Episode 34: Ladder To The Stars

Physicists: Ben Tippett, Mookie Terracciano, James Silvester and Amanda Bauer

The Titanium Physicists Podcast

www.titaniumphysics.com

Transcribed by John Robinson

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

[1:47]

Ben: If I recall correctly, the ancient Greeks did a lot of astronomy and we know how they imagined the universe was constructed. So at the center there was the Earth and above it the sky, across which circled the Sun and Moon. They recognized the planets. They imagined them as fiery wheels touring the sky on large circular tracks. In fact, the word planet means 'wanderer', because their motion contrasts with the rest of the stars and the sky, whose location with respect to one another was fixed, you see? They imagined all the others stars as being fixed, bright points on a huge black sphere that rotated slowly across the sky over the course of the year. OK, so that was the universe as we knew it in antiquity, and since then our understanding of the universe has changed dramatically. In my opinion, the largest revolution in our understanding happened near the start of the 20th century. Prior to the 1920s, our modern understanding of the universe involved only the Milky Way. We imagined the Milky Way as being an island of stars in the universe of darkness. Now of course, astronomers could still see other… what we now called galaxies. They just thought that they were clouds and nebulae and other smudgy things. So, the man who opened our eyes to the universe, his name was Edwin Hubble. He was looking at a type of star called the Cepheid

Variable. It's a type of star we call a standard candle. Now, the star in particular that he kept seeing was in what we now know as the Andromeda Galaxy. He figured out how for it was from us, and the answer is that it's very, very, very, very, very far away from us, so far away that is well beyond the 100,000 light years of our Milky Way. Hubble's discovery opened up the possibility that our Milky Way was not just an island in the darkness, but rather an unremarkable cluster of stars in a universe blooming full of other galaxies just like it. Boom! The deal is, the discovery depended on figuring out the distance between the Earth and the Andromeda Galaxy. But how do we know how far away astronomical objects are from us? It's not a trivial question, and as it happens, astronomers have a whole toolbox of different techniques that tells the distance to other stars. On today's show, we're going to be talking about the cosmic distance ladder [a.k.a. the extragalactic distance scale]. So stars, they're far, far away from us, and if we ever travel to other stars, it will be a really, really far trip. Going the distant is a really daunting task. Speaking of going the distance, our guest today is a world famous web cartoonist who has just concluded his epic heroic fantasy comic which has been running almost daily for over 11 years. Dominic Deegan: Oracle For Hire started in May 2002, and has been updating almost daily ever since. Welcome to our show, Mookie Terracciano!

[4:37]

Mookie: Good to be back, man. You give me far too much credit for world famous. My head I think grew a couple of sizes.

Ben: So Mookie. You've just started a new web comic called Star Power. Do you want to tell us anything about it?

Mookie: Yeah. Star Power is very different from Dominic Deegan. Near the end of the comic, I've started to get a little more astronomical because I took up star gazing. So I was starting to lean in that direction anyway. So Star Power was just kind of the next step. It's about a young astronomer in the far future on a distant space station who gets granted the 'Star Power'. She becomes the last of the Star Powered Sentinels and now it's up to her to explore a galaxy that is both more dangerous and more wondrous than she could have ever imagined. You can read about it at *starpowercomic.com*

Ben: That's awesome. Our web site will also link to your new comics. So Mookie, today, I've assembled for you two titanium physicists of note. They are amazing astronomers. So arise, Dr. Amanda Bauer!

[Ziieee-eeeuuummm!]

Ben: Dr. Amanda is in Sydney, Australia, at the Australian Astronomical Observatory. She got her PhD from the University of Texas at Austin and she studies galaxy formation. She is a notable public figure on the Internet, where she blogs under the name of Astral Pixie. Now arise, James Sylvester!

[Aauurrr... errr!]

James: That's the worst, hardest sound ever.

Ben: James is currently a doctoral candidate at Queen's University in Kingston, Ontario where he studies stellar magnetism. Until recently, James was the manager at the Scottish Dark Sky Observatory, and he has a podcast called *Astrarium*, where he and David Warrington introduce us to astronomy. So, there's going to be a link to Amanda's blog and James' podcast on the Ti-Phy website for you. All right everybody, let's start talking about distances.

[6:27]

Amanda: There was a time when I was playing Soccer, and my coach asked, "If you're waiting for somebody to pass the ball to you, you're supposed to stand about ten meters away". So he kind of made us do this little competition to see who could actually tell how far ten meters was. It wasn't really that easy [laughter]. We were all pretty different in our guesses. And it made me start thinking from that time on how far are things. You kind of get an idea of maybe a hundred meters or so because most sports fields are about a hundred meters. But then it gets more and more difficult to tell distances. We can only estimate to a couple of miles. So for humans, telling distances on Earth isn't actually a very easy thing to do. Now, imagine if you are trying to do it at night. If you see some lights off down the road, you have no idea if it's a person with just a flashlight that's pretty close to you, or maybe it's somebody on a motorcycle that's pretty far away. We can use little clues like the motion. If it's a car, you can tell it's moving towards you so the lights are getting brighter. But now imagine you are looking up in space, and you see all these stars. Some look brighter than others, but you really don't know if the bright ones are because they're closer, or because they're bigger and just intrinsically brighter. People looking up at the sky have been thinking about this for a long time. The ancient Greeks were trying to think about the Moon, how far away is the Moon, and how far away is the Sun. It turns out that determining distances to things is actually really hard. Almost every astronomical theory that we have on any object out there is dependent on the fact that you know how far away it is. And yet, this is one of the most difficult measurements to make in all of astronomy. So, one of the early tools that we use to try to figure out how far things were is this thing called parallax.

Mookie: You have to remind me what parallax is. It's an eyesight trick, isn't it?

Amanda: Exactly. If you have say something like a table in front of you, and you cover one eye and look at it, and look at where it is relative to all of the other things in the background. Then you cover the other eye, you see that it actually moves a little bit relative to what's far away on the other side of the room. And so your eyes, working together, can give you a 3-dimensional view of where things are relative to you. By knowing that the Earth orbits around the Sun, we can use this parallax. So when the Earth is on one side of the Sun, you can see a map of where all the stars are. Then, six months later, it's on the opposite side, and you can see another map of where the stars are. So, stars that are kind of close will actually move their position a tiny little bit based on parallax. So it will look a little bit different.

Mookie: Now is this the natural movement of the stars, because they're close to us? Or is it our perception of the stars?

Amanda: Exactly. It's because we have moved to the opposite side of the Sun that we see the nearby stars shifted just a little bit relative to what the background stars look like.

Ben: It's kind of like when you look at a forest as you're walking past a forest. As you move past the forest, the trees move past you, right? But the ones that are farther into the background will move kind of slower than the ones closer. So they move relative to one another as we move around, just as a matter of the distance to us differs.

Mookie: Right, right, right. The amount of the stars shift is pretty…

Amanda: It's pretty tiny. It's a tiny amount.

Mookie: We need super instruments to like detect it, right?

Amanda: Yeah. So the first parallax was actually measured in about the mid 1800's. The nearest star is Proxima Centauri, its parallax is actually really small. It's less that one arc-seconds, and an arc-seconds is 1/3,600 of a degree [laughter]. So it's a teeny tiny little movement. We can only measure it…

Mookie: It's crazy that they were able to measure that during the 1800's.

Ben: One arc-second is a parsec, right?

Amanda: And a parsecs about three and a half light-years, or three and a quarter. So that brings up an interesting point. That's where the name parsec comes from. So the parallax of one arc-second, that cuts those down, and that's what parsec means.

Mookie: Oh, neat.

Amanda: So most distances that astronomers talk about will be in parsecs, or thousands of parsecs, kiloparsecs, or even megaparsecs. Then we go to the media, we translate that into light-years, because light-years just sounds cool.

Mookie: It just sounds pretty neat. Someone says parsecs, they start thinking of the Millennium Falcon anyway. So they were able to measure that crazy small amount of shift in the 1800's?

Amanda: Yup. They had a telescope called the Hipparcos telescope, which did measurements of several thousand stars. So they were able to make pretty precise measurements.

Mookie: God. That blows my mind. I know how they discovered Pluto. They just took, like, picked two pictures of the sky, and some poor dude had to eyeball it. You know, comparatively, it's like "Well, this looks like it moved. Hey, you're right! Planet X. Yay!" But like, did they eyeball a couple of arc-seconds in the 1800's?

James: Well, Tyco Brahe was a famous Danish astronomer is famed even to this day, is the one human that made the most accurate naked eye observations of stars. It was claimed he was getting measurements in about, you know, in these sort of ranges of very small measurements. No one has surpassed him since because soon after that telescopes were created and invented. So I think Tyco Brahe still has the legendary status of being the most accurate naked eye astronomer ever.

Mookie: Well, why would you go back to naked eye astronomy when you have all these awesome telescopes at your disposal?

[11:41]

Amanda: So, parallax was one of the first ways we determine distance to some objects, the very close ones, actually. But it's the only method that doesn't make any assumptions about what that object is, or physically how that object works. It's just based on the fact that Earth moves around the Sun. It doesn't matter what you're actually looking at. You can only do it with stars, but it doesn't make any physical assumptions about the object, as opposed to every other way that we determine distance has some basic assumption about the actual object that we're looking at. You can only use parallax to measure stars up to about 1,000 light-years away.

Mookie: That's still pretty good.

Amanda: It's still pretty good but then you consider that the Milky Way itself, our galaxy, is about 100,000 light years across. So, this really is kind of our local neighborhood that we're measuring things in this method. So in order to look at things beyond that, you have to start going to different methods.

Mookie: OK.

James: So, it has been said that parallax has this limit so the next step out, so to speak, is standard candle.

Mookie: Candle as in like the thing that burns?

James: Yep. That you have on your birthday cake, or that lights your room in a power outage. The name itself is actually a big clue to what it is. And essentially, the way to think about it is if you hold a candle, you sort of have an idea of how bright is. If you give your candle to your buddy or a friend, and they walk away, the further they get, the fainter the candle will seem to your eye. If you imagine all the candles throughout the world were manufactured identically and they all burned with all the same brightness, you could look at any candle, and with a bit of knowledge, you can try and work out how far away is by saying, well, it's so much fainter so it's so far away. This is called the inverse square law. So basically, as you double the distance away, you quarter the brightness, so the brightness goes down. So this is the idea. You look for astronomical objects of which you know something about its intrinsic brightness of this object. So you can use that information to try to discern how far it actually is from us.

Mookie: It's more comparative, like, you just pick a star that is like about standard, I guess. You then compare other stars to its brightness and try to determine the distance?

James: That's essentially right. The thing you have to be careful of is, stars, they look like they behave normally and very consistently. But actually the more you study them, the more you realize that they behave in different ways. You need to make it's a type of star where you know for sure that it behaves the way you expect it. It could be fainter for other reasons, not just because of the distance. This is where we get the term standard candles. So this is not for all stars, this is for certain types of stars and that sort of brings us onto different variables.

Mookie: What kinds of stars do apply? Are Cepheid Variables the only star that standard candle applies to, or are there other ones?

James: There are other types of stellar objects, but Cepheid Variables is one of the more reliable ones. As we go further out, you can start thinking about things like supernova which we will talk about. Cepheid Variables is a reliable one. The reason it's reliable is first of all its light intensity varies, it's why it's called variable. If you look at the amount of light coming from it, it goes up and down with a pattern.

Mookie: Is that what defines a variable star? That the light comes from it is variable? Is it that simple an explanation?

[15:01]

James: That is exactly it. There's types of variable stars because there's different mechanisms which lead to this variation. With the Cepheid Variables, essentially because the star is pulsating, so it's sort of expanding in and out. This is due to what's called the kappa mechanism. The easy way to think about this is imagine a star, and it's got a lot of gas inside and it's very hot, and there's a lot of energy happening. What you're going to get is, if you put water in a sauce pot and you start boiling it, what you'll see is vapor, steam collecting, especially when you got the lid on. And what you'll notice is, as time progresses, you start to not be able to see the water, because you've gone from a cold liquid and it's getting hot, you got this steam vapor, so it starts to get cloudy. What you have is a situation where these stars have a lot of ionization happening, it's kind of cloudy. This cloudiness prevents initially a lot of heat escaping. So they just get hotter and hotter. What happens as a result, they just have to expand to allow this [energy?] to balance. When they expand, they get slightly bigger. This means it becomes a little bit more transparent for a little while. That lets some of that energy escape, and then they collapse back down again.

Mookie: How much does expand? Are we talking like a lot, or like a super?

James: Well, we're not talking massive like it gets ten times bigger. It's sort of almost a pulsation star.

Mookie: So it's relatively subtle?

James: Yes. If you're close, it would be pretty obvious. Yeah, it's a subtle effect. But it's enough of an effect that it presents itself on the surface in the way and it sort of changes the light pattern, the pulsation.

Amanda: The period can vary on the term of a few days to a few months, and it can get a hundred times brighter and then a hundred times fainter over that time.

Mookie: Really?

Amanda: So it's called the period-luminosity relationship, and because of how quickly it gets brighter and fainter, you can tell how intrinsically bright the star is, like how bright its internal candle actually is.

Mookie: With how these stars fluctuate, because they can get so much brighter and so much dimmer, is there a known 'standard' for them? Do they have a standard brightness or are they just known to get dimmer and brighter, or do they ever have anregular time, I guess?

James: The pattern of brightness to darkness, let's call it, usually if you consider a standard candle for this type of work, it would have a regularity to this brightness and dimness. So it's a repeating pattern. Amanda pointed out that then leads to this period-luminosity relationship where you say, well if it's got this pulsation period of five days it must be this bright, if it's got a pulsation period of ten days is must be this bright. Then you basically have a really assured number for the brightness, and then you can use that to work out its distance.

Mookie: Gotcha.

Ben: The relationship between the period and the luminosity as a process is kind of easy to intuit. One of the names for this K-mechanism, they call it the Eddington Valve. It's kind of like, it's fun that James started off with an example of like a pot with water in it. Have you ever taken a pot and filled it with water and put a lid on it, and then set it to boil?

Mookie: Oh, quite often.

Ben: And then what happens, like steam builds up inside until there is enough pressure on the inside to blow the cover off, right?

Mookie: I've never done that, but…

Ben: No, no! It doesn't blow off, it just lifts a little bit, and you get a puff of steam out, right?

Mookie: Off right, right, yeah.

[18:19]

Ben: So essentially, that's the same thing that is happening in the star. So essentially, there are all these helium atoms inside the atmosphere of the star. The star is so hot, that all these helium atoms have lost their electrons. That means that they absorb light, and bounce off light really easily, so light isn't traveling through this atmosphere very easily. So it's just like the pot with the lid on it, it's keeping the steam in. All these photons are causing essentially a big buildup of heat. And then, it's just like how eventually the heat on the inside gets big enough that it can pop the lid just a little bit off the pan, and cause like a little puff of steam to come out. Eventually, the heat inside the stellar atmosphere causes the stellar atmosphere to puff out. As it puffs out, the helium cools and it can get electrons back again, so all the atoms in the atmosphere becomes slightly less charged so they interact less with the light. Suddenly, all the light can leave like when the lids off the top. But that lids still kind of hovering in the air briefly, so as the temperature on the inside drops, the lid goes back down. So what you do in the stove, you turn it on really high, and the lid goes "Clap Clap Clap Clap Clap Clap Clap" really periodically, right? The hotter you turn it up, the faster it's going to clap. Anyway, there is a relationship between how hot the stove is and how much steam gets released and the period of clap on the lid. Same thing with these stars. There is a relationship between how many photons gets released, how bright the photons are when the star finally lets go, and how hot it gets, how heavy the star is. So, this is what's causing the standard candle, the fact that this process has a nice relationship between the brightness of the star and its period. So we can measure the period using a telescope and a clock, or a calendar. From there, you can tell how bright the star was originally, and we can compare the brightness of a star as we see it to the brightness as it was when it was originally. We can figure out how far it is away from us.

Mookie: Well that's really cool.

Amanda: So this method was originally calibrated by a woman in 1905 or so. Her name was Henrietta Leavitt. She's spent a lot of time looking at these fuzzy blobs called the large and small Magellanic Cloud [or Nubeculae Magellani]. So she cataloged maybe twenty or thirty of these things, and came up with this relationship. And one of the best ways to be able to determine the distance to object. This is a very reliable method.

Mookie: And it's still applicable like a hundred years later?

Amanda: Yeah, we can still use it. You just have to be able to identify the Cepheid, which you do by this variability, then you can determine it. You can use it to calibrate other distance indicators.

Mookie: That's great. And you said that Hubbell was looking at a Cepheid Variable in the Andromeda galaxy?

[20:46]

Amanda: So Hubble spent a lot of time in about the 1920s. He sat up all night at this telescope looking at these fuzzy blobs in the sky. The one that he looked at a lot was Andromeda, and he would look at it every month or so, he'd go and take another image. He was really great at finding patterns in the stars, and noticing when there was an extra bright spot. He can see this old plate where he would mark off one and say, "Oh, this is a nova star exploded". Then it would fade away after a couple months. But he noticed that one of these spots he marked as a nova actually got bright again after a few months. Stars generally don't explode twice, so he realized there is something up with the star and it wasn't just a nova, but it was one of these Cepheid Variables. He got very excited about the potential, and he used Henrietta Leavitt's methods to determine the distance. At this time, in the 1920s, we thought that the Milky Way galaxy was the extent of the universe, 100,000 light-years, that's all we got. So he used this method to determine the distance to Andromeda galaxy because this Cepheid Variable star was inside that nebula, discovered it was 4,000,000 light years away. So our universe goes instantly from 100,000 light-years to 4,000,000. All of these little fuzzy blobs that we see in every direction aren't just little nebulous things, but they're entire galaxies on their own.

Mookie: That's crazy to me that that this all happened less than a hundred years ago.

Amanda: Isn't it? Yeah.

Mookie: It's still relatively recent information for us. It's wonderful. I love it. So, was Hubbell's first discovery of a nova not being a nova but a variable star, was that the first variable star that was discovered, or have there been other ones? Like in the Milky Way that we'd seen before.

Amanda: Yeah. They had been in the Milky Way. So Henrietta Leavitt's catalog was for very… two very, very nearby galaxies. Then other ones in the Milky Way. So this was the first one that was confirmed to be in a distant galaxy.

Mookie: Oh, Ok. So part of the excitement was that he knew he was looking at a variable star? Somewhere else?

Amanda: Yeah, exactly. It was in the Andromeda galaxy.

Mookie: That's crazy. Oh, man, I can't imagine what he must have been thinking… bad omens [making scary sound like a thin wail].

James: Yeah, so a lot of stars are variable, and if we want to take it to a terminal variable star, that would be a supernova. One that is particularly useful for distance determination is what's called the type 1a supernova. Basically, what you have here, this is a supernova explosion that is a result of a binary system. You usually have two stars, one orbiting the other, and one of the stars is a white dwarf. The reason this is important, because these white dwarves are quite small, compact stars, and they basically, relatively speaking, have a small massing before they get very unstable. If this is a massive star, pile loads of mass on it, and it will be pretty happy. What happens in this binary system, you have this white dwarf and you have this second star, and you get a situation where the second star, maybe it's coming towards the end of its life. The white dwarf may start to what is called accrete material. So it basically starts to suck some of the material off the companion star. You may get a situation where it has accreted so much mass that it becomes unstable, and this results and a very energetic explosion, which is a type 1a supernova.

Mookie: Type 1a. So type 1a is when the white dwarf explodes in the binary system? Because it's taken up more than it can handle?

James: Yeah, essentially. That's a sort of basic description.

Ben: So, you know how the Earth's going to meet its end, right, Mookie?

Mookie: Oh, yeah. The sun is going to swell up, it's going to become a red giant at the end of its life, and it's going to eat up Mercury, Venus and Earth and then it's going to shrink again, right?

Ben: Yeah, that's right. Do I have that right?

Amanda: You're absolutely correct, yep.

Mookie: Woooo!

[24:28]

Ben: So stars have life cycles. Essentially they're big nebula reactors. It's the nuclear reactions in the center of it are what powers a star, makes it glow. They are what generate all the photons that heat up the rest of the star and make photons pour out the surface. Fantastic stuff. Anyway, that depends on kind of the chemical makeup of the reactions going on inside them, right? So the different types of elements fusing produce different types of energy. So helium reactions put out more energy I'd think then hydrogen fusion. As a star burns out of one type of element, it will start burning other elements, and that will cause the star to puff up, which is how the Earth is going to end. So, the way these systems work is essentially, there are two kind of older stars. One of them is a white dwarf, and the other one has just puffed up. It's puffed up just like how the Sun is going to puff up and swallow the Earth, only it puffs up and the surface of the star kind of enters the gravitational regime of the other star. So, gas from one star is going to start getting sucked on to the other one. If I could jump really high, I could jump high enough that I would get stuck on the Moon. Maybe if I was on the Moon, and I jumped really high, I could jump high enough that I could get pulled onto the Earth, right? So a similar thing, stuff from the red giant is puffing up and getting sucked down onto the white dwarf. So, there is a variety of chemical things. It turns out the end state of a star s is kind of a subtle thing. If the star is light enough, then the gravity involved isn't enough to cause really heavy element burning. On the other hand, if a star is really, really heavy, it might supernova. Usually stars don't gain any more mass over the course of their life, so they start off one type of star and then they'll burn through all of their elements, etc., and then die in an old folk's home. In these binary stars, because their mass is changing, because the chemistry is changing from this inflow, suddenly it can go from the type of star that won't be exploding, and can cross the mass threshold [the Chandrasekhar limit] into a star that does run away explode.

Mookie: I see. And that's a type 1a?

Ben: Yeah.

James: So the reason these are type 1a supernova, useful for standard candles marking th distance is, basically, these type 1a's always have the same light curve. So what that means is, if you plot how the light changes with time, it arises to a really bright, and over time it slowly fades out. Regardless of roughly speaking where this 1a explodes, it pretty much has the same curve. What that means is, essentially, it almost has the same maximum luminosity. So you can treat, within reason, one 1a the same as any other. That means wherever they are, they're going to behave in the same way and have the same intrinsic brightness.

Mookie: Are these usually seen in other galaxies, or do we observe them here in the Milky Way?

James: Usually in other galaxies. If there was on relatively observable in the Milky Way, it might be quite concerning. [laughter]

Ben: Alright. These are great, these supernova 1a's, because they're really, really, really, really, really, really, bright. They're bright enough to see at really, really, really, really, really, really, really large distances.

Mookie: Like other galaxies.

Ben: Like other really, really, really far away galaxies.

Amanda: Like galaxies that existed when the universe was about half its age.

Mookie: Really?

Ben: And so it's fantastic because we can use them to figure out how the universe is changing in size over time.

Mookie: Ahhh, very good.

[27:47]

Amanda: So, there were two different teams in the 1980's and 1990's. They were looking for as many of these supernovas as they could find. They were trying to figure out how far away the galaxies were that they lived in. They were using this to try to figure out how quickly those galaxies were actually moving away from us, under the assumption that the whole universe was expanding. They wanted to know how quickly the universe was expanding.

Mookie: Ok.

Amanda: So these two teams independently using supernova that they discovered, determined that not only is the universe expanding, but the universe is accelerating in its expansion, which is kind of crazy. This discovery actually won these lead scientists of these projects a Nobel Prize in 2011.

Mookie: Really?

Amanda: Yeah. So the discovery that the universe is accelerating and its expansion was a pretty decent discovery, good enough to win the Nobel Prize [laughter]. They originally published this and 1998, and they didn't get the prize until 2011.

Mookie: Two years ago? Jesus.

Amanda: Yeah. It's taken a while. But you have to verify that the results are right and it stands the test of time and all that.

Mookie: Right. And they were measuring it by these supernova?

Ben: Yeah, that's right.

Mookie: Ok.

Ben: Incidentally, so the history of the expansion of the universe is really fun because this represented a new level of understanding of how the universe worked. It threw in something completely out of the blue that Einstein predicted accidentally in the 1920's. So Hubble, we started talking about Hubble, right? One of the things he discovered is that the universe is increasing in size. He did it using something really fantastic. He could look at other galaxies. He was looking at how the color changed. Last time we were on, we were talking about special relativity. Do you remember?

Mookie: I remember, yeah.

Ben: Ok. In special relativity, if something is moving towards you really, really, really, really fast, it changes the color.

Mookie: This is Doppler, right? Blueshift and redshift?

Ben: That's right. It's the analog, the special relativity analog for the Doppler shift. So if you're moving towards me, a white light will look bluer, same way your car will go [Vroooooooooo – high pitch] when you're going towards me, and [Vroooooooooo – low pitch] when you're driving away. If you are moving away from you [me], the white light will look more reddish color. We call those redshift.

Mookie: This is moving at very, very fast speeds that we notice this, right?

Ben: That's right, yeah.

Mookie: If you're running at me with a flashlight, I'm not going to notice that before he hits me with the flashlight, I saw a blue light. Oh, shit!

[30:10]

Ben: That's right. So what Hubbell did was that he looked at the colors of galaxies that were fairly far away from us. He could figure out how far these galaxies were using these standards candles. Is that right?

Amanda: He didn't, I mean, he didn't use standard candles. He used their redshifts, essentially. He measured the hydrogen that was coming from the stars. If you've got some hydrogen that's coming from a star at a distant galaxy, that hydrogen light travels in a wave. What that little hydrogen wave doesn't know is that the universe is actually stretching around it and it's stretching the wavelength, so it's a little bit longer. It becomes redder. So by the time that hydrogen light reaches your eye, it actually looks redder. So he measures this little hydrogen notch in the spectral rainbows of all these galaxies, and how far that hydrogen shifts to the red is how long that light has been traveling, and therefore how far away that galaxy is.

Mookie: Ooohhhhh.

Amanda: So he figured out that every single galaxy, except for Andromeda in our little neighborhood…

Mookie: Which is coming right for us…

Amanda: Yeah, exactly. Every single galaxy is redshifted. The really crazy thing is that the farther away the galaxy is, the faster it's moving away from us.

Mookie: That's something my brain has trouble wrapping around, and I love that simple fact is just so mind-boggling. I just get a kick out of it.

Ben: Alright, so. Imagine you've got a couple ants and you put them on a balloon. Let's say put three ants, one at the north pole, one at the south pole, and one equator, Ok? You start blowing up the balloon, and we can talk about the distance between the ant at the equator and the ant at the north pole, and the ant the south pole, and the and at the north pole. As you inflate the balloon, the rubber is stretching kind of evenly throughout the balloon. What happens is the distance between the ant at the equator and the ant at the north pole is increasing, same as the distance at the bottom in north [south] pole, but also the speed at which the distance is increasing increases as you inflate the balloon.

Mookie: Gotcha!

Ben: It's like space itself is expanding in the intergalactic regions. So objects aren't moving farther apart, it's that the distance is actually increasing like on the surface of the balloon.

Mookie: Gotcha. I did hear that once before. Thank you for reminding me. It's still a neat analogy. I think it's great that we're in a big universal balloon.

Ben: Well, it's a three dimensional balloon instead of a two dimensional balloon. I mean the surface would be three dimensional.

Mookie: I hope were shaped like a dog.

[Laughter]

[32:30]

Ben: So this type of universe is consistent with one of the early predictions of Einstein's general relativity. In 1905'ish, he wrote a whole bunch of papers that revolutionized physics. This is when he was a patent clerk. It was called his miracle year because it was when he published all these crazy papers that revolutionized everything. Then he spent the next ten years of his life trying to perfect a theory of gravity that used his special relativity laws. This theory is called general relativity, and it's the theory of gravity that predicts things like black holes. One of the things his model of gravity predicts is a model of the universe. If you assume that matter is pretty evenly distributed over the universe, and you want it to be evenly distributed because if you clump up too much matter in one place, it will suck itself down in, and make a little pocket, a gravitational well. You make sure that the universe at the start is really, really uniform, matter is evenly distributed. You'll find that what happens is, you can make it expand. What will happen is, in these early models, the ones that essentially Hubble ended up confirming, is that they expand uniformly, and they'll keep on expanding. As the effect of gravity pulls these massive objects apart, it slows down. It's like the universe started off with a bunch of momentum, so it's slowing down as it stretches out. Depending on how much momentum it has originally, the universe can either re-collapse or it can keep expanding forever. It might re-collapse and form a Big Crunch, right?

Mookie: I've heard of the Big Crunch.

Ben: So what the discovery of, by looking at these supernova 1a's, what we can do is we can get a much better handle on the history of how the universe has been expanding over time. We can have a sense of how this expansion has changed over time. We had expected that it would kind of be slowing down as time went on. What we see is that it's speeding up as time goes on. Because these supernova 1a's gives us a better sense of history of the universe as it expands, we can see that way billions of years ago it was expanding at a slower rate than it currently is today.

Mookie: And they can figure that out just by looking at type 1a's?

Ben: Uh, yeah. That's right.

Mookie: and measuring the distance?

Ben: that's right. It gives us a profile for how the universe is expanding. What we can do is we can figure out what type of matter is in the universe, and it turns out that there is like 70% of the matter in the universe is this weird thing called dark energy. Nobody knows what dark energy is, but its ripping everything apart.

[35:03]

Ben: All right, that was a wonderful. Well, absolutely fantastic! Thank you, James. Thank you, Amanda. You've pleased me. Your efforts have borne fruit, and that fruit is sweet. Here is some fruit. Amanda, you get the latterest us of all fruits. It's a banana!

Amanda: Yeah! My favorite fruit! [Nomb Nomb Nomb Slurp!]

Ben: Alright, James. For you, I've brought in a starfruit!

James: [Nomb Nomb Nomb Nomb Nomb]… Pointy!

Ben: I'd like to thank my guest, Mookie Terracciano. Thanks, Mookie.

Mookie: Thank you for having me, Ben. It's always a great time.

Ben: Good work on finishing up Dominic Deegan, and good luck on Star Power.

Ben: Alright, my Ti-phyters, listen to me. I love the show. I hope you do to. But for every listener of the show, I know there are a hundred other people who would love to listen to the show but they don't know how. So I want you to spread the word. There are three ways you can do this. First is iTunes! It's still the place that everybody goes, even though the iTunes app is kind of crummy. Go to iTunes, write us a review if you haven't already. Each review puts us closer to the top and more people will find out about us. The second way is to teach people how to listen to podcasts. Listen, everybody's got a smart phone these days, or an iPod, or and iPad. Listen, most of those people don't know how to listen to a podcast. I don't know why, but they don't. So, tell them to download the **Stitcher** app. In fact, show them how, it's very easy. You go to the **Stitcher** app thing, you download it, you enter your name, and you can listen to all sorts of podcasts and subscribe to them. Subscribing to them is the best thing about podcasts, because it does it automatically. Week after week, you can listen to your favorite shows they update. So it's free and easy to use the **Stitcher** app and it works on every handheld device. Also, when you're up there, you tell other people to listen to our show. Fantastic! The third way to spread the word is to tell people online about us. I've been seeing people doing it, it's a fantastic thing. The Internet is full of people who want to know more about physics and are trying to explain it to each other. So if you see somebody who wants to know about us or maybe there is a news article about some topic we've covered, tell them about the show. People will be happy and it'll drive new listeners to our show. So, that's it. I hope you'll help us out and point listeners in our direction. So, that's the main part of today's show. Remember. If you like listening to scientists talk about science in their own words, you might want to listen to other shows on the Brachiolope Media network, like the *Weekly Weinersmith*, where Kelly and the Zak Weinersmith talk to academics about their research. Or S*cience, sort of*, where we talk about science in the news. Editing and support for the *Titanium Physicists* podcast is provided by a gentleman named John Heath. Thanks, John. You do a bang-up job of making us sound better. The intro song to our show is by Ted Leo and the Pharmacists, and the end music is done by John Vanderslice. Until next time, my friends, have a nice evening and remember to keep science in your hearts.

[38:49]

[Excerpts]

Ben: That can't be right, because it's like a light-year and a half away, right? Promima Centauri?

Amanda: Proxima Centauri. It's four light-years.

Ben: Yeah, and then one arcsecond is a…… parsec….. right?

Amanda: So…. The distance corresponding to a parallax of one arcsecond is three light-years. Oh, yeah, you're right. That doesn't actually make sense. Huh…

[Various verbal 'shrugs']

Amanda: No. No, that's right. So it's about…. Yeah, that's right.

James: That sounds about right.

Amanda: So the distance corresponding to one arcsecond, and this is just a little bit less than an arcsecond, and a parsec's about three and half light-years, or three and a quarter…

Ben: But shouldn't it be more the closer, it should have a larger parallax the closer it is to us, shouldn't it?

Amanda: Right, exactly. And Proxima Centauri is about four light-years.

Ben: Oh, it's four light-years away. Aww, crap. I'm never getting there. Frack!

[Laughter]

Amanda: Join the club, man!

Ben: Alright, carry on. [laughter]

[40:04]

Mookie: Oh, well.

Ben: Hey, Mookie. I gotta tell you about Tyco Brahe after we finish recording.

Amanda: Ahhh, he's a good character.

Mookie: Oh, about his golden nose, and… moose, right?

Ben: He died because he didn't want to ask to go to the bathroom, and so his bladder exploded, or something?

Mookie: Are you kidding me?

Amanda: There's actually quite a bit on controversy over that, isn't there?

Mookie: His bladder burst over a party?

Ben: He was having dinner with the king, so he didn't want to ask the king if he could get up to go to the bathroom.

Amanda: I think this is one of those…

Mookie: Oh, it's courtesy. He wasn't trying to break the seal? Royal courtesy that killed him?

Ben: Correct.

Mookie: Oh, man.

Amanda: One of the reasons Kepler is one of my favorite astronomers is because he had to deal with Tyco Brahe as a boss.

[Laughter]

Mookie: Just ask to pee! It's not a big deal! "No! I'll be fine!" Oh, well…

Amanda: Wow. So, where are we? So…

Mookie: It's hard to rail a conversation…

[41:09]

James: I think it's important to point out that actually a lot of stars are actually variable, not Cepheid variables, but variable. There are multiple reasons for that. Some are just variable because there happens to be some… planets pass in front of it and there might be a light drop. The stars are variable because they have clouds of chemicals in the atmosphere that pass and reduce the light or increase the light. There are all sorts of stars that are variable for many reasons, but obviously the Cepheid variables has a one that works particularly well for distance determination because it's consistent… the light, the luminosity to another parameter. The reason that this is important is, we're already described that if you know how bright something is, if you know, you take it further away, it's going to get fainter. But the difficulty is, are you looking at a big star far away or a smaller star close? And that's where things like Cepheid variables is good because you get information about luminosity separate from that sort of assumption. You get sort of a second cursor to the luminosity, if that makes sense. So that's why it's so important.

[42:12]

Mookie: I mean, please correct me if I'm wrong if. Supernovas are clearly very bright if we can see them from other galaxies. Would it be of great concern to us if, say, a type 1a supernova were to happen on the other side of the Milky Way? Still very observable to us, but wouldn't like still affect us?

Amanda: it's not going to affect us. So when a supernova explodes, it is brighter than an entire galaxy for a period of a month or maybe two months, depending. So they are really bright and they put out a lot of energy, but you would have to be actually pretty close to the Earth in order to affect it. We have this really great atmosphere which protects us from most of the radiation that a supernova would put off. So, unless it was within like a few hundred light-years, then it would be Ok. So we've seen supernova explode. 1987 was a big one, so that was a supernova that was in our galaxy and… A fun fact, Betelgeuse…

Mookie: 1987?

Amanda: Yeah, it was huge. That was…

Mookie: What?!? I was alive then. I didn't hear about this.

Ben: Oh, yeah. It was the first supernova confirmed using neutrino observations. Because we were bombarded by the neutrinos and so the very early neutrino detectors heard of it.

Amanda: We've been able to observe it and watch its little shell expand over the years. It's pretty exciting.

Mookie: Ohhh… We didn't actually see like... [sound of massive explosion]. 'Ahhh, brighter than everything!" It was…

Amanda: No, no, no! You could see it through telescopes. I'd think you probably could see it with your eye, but it would just look like a bright star at night. It wasn't like a…

Mookie: Ahh, Ok. So it wasn't like a 'brighter than a full moon', change everything sort of…

Amanda: Now it would be cool is the star Betelgeuse which is part of Orion if…

Mookie: I'm waiting… I'm waiting… I'm waiting for that one. I'm hoping, like, come on…

Come on!

Amanda: So this thing could go supernova any time now. If it does, it will be visible during the day for about a month, which would be…

Mookie: That's gonna break my wife's heart though. Orion is her favorite constellation. As awesome as that would be, she would start to cry knowing that her favorite constellation…

Amanda: It's only one star in Orion. Everything else would be ok…

Mookie: Oh, no. She likes the whole thing, trust me.

Ben: I'm with your wife, man. That star is the only constellation for wandering around in the winter… in Canada.

Mookie: Oh, no! She loves it. She loves it. She's attached to the damn thing. She says hi to him at night more than me sometimes. "Oh, I know you're going to be here. You're gonna be here in the summertime. He's not going to. I have to go talk to Orion."

Ben: Yeah. It's like winter, and I'm cold. It's like 9 p.m. and I'm walking home freezing to death. I look up, and there's ol' Orion, sitting on…

Mookie: Yeah. So I'd be excited for Betelgeuse to go. I'm just waiting. I'm like, "Yeesss!! Supernova!" But then, I know afterwards, I'd have to hear, [sobbing] "He's…He's head is gone!", or whatever the hell part of his… Betelgeuse's, I don't know, his arm or elbow. His shoulder? Aww, he'll be fine.

Amanda: But even so, if it does explode, physically, we'll be fine on Earth. It's something like six hundred light-years away. We'll be ok.

Mookie: Excellent. If things derail, just blame me. It's probably me just… It's probably me.

Ben: It doesn't matter if things derail, because I edit it, right?

Mookie: Oh, excellent! Alright, very good.

Ben: I'll be shaking, I might be shaking my fist at you in the future. Well, none of these derailing's are too bad.

Mookie: Oh, come on! I'm not trolling your podcast.

Ben: No, no. It's good. Listen…

Mookie: At least not on purpose. I might be doing it by accident.

Ben: As long as you're having fun, it's good.

Mookie: I'm having a blast, I'm having a blast.

[45:59]

Ben: As opposed to regular supernovas which are just, what, type 1's?

Amanda: Type 2's.

Ben: Type 2's? What's a type 1? Is there a type 1b?

Amanda: Yeah, there are. Those are closer to type 2's. Type 1a's are the special ones, with the light…

Ben: Ok, ummm. Yeah, right.

Mookie: Crazy numbering scheme.

Ben: I know, right?

Mookie: It's like there one type, and then somebody decides to make a prequel.

Amanda: Well, that's exactly right. The more you study them, the more you know the subtle details, you know. You have to like separate them into different categories, and give them more uncreative names. That's essentially astronomy, summarized.

Mookie: They got to hire some writers in astronomy, man, and give shit like really cool names.

Amanda: Oh, please.

Mookie: Like this is a Dark Star supernova! Oh, man, that'll sell some books.

[46:51]

Ben: One of the candidates for dark energy, actually. So Einstein, when he first found this theory that said this universe was expanding, he didn't like it. Philosophically, Einstein wanted a universe that was static… that was standing still, where galaxies weren't pulling away from each other. It's weird. You imagine this classical man thinking philosophically. That's crazy. So he inserted a term into his equation that wasn't in there originally. Mathematicians have decided since then that this extra term is ok to have inserted it. It's kosher to have inserted this term, but back then he was just, "Well, I'm just gonna shove in this term." Because, what this term let him do was, it let him make a universe that stood still, that wasn't expanding. He liked that, but then the next year, Hubble came out with his discovery, and he was like, "Oh, snap!" He was like, "Adding this term is the biggest blunder I've ever made." So, this extra term, it's called the cosmological constant, it's known as Einstein's biggest blunder. But, here's one of the neat things. The accelerating universe theory we've just discovered? One of the candidates for the reason it's accelerating is that maybe it's that term Einstein added to his equations. Maybe it just has a value that's causing the universe to 'Vroooooop' accelerate out. So it turns out his biggest blunder was like a hundred years…

Mookie: It was like a prediction. Like an accidental prediction.

Ben: An accidental prediction that was absolutely right a hundred years later.

Mookie: But he didn't like it.

Ben: No, well, yeah. That's right.

Mookie: No, he didn't like the fact that, "Hey, we're inflating." "Well, I don't like that. Everything's constant." "Well, everything's constantly inflating, Einstein." "Well, bugger! Shit…"

Amanda: Well, this was a pretty big argument, even into the… Physicists were arguing the universe always has been, it always will be, it's as it is, and others were fighting for the expanding universe. So, Hubble found out that it was expanding at a constant rate, but they wanted it to just not be accelerating, or not have a Big Bang, just a steady state of the universe.

Mookie: But that's… wrong, isn't it?

Amanda: Yeah. But that's controversially…

Mookie: They were arguing this in the 50's?

Amanda: Yeah. It had been around for a while. There were some people that were…

Mookie: Thirty years later?

Amanda: Really holding onto their…

Mookie: You can see these galaxies running away, and a galaxy's not a tiny thing. It's fucking huge! "Look, they're all getting away from us." This is not a subtle thing, guys. We're not making this up. We've been arguing this for thirty years, come on.