fast that even though the ants moving fast on surface of the balloon he'll never make it to the north pole because the distance between him and the north pole will be increasing faster than he can cross that distance.

Ben C: So, the medium that light is moving across may be expanding at a faster rate than the light is traveling.

Ben: That's right

Ben C: It has no impact on the speed of light itself.

Ben: That's right, yeah, so, to talk about ants very briefly, what you can do is, if you know how fast the balloon is expanding you can draw a circle around the north pole or any point on the balloon, in fact, and say that ants that are farther away from the north pole than that circle will never be able reach the north pole because of the expansion of the balloon. Similarly you can say that in our universe today because we know how it is expanding, we can say that there is a distance away from us where anybody past that distance will never be able to communicate with us because the distance between us is increasing faster than light can cross it.

Vicky: So, like even in the whole time of the Universe's existence there won't have been enough time for that light to travel across there.

Ben: Yeah, well given an infinite amount of time it will still never be able to make it. It's kind of like Lucielle Ball on the assembly line, she can't eat the chocolates fast enough and they are piling up. So this is called the cosmological horizon, incidentally and it's kind of like the Earth is in a black hole, we can't communicate with anybody past this distance, it's really really large. The deal is the faster the Universe increases in size the smaller that cosmological horizon gets. So if the Universe is expanding really, really, really fast we might not be able to communicate with Andromeda anymore so in this big rip scenario what happens is we imagine that circle getting smaller and smaller and smaller and smaller as the acceleration and expansion of the Universe gets faster and faster until your legs can't communicate with your head because the distance between them is increasing too fast.