Episode 53: Consistent Variables with Lucy Knisley

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The Titanium Physicists Podcast

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

[1:46]

Ben: It's around Christmastime right now, in the end parts of December. Yesterday was the winter solstice and the night was as long and as dark as it's ever been. One of my favorite things about the Christmas season in my country is that people decorate the outside of their houses with blinking colored lights. The winter night is dark and cold and deep enough to swallow anything and the snow packs down on the hard ground and it's not a welcoming place. But people have their Christmas lights on, hundreds of little colored bulbs shining bravely. The warm glow reflects on the snow and the cold air carries the light as far as it will go. And these long deep nights are no longer as unforgiving. As far as you can see, as far as the town or city goes, the decorated houses beam out their welcoming colors like a birthday cake lined with candles. You still might be cold but you don't feel cold. And above them all, the cold air lets the light of the stars shine through. In the deepest part of winter the stars are at their prettiest. And when some people think about going into space, they can only imagine how cold it is, how lonely. But because of these festive lights on nights like these, all I can imagine is how glorious the stars must look up there. There are stars that blink, like Christmas lights they fade on and off. This surely would be heretical news to those ancient philosophers who imagined the heavenly firmament was unchanging and static. But it's none the less true. It's more than true in fact. These blinking stars called Cepheid variable stars are the ladder that astronomers have used not just to discover our place in the galaxy but the distances to other galaxies and even explore the expansion of the universe. Okay so Lucy Knisley is one of my favorite comic artists. She makes comic books and she's a New York Times bestseller. She went to France and logged her experiences in a travel journal called "French Milk" and her book "Relish: My Life in the Kitchen" was released in 2013 and it's about food. And she just put out another book that I haven't read yet called "Age of License" because my wife has hidden from me. But she just dragged it out and showed me that we actually have a copy. And I'm really excited to read it after we record the show. So listen, Lucy's books are great. They're unblinkingly honest but they stimulate your appetite for both food and life and I'm super excited to welcome her to the show today. Welcome Lucy Knisley.

Lucy: Thank you so much.

Ben: Alright, so Lucy for you today I have assembled two of my favorite titanium physicists. Arise Dr. Vicky Scowcroft! Dr. Vicky got her PhD from Liverpool John Moores in the UK. She's currently a postdoc at Carnegie Observatories where she works on the Carnegie Hubble program and she also has a knitting podcast called *One Starry Knit*. So we'll have a link to it on our website if you want to find it. Now arise Dr. David Tsang! Dr. David did his undergraduate at UBC with me and he did his PhD at Cornell. He's currently a postdoc at Mcgill and Caltech researching black holes and the neutron stars and planets.

[4:47]

Ben: Alright everybody it's time to start talking about Cepheid variables. Alright so where should we start? They're blinking stars. How do we see them?

Vicky: Whether you know it or not everyone has seen a Cepheid. The North Star, which everyone knows, if you look in the sky and you look at the Big Dipper, the constellation that everyone knows, and it points to the North Star. Unless I'm talking to you in the Southern Hemisphere than you might not have seen it. But the North Star is a Cepheid. Polaris is a Cepheid. So it wasn't the first Cepheid to be discovered but it is one of our most well-known ones. So the way they were discovered is we look at them like constantly for like days at a time. And people like stare at them with telescopes and see how their brightness changes compared to other stars that are close to them. So in 1780-something in England there was this man named John Goodricke and him and his mate Edward Pigott had been looking at some stars. And they were looking to see if there were any of these variable stars which varied overtime and they discovered the first Cepheid. And this man John Goodricke, it's really sad because he's like Cepheids are awesome and I'm going to look at them. So he was looking at these Cepheids and they discovered one and then they found another one. And this is like the middle of winter in England. And I grew up there so I can tell you it's horrible. It's cold and it's a rainy. So he was in Yorkshire. And he discovered this Cepheid and was like I want to work out how fast this star changes brightness. So every night he went out there and he looked at this Cepheid and compared its brightness to the other stars and mapped out how the star changed. And he was out there every night for months. And he became so obsessed with this star that he caught pneumonia and died from Cepheids. That was the end of John Goodricke. But basically that's what we still do today. So we look to the stars typically from a few days to a few months and we measure how bright they are. And we look for the ones that change. And if they change by a certain amount then we say that one is a Cepheid. And that's how we find them. Does that make sense?

Lucy: Yes. How did they measure the brightness in comparison to the other stars though?

Vicky: So in the 1700s this guy basically by just looking by eye. He was like well this one looks brighter than the one next to it today and it looks fainter than that one next to it and he just drew a map. But today what I do is I use a telescope. I use a telescope in space called Spitzer but we can do it with the Hubble space telescope as well. And we have basically a digital camera on it, exactly the same as the one in your phone. Actually the one your phone is probably better because ours was made about 10 years ago. And they have to be really well tested to go into space. So the ones in your phone are much more advanced. But we take a picture of them and the ones around them won't change, like the other stars won't change. So we can calibrate, we can say we know these ones aren't changing but then the ones that are changing we can see how they're changing overtime.

Lucy: How long do the changes last?

Vicky: So it's quite like a regular change like a sine wave. Do you know what that is?

Lucy: Mhmm.

Vicky: Okay. So they look like a sine wave basically. And they take typically three days to around 60 days. But it carries on like that for a hundred to thousands of years.

Lucy: It just seems really incredible that people can use their eye, like a 60-day pulse.

Vicky: The one that he measured, that killed him, was like five days. And he measured it so well that he got it to almost exactly to what we measure it today.

Ben: Yeah people's eyes are pretty good at gauging intensity of stars right?

Vicky: Yeah.

David: It's about relative intensity. So he compared it to stars that he knew the magnitude of. That's the sort of unit we use, magnitude of stars. It's a logarithmic unit. So if he knew this particular star was…what's the standard star?

Vicky: Vega.

David: And what's its magnitude?

Vicky: Zero.

David: Zero, okay. So he compared it to Vega and that has a particular brightness which we call magnitude 0. And you might compare to other stars where people have figured out sort of OK this is the particular brightness of the star. So because we're good at doing relative brightness they were able to sort of pin it down that way.

Vicky: Yeah your eyes are really good at telling whether something is brighter or fainter.

David: But yet it was still a very difficult task.

Vicky: Yeah it was still really hard. It was only a couple people who could do it.

Ben: Can you imagine going out with a telescope and saying I think it's 4 tonight.

Vicky: Yeah, it's crazy. I'm glad I don't have to do that. I'd get cold. So yeah, that's how they were discovered.

[9:49]

David: So they're useful because we can measure their periods. And it turns out that a very famous astronomer discovered that there is a relationship between how large the brightness change is to how long it takes for that brightness change to occur.

Vicky: Not quite. So this woman called Henrietta Leavitt. She's awesome. She was like what they called a computer at Harvard, which I think is stupid; they should have just called her an astronomer because she was. But because she was a woman they were like, No you're just a computer. You're not a real astronomer, lady astronomer." So her job was basically to do a catalog of all these stars in one of our nearest galaxies. So she looked at all these stars. I'm not even sure they knew it was a galaxy at that point. They were just like look at all those stars over there. And she looked at them all and she found that there was a relationship between how fast their brightness changed, which is like the period of their brightness change, and how bright the average brightness was. So if you took the average of the brightness and the period, she found like a direct relationship. And because of that if you knew the period and you knew how bright the star looked to you, you could work out how far away the star was. For example, if you had like 50 watt light bulb and you held it up to your face it would be super bright. But if you had it on the other side of the room it would be less bright but it would still be a 50 watt light bulb. And you could work out how far away that light bulb was by working out how bright it should be and how bright it actually looked to you. And she was basically doing the same thing with stars. And she was the person that discovered this. So she worked out that we could work out the distances to things by looking at how fast the brightness changes were in these stars. But she never got any credit for it. Well she got some credit for it at the time but basically because she was a woman she didn't get the proper credit for it. So they were just like, "Yeah cool lady astronomer." But now, I think it was like five years ago, the International Astronomy Union, which is like in charge of like all the astronomy in the world, basically passed this astronomy law where we have to refer to this law as the Leavitt Law, to give her the proper credit.

Lucy: Nice.

Vicky: So that's good.

David: There's a long history of male astronomy professors taking credit for discoveries by women astronomers that were employed by them.

Lucy: What was the thing about the computer title at Harvard? Were there male computers or were they all women?

Vicky: I think they were all women basically. So this was in the 1920s and there would be like one professor and he would have this collection of women computers who would do all the calculations and do all the observations and basically do all the hard work.

Ben: As I half-remember it, the deal is that modern computers take their title from this job that you could get where you essentially do repetitive tasks over and over, like comparing stars or adding long tables of numbers. And so it's a job you could get essentially doing a repetitive tasks. And they found, and this is like Victorian era, that you'd employ a warehouse of computers to add up numbers together or do a calculation for you. And they found that women were better at it than men. The men get distracted and make lots of mistakes. But women never make mistakes…

Vicky: Like getting pneumonia and dying.

Ben: Yeah that's right. So this title of computer is a laboratory technician type at Harvard and is probably inherited from his previous job. And the deal is that modern computers have just taken over that role. So a computer can take a photograph and compare things for you or a computer can add long chains of number for you instead of having to employ a warehouse full of people.

Vicky: Yeah but she was awesome. And she discovered all this stuff. And the relationship that she discovered is basically the exact same thing we're using today to work out the distances to all the other galaxies in our local neighborhood. It's exactly the same thing I use right now to measure the distances to other galaxies and to work out how fast the universe is expanding. It's not like this old thing that's like "Oh she discovered this thing that we used 100 years ago." This is like this thing we still use to do cutting edge astronomy.

Lucy: Cool.

Vicky: It's super cool. I think it's cool anyway.

[14:27]

Ben: So the thing that Vicky was referring to is a type of technique referred to as a standard candle. That's what she was saying with the 50 watt light bulb. Because a 50 watt light bulb, it doesn't matter which socket in the house you plug it into, it will shine with the same intensity. So if you know a light bulb is 50 watts, if you knew that beforehand, then you can use the brightness you observe, based on where you're standing, and then the knowledge that it's a 50 watt light bulb to figure out the distance. So in these standard candles you measure the amount of time it takes to go from bight to dim to bright to dim. And then you look it up and say OK we know how intense the light is coming off of it. We know how bright it is. And so it looks pretty dim to us from here so it must be really really far away. And so you can calculate numerically how far away it is based on knowing how bright it is as we measure it.

Lucy: Because the dimness is the star farther away from us? Is that correct?

Ben: Yeah. So light is kind of like sound. The farther away someone who is speaking is from you, the less intense the sound wave is or the less intense the light wave is. So in essence, these standard candles, so these Cepheids, the farther away it is from us the dimmer the light will appear. So if it's five galaxies over, really really far away, it'll be really dim. Even if it's one of these stars that shines a ton of light out, it will still look dim. But because we know how much light it shines out based on its period, we can figure out how far away it is from us by figuring out how intense it looks from our perspective.

David: The key is that the period that we measure doesn't suffer from any bad effects from being far away. So from the timing we can ask Henrietta Levitt and use her law to tell us how bright it should appear to us and then from that we can figure out how far away it is, from how bright it actually looks to us.

[16:14]

Ben: How bright is the North Star? Is it one of these ones that blinks out entirely?

Vicky: Just a short period Cepheid, like a few days. So I think it's pretty faint. The North Star is really weird. It's like evolving now. So its period is actually changing and it's almost not pulsating anymore. There's something weird going on with it. I haven't looked at this for a while but it's almost not pulsating anymore. This is another weird thing about Cepheids. So they start off as a different type of star. Basically all stars start off as the same type of star, just a regular star. And then some of them as they age, their conditions are right and they turn into Cepheids. But eventually they become a different type of star again. And the North Star is in that stage where it's becoming no longer a Cepheid. It's moving away from the Cepheid stage. So we can actually see that happening like on human time-scales. So as we repeatedly take more images of it we can see that the brightness changes are starting to disappear.

Lucy: So nobody knows why that's happening?

Vicky: We know that it has to do with the evolution and it's changing into a different type of star. The good thing about the North Star is that it's in our own galaxy and we have a lot of observations of it. So we don't always get to study a star like this in such great detail. So we don't always have a lot of examples of this. This is one of our first opportunities to study it in really amazing detail.

David: We know generally why it's happening. It's leaving a stage of its evolution called the instability strip. Instability here refers to the fact that it's pulsating.

Vicky: Yeah so it's becoming a stable star again. And we have a general idea, we have models of what's happening to stars in that situation. This is one of the first chances we have to really make an in depth study of this. So it's really exciting actually that we can look at that. So we have an idea. But I don't have a huge idea because it's not my specialist thing.

[18:29]

Ben: But we do know the mechanism that causes Cepheid variables to pulse the way they do.

Vicky: We do.

Ben: Yeah. We're just not sure about the details as to why the North Pole star is doing what it's currently doing. But we know why nice stable Cepheids that are pulsing pulse.

Vicky: We do and Dave will tell you about that…When he stops coughing.

David: Why don't you start Ben.

Ben: Okay sure. Let's talk about what makes up a star. The deal is that it's essentially a big cloud of gas that collapsed down in on itself and so now it's a sphere of gas and plasma. And at the center of this sphere, nuclear fusion is taking place. And that's releasing a ton of energy. So on the inside of our star, like our sun, we're burning hydrogen into helium and that's releasing a whole bunch of energy. So the inside is really really hot. So that generates a whole bunch of light that pushes outwards and tries to leave the sun. And that's the photons we see, bathing us every time we go out. Now the deal with Cepheids is it kind of has to do with chemistry of the outer layer of gas and how opaque they are. The deal is that in these stars the outside of the ball of gas is kind of opaque. It's not letting very much light out, not as much as it wants to. And so energy is building up and building up and building up inside of it. And this causes the star to puff up. It gets bigger. The outer envelope, the parts we can see, get really really really hot. And they get so hot that they change the chemistry of the outer envelopes and it becomes transparent. And then as soon as it becomes transparent all those photons explode out and the star gets really really bright. But then in doing so lets the temperature inside drop and then the star shrinks down and the chemistry goes back to what it once was and it becomes opaque again and energy starts to build back up.

David: So imagine a pressure cooker that was made out of balloon.

Lucy: Sounds horrible.

David: Yeah this is terrible. So now we have a valve in this pressure cooker that lets stuff out. But let's say I broke the valve and as the temperature increases it lets less stuff out. As the fusion goes in the star, inside the pressure cooker here, the temperature goes up and that makes the valve release even less of the pressure. So that will cause the balloon to expand until the pressure falls enough that you match what comes out. And then it lets the pressure go because the temperature has gone down because the balloon is expanded and then it can shrink back down again. So that's kind of what's happening in the star because basically the amount of light it lets through or the amount of pressure it releases decreases as the temperature goes up. The star itself expands like the balloon does until the temperature goes down enough that it can let the light out and then it shrinks back down again. That's what causes the cycle.

Ben: So the moral of the story is that this star isn't letting energy out fast enough so the energy is building up inside of it. And then what happens is it gets so hot that it just kind of melts the outside and all the energy can escape and the star gets really really bright. But then it's letting the energy escape faster than it's being generated so it cools down and shrinks down until the initial conditions restate themselves and it becomes opaque again. And then it will start puffing back up.

Lucy: Yes except for the fact that larger stars appear brighter to us correct?

David: Right.

Lucy: So if it's puffing up wouldn't it then appear brighter to us?

Vicky: But because the atmosphere is opaque none of the light can escape. So all the light is trapped inside it. So the bigger ones normally appear brighter but this is a special case because all the light is trapped inside. So when the light does escape it appears brighter because it's bigger…

Ben: It appears like really really really bright because all that trapped light is escaping.

Vicky: Yeah. As it’s getting bigger all that light is trapped.

[22:21]

Lucy: Is the growth observable?

Vicky: Yeah we can measure it. There’s this huge telescope in Chile called the Very Large Telescope because astronomers are like super original.

David: Not to be confused with the Extremely Large Telescope.

Vicky: Or the now defunct Overwhelmingly Large Telescope.

Ben: Oh no it’s defunct.

Vicky: I know I was so looking forward to the OWL. But they have this special setup basically where you use lots of telescopes together and we can literally measure the width of these stars as they grow and we can see them growing.

Lucy: Do they change in brightness as they grow?

Vicky: Yeah you can see them change in brightness like slightly. But you can actually measure the physical size of them change.

Lucy: Oh neat.

Vicky: Yeah it’s really cool.

David: So the difference between this and a normal star really is sort of that pressure valve. Whether how much light it lets through is a function of temperature. So normal stars, as you increase the temperature you tend to let more light through. But in these stars, in the stage of their evolution and the chemistry that's involved in that stage of the evolution, as the temperature goes up less light gets through.

Vicky: Yeah there's like a little lag.

David: That's why these guys pulsate like this. Stars in sort of the regular portion of their lives don't tend to pulsate.

Lucy: Is that because they lack this outer layer of gasses?

David: They have different chemistry in their outer layers I guess.

Vicky: Yeah this one has a layer of helium with a special ionization state. So a couple of the electrons have been knocked off the helium in the outer layer. And regular stars, what we call main sequence stars, which is what most stars start off as, you're just burning hydrogen. But these ones are much later in the star's lifetime so all the hydrogen is gone and now we're going into helium. So this is like a much different type of star.

David: It's an older star. Stars can change a lot over their lifetime.

[24:25]

Ben: You want to talk about the history of how we used them to expand our idea of what the universe is?

Vicky: Okay. So Hubble, who the telescopes is named after, he used to work in my office.

Ben: What!? Like your actual office?

Vicky: Well not my actual office. Not the physical office

David: His office is upstairs.

Vicky: Yeah he's upstairs.

Ben: Okay, so he worked in the same building as you. That's still impressive.

Vicky: Yeah he was at Carnegie. So was Einstein and like all the cool people. Anyway, so Hubble, one of the things he studied was Cepheids.

Ben: There was a time when we thought our galaxy was all there was to the universe. Galaxies only looked like smudges so we thought that they were just clouds of gas out past the edge of the universe, our own galaxy.

Vicky: So yeah Hubble, while he was in my office, he was looking at a nebula called Andromeda and he found some Cepheids. And by looking at these Cepheids he worked out that Andromeda must actually be a really long way away and couldn't be part of our own galaxy. So it must be really far away and that's how we found out that actually our galaxy isn't the only thing there is. There must be other galaxies outside of our own. So basically that was the discovery that we are not the only thing in the universe. There are other galaxies outside our own. And that was just from looking at Cepheids. And it's really cool, you find these pictures that he'd taken on the telescope at, I think it was on Mt. Wilson which is in Los Angeles. We still have these photographs that he took and he's basically drawn on them. It just says "Variable!" where he has found these Cepheids. And he has worked out that this galaxy is a real thing. It's not just a cloud. So then maybe 15 years later he continued to do this. And he found other galaxies. And then what he worked out is that each of these galaxies that he worked out the distance to were actually moving away from us. So he calculated how each of these galaxies were moving away from us and he worked out their distance and he found that there was a relationship between how fast they were moving away from us and how far away they were. And he found that the ones that were farther away were moving away faster. So basically we were in the middle and everything was moving away. But the farther away it was the faster it was moving away. It was basically evidence that we were in some kind of explosion. And that was the first evidence that we had expanded into the universe that we know we're in now. And again this is just from these few Cepheids that had been discovered in different galaxies.

[27:13]

Ben: So let's take a brief tangent away from this. So he was doing this in context of Albert Einstein and other people working on Albert Einstein's theory of gravity. So Einstein's theory of gravity, if you make some very simple assumptions it lets you describe what the universe looks like. And Einstein and other people working with Einstein's theory imagined that the universe … There's something called the Copernican principle. Do you remember who Copernicus was Lucy?

Lucy: Yep.

Ben: So Copernicus was the guy who said that the sun doesn't go around the Earth. Copernicus is famous in European history as being the person who said, "Hey, the Earth isn't the center of the universe." And so we extend his theory as saying the Earth isn't the center of the universe and neither is the galaxy, our galaxy the Milky Way, the center of the universe. There must be other stuff farther out equivalent to ours. So the Copernican principle says that there's nowhere in the universe that's any different than anywhere else in the universe. So if I were to go a hundred-gabillion parsecs away in that direction, the universe would look pretty much the same as it does here, give or take. You have to do some averaging. You have to say things like the average mass density of the universe over there is going to be the same as over here. The average temperature over there is going to be the same as over here. And that assumption has been borne out in observations that came later in the 60s. But so back this truck up. Einstein was saying we've got a theory of the universe that we can use, a theory of how the universe looks at very large scales. The problem with his theories though is that they predict a dynamic universe. So in his model of the universe what you imagine is that the universe is infinitely large and infinitely wide and infinitely tall. And that the mass density and the temperature at every point in the universe is the same but the universe will expand over time. And as it expands things cool, the matter becomes less dense. And the problem with this assumption is that Einstein hated this conclusion that his theory naturally drew that the universe was dynamic. He wanted the universe to be static, something that never changed. Because up until Hubble came along there was no reason to think the universe would change for any reason. We always imaged that the stars would always be in the sky somewhere. I guess they would go out in some places but other stars would be born and that the universe on average would stay the same over all time. And so Einstein famously calls it his "biggest blunder", he inserted a term into his equations called the cosmological constant which let him build a model of a universe that never changed over time, that wasn't dynamic. And so he was happy with that. And then immediately after publishing that, Hubble published his groundbreaking discovery that the universe was indeed expanding, which is crazy because it confirms the prediction that his theory predicted that he tried to change his theory to get away from. So there's a fun history of that. Moral of the story is it turns out that at very large-scales the universe is increasing in size. Einstein's theory describes the idea of distance as being a dynamic quantity. I'm not sure how to put this in a way that doesn't involve me giving you a lecture on general relativity at this point. We're trying to keep it to Cepheid variables. But the idea is it's not that other galaxies are moving farther away from us. It's not that our galaxy was the center of an explosion that pushed all these galaxies away from us but rather the distance between us and farther galaxies is dynamic.

Vicky: It's like a cake. If you baked a cake with raisons in, initially all your raisons will be close together and as you baked the cake all the raisons will get farther apart because the cake itself would be expanding because space between the raisons would be getting bigger because the cake would be expanding.

David: For any given raison you would look at all the other raisons and you would notice that the raisons that are farther away from it are moving away from it faster.

Vicky: Yeah, even though any raison wouldn't be at the center of the cake.

Ben: So every raison would look at all the other raisons and say I'm the center of the explosion, all the other raisons are moving away from me." So that's essentially what Hubble discovered is that the universe is full of other galaxies. Those galaxies look like they're moving away from us. But the details of the way they are moving away from us mean that it doesn't matter which galaxy you're sitting in. So you put your astronomer down in any galaxy in the universe and look at all the other galaxies expanding away from it and say, "Oh our galaxy is the center of the explosion." Because there is no center of the explosion. It's this distance between the galaxies that's increasing. And so the larger the distance is the faster the rate of increase. So the deal is that we want to get a better understanding of how the universe is expanding. We know that it does thanks to Hubble and thanks to Einstein's theory but we still want to work out the details of it.

[32:14]

Ben: For instance, have you ever heard of dark energy?

Lucy: No.

Ben: Okay, well there's a couple of gaping holes in our theory of gravity. In essence when we model how gravity should make galaxies spin or how Einstein's theory of gravity allows the universe to expand there's a couple types of matter that we're not seeing observationally. So one of them is called dark matter. It's a type of matter that doesn't interact with light and so we can't see it. But it looks like it's clumping together at the center of galaxies and it lets the galaxies spin faster than we would otherwise expect just counting the stars. So the galaxies have a lot more mass than we'd expect. But there's another type called dark energy and it's causing the universe to accelerate in its expansion. So the deal is in the model for the universe expanding. What Einstein's original theory predicted is that the universe would expand, get bigger bigger bigger and then maybe recollapse in on itself. You might have heard of that. But what we know and we've known for marching towards 20 years now is that the universe isn't going to recollapse ever. It's expanding at a faster and faster rate. So overtime the universe is accelerating this dynamic distance between us and far away galaxies is increasing. So the speed at which the universe is increasing, it's getting faster and faster and faster. We're not sure why. We say mathematically the cause of that is some type of matter that we've never detected called dark energy. Anyway, moral of the story is that we figured out that this must be true using a type of standard candle that we haven't talked about yet. So before I was telling you this idea that there was this 50 watt light bulb and you could tell based on how bright it was the distance away because you knew how much light it was putting off. So the farther away it gets the dimmer it gets. And we use Cepheid variable stars to figure this out. But there's another type of standard candle called a Supernova Type Ia. And what happens is there's like a white dwarf somewhere and matter is falling in on it or something and it explodes. A ton of energy comes out of it and it's really really really really bright, brighter-than-a-galaxy-bright. And the thing is these specific types of supernova get dimmer over time. After the big explosion it gets dimmer. And we know that there's a precise relationship between how long it takes to get dim, the rate at which it's dimming, and how bright it originally was. So we can use these as standard candles. And because they're so bright, like Cepheid variables are wonderful but you can't see them really really really really really far back because they're too dim. But these supernovas Ias, rarer occurrences than Cepheids, but they're super bright. So we can use them to figure out how far away really really distant, really distant, dawn-of-time-distant galaxies are. And the thing about that is the universe is expanding but the rate at which the universe is expanding changes over time. I mentioned before that it's speeding up. And the way we know it's speeding up is that the light emitted from these supernovas a really really long time ago, this light has experienced a large chunk of the history of the expansion of the universe. And so based on how far away it is, the farther away they are correspond to how long ago they were emitted. So we can look at these specific standard candle supernova and figure out how the rate of expansion has changed over time and this is how we know the universe is accelerating. But the problem is that there isn't all that much data on it. Because we counted all those supernova and we have a good sense that the universe is expanding in one specific way. We know that the expansion is accelerating. But we don't know if say that acceleration is accelerating or if that acceleration is decelerating. And there's all sorts of end-states of the universe that can happen depending on what this dark energy is doing. So the more we know about how the universe is accelerating, the more we can figure out about this dark energy. But we don't know very much yet. Alright Vicky.

[36:22]

Vicky: Okay, so my job is to make sure that all those measurements of the supernova are as accurate as they can be. So to do that, I take all the measurements of the Cepheids. And because these supernova are so far away, because they're very rare, it's very very very rare that we ever get one in a nearby galaxy. But we had one last year was it? It was last year and it was the first time in a very very long time that we had one in a nearby galaxy, that you could actually see with your eyes, without looking through a huge telescope. And this was like a huge thing that happened. But most of the time they're in really far away galaxies. So my job is to take the observations of the Cepheids in the farthest away galaxies that I can possibly do. And where we also had like one supernova that has gone off. And try to match them up to make sure everything is consistent. And try to find out if there is anyway that anything could have gone wrong or try to work out what's happening or if there's anything we haven't thought of. Maybe there are some weird stars in that thing or maybe that type of galaxy has some weird stuff happening. Maybe there's just something weird about that type of Cepheid or that galaxy has lots of dust in it or something. That's my job basically. Like dust is a big problem, and not just in a house. But yeah that's basically my job. But the other thing we've started to do now is try to look at other ways we can do this because there's this big problem right now, well they say it's a big problem, with people like me. There's this other experiment called Planck where they found a completely new way of trying to measure how the universe is expanding. I won't go into it now but it's completely different. They use this thing called the Cosmic Microwave Background. It's like the patterns left behind by the Big Bang basically. But it doesn't use stars. It's completely different from what we're doing. And the answer they get from that doesn't match up with the answer we get from Cepheids and supernovas which is kind of bad. So now we're trying to think of a new way of trying to measure it.

Lucy: To reconcile the two.

Vicky: Yeah because right now we have our way and we're like "Well we're fine. We didn't do anything wrong." And they have their way and they're like "Well our way is fine." So now we have to try to think of a third way. Our idea for the third way is we have this other type of variable stars called RR Lyrae, which are similar to Cepheids but are really really old. They are like the oldest stars in the universe. So the universe is 13 billion years old and so are RR Lyraes. They are like the first stars that formed in the universe.

David: Cepheid stars.

Vicky: Yeah, the Cepheid stars that formed in the universe. Sorry Dave. Newer stars have like contamination from when supernovas went off they released all their crap into the sky. But these stars are so old that they don't have any of that. They're really interesting because they're like that. So we're going to try to use those instead to try and fix this problem.

David: So there's a lot of comparing different ways. You need overlapping ways of measuring distances. For instance, to measure the distance to a supernova you have to have them overlap with where you can see Cepheids. So you have to have them in the same galaxy. And in order to calibrate our understanding of Cepheids, to figure out that distance relation, we need some Cepheids that are close enough so we can do what is called parallax on them.

Vicky: And so parallax is when if you close one eye and close the other eye and you see that the things that you can see move. That's basically parallax.

David: Right because that's the combination between the distance from you to that object and the distance between your eyes. And so we can do the same thing but for different sides of the Earth's orbit.

Vicky: Yeah so that's how we measure the absolute distance to a star.

David: Right. But in order for us to figure out what the parallax is we need to know what the size of the Earth's orbit is. So that involves us figuring out the distance to the sun, which comes from I think radio ranges to Venus. But it all comes back down to laboratory measurements of the speed of light because that's how fast radio waves go. So it all starts from figuring out how fast light goes. And then we gradually step up and have all these overlapping measurements until we can figure out how far apart these really really far away galaxies are.

Ben: Well that was fantastic. Thank you Vicky. Thank you Dave. You've pleased me. Your efforts have borne fruit and that fruit is sweet. Here is some fruit. Dave you get a mandarin orange, the most variable of oranges. And Vicky you get a Terry Chocolate Orange because high-quality work today. I'd like to thank my guest Lucy Kinsley. Her latest book is called "An Age of License: A Travelogue". It's lots of fun. Thank you Lucy.

Lucy: My pleasure.

[41:44]

Ben: I hope you had lots of fun. Alright, hi everyone. So it's announcement time. First, I hope you've been enjoying the question barn episodes. If you'd like us to answer your questions send your questies to Tiphyter@titniumphysics.com. Second, good news everyone, our Patreon campaign has reached one hundred dollars. That's our second level of funding. So we're going to use that money to get two episodes, a current episode and one past episode transcribed. Our transcriber is working as fast as he can but he's a physics student so he doesn't have to most time in the world. I'm going to start putting them up as PDFs at the bottom of the current and past episodes as he does them. So they should be searchable by google. I'm really excited. So, on that note I'd like to remind you that we're now accepting donations. We'd be grateful to receive your support. You can make a one-time donation via Paypal through our website or you can set up automatic donations each time I finish an episode through our Patreon website. This particular episode of the Titanium Physicists has been sponsored by a collection of generous people. I'd like to thank the generosity of a man named Hugo for his support and also a Mr.

Ryan N., a Mr. Adam K, and Mr. Jacob S, a gentleman named Brent Evens, a lady named Jill, a gentleman named Greg. Thanks Josh and Steve, Mr. James Clossin, Mr. Debenorth, a gentleman named Scott, Mr. Ed Lollington, Kelly Weinersmith, Joselin Reed, a Mr. S. Hatcher, Rob Abrazado, and Mr. Robert Steitca. Thanks also to Brent Knopf for remastering our intro. I appreciate all of the help on my poor audio skills. So that's it for *Titanium Physicists* this time. Remember that if you like listening to scientists talk about science in their own words, there are lots of other lovely shows on the Brachiolope Media Network for you to listen to. Remember there's more podcasts out there than this serial podcast. The intro to our show is by Ted Leo and the Pharmacists and the end song is by John Vanderslice. Until next time my friends, have fun, and remember to keep science in your hearts.

[45:07]

Ben: Or image you have a dough of bread. Imagine you wanted to be a bread maker but you weren't very good at it. You put way too much yeast in at first and you also decided to videotape it instead of bake it. So you have this ball of dough and inside there's yeast. And the hotter the yeast gets the more it reacts. All this yeast is producing carbon dioxide; it's producing air. Because you kneaded the hell out of this bread, the bread is not letting any of this air escape. And so it puffs up. It increases in size, bigger, bigger, bigger, bigger. It's inflating because it's not letting any of the air escape. Just like in the stars because the outer envelopes are opaque, they're not letting any of the energy escape. So it's puffing up, getting hotter and hotter and bigger. Until, in the bread dough what will happen is the bread dough isn't strong enough to contain all of the gas anymore. So maybe there's a bubble and it ruptures. And your bread dough will go pbleewff! Maybe a soufflé is a better example. And it shrinks down. You know gets small again. And then the bread dough will heal itself and it can contain itself again. And then it will start the process over again, inflating and deflating. I don't know, does bread actually do that?

David: No. It will over-proof and the yeast won't grow anymore.

Ben: Oh, won't grow anymore.

Lucy: Yeah, I mean it'll rise again. There's a limit on the rising.

Ben: Yeah but you're supposed to knead it between rising again so your actually pushing it in. I'm not sure if that's the greatest metaphor, I just like bread. But it usually tastes gross after you let it do that too long. Anyway…