Astronomy Cast Episode 279 for Monday, November 5, 2012: The Hubble Constant

Fraser: Welcome to Astronomy Cast, our weekly facts-based journey through the Cosmos, where we help you understand not only what we know, but how we know what we know. My name is Fraser Cain; I'm the publisher of Universe Today, and with me is Dr. Pamela Gay, a professor at Southern Illinois University-Edwardsville. Hi, Pamela. How are you doing?

Pamela: I'm doing well. How are you doing, Fraser?

Fraser: Good. Global warming is treating us really well here on the west coast today. It's beautiful! I'm wearing like shorts and a t-shirt in the middle of November. We're recording this episode a little late, so it's almost December and the weather is beautiful. So yeah, it's great!

Pamela: We have the exact same thing here. I was riding my horse outside in short sleeves yesterday and me and the horse were both sweaty, and that doesn't normally happen outside this…yeah, we're destroying the environment in ways that allow t-shirts in November.

Fraser: Yeah. Thanks, global warming! So as always we're recording this episode of Astronomy Cast as a live Google plus hang-out, and if you want to watch us record live (trust me it's so much better!),then what you do is you circle Astronomy Cast on Google plus, and then you'll get an event notification in your stream, in your calendar of when we're going to record our next episode and then you can just watch us live and ask your questions and stick around and interact with the fans and it's super-fun. So it's a really great way -- if you really enjoy Astronomy Cast, this is a great way to take it to the next level. Alright, let's rock!

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Fraser: So when Edwin Hubble observed that distant galaxies are speeding away from us in all directions, he discovered the reality that we live in an expanding universe. Hubble worked to calculate exactly how fast this expansion is happening creating the Hubble constant, which astronomers continue to refine and reference in their research today. So, Pamela, I guess the first step is to go back…now we've talked about Hubble and we've talked about the Big Bang, but I think it would be great to go back for a second and talk about that discovery that Hubble made as part of his research. So what was he looking for?

Pamela: Well, so the interesting thing is I need to take you back a step, actually, because it wasn't just his discovery. It all started with a guy with an awesome name who's been forgotten largely by history, whose name is Vesto Slipher. He was working at Lowell Observatory in Arizona, and he was a spectrometrist. He took images of galaxies that were not the type of pretty spiral or elliptical images that you see on astrophotography websites, but rather he took the light, put it through a thin slit, and I believe a prism, and spread that light out into a rainbow that he imaged, called a spectrum, and we've talked about those in other episodes, and when he looked at these spectrums, he was able to use Doppler shifting to measure the velocity of the galaxies, and the expectation was that the galaxies would have a random distribution of motions -- that some would be moving towards us, some would be moving away from us, and what he found was the majority of the nearby galaxies, while there are a couple moving toward us like Andromeda, the majority of them are moving away, and that just completely blew his mind, and this was back in a time when we didn't know galaxies were galaxies, we just called them spiral nebula. And this was like all kinds of confusing.

Fraser: I mentioned this, that I've got an old astronomy book that's like from the 1920s and if you look through it, it has the Andromeda nebula, and it has these other nebulae, and it's just so cool to see in fairly recent history that this was still their idea. Now one thing you mentioned the Doppler shifting, the red-shifting the blue-shifting…so what exactly was going on there with the light from these galaxies?

Pamela: So when an object is moving away from you, its light will get shifted toward the red. If it's sound, the sound will get shifted to longer, deeper wavelength noises, so it will go from sounding like a trumpet to sounding like a tuba basically. We're used to experiencing this with fire trucks. We hear them the pitch gets more high-pitched as it's coming towards us, as it moves away, we hear this low-pitched noise. Well, light does the exact same thing, more or less, and so when we see galaxies moving away from us, light from specific spectra lines that we know the exact color they should be, it gets shifted, so if we were to use…like we use Gary Gonella's h-alpha filter every virtual star parties on Sunday nights and we see these beautiful nebula. Well, these beautiful nebulae that show up so nicely through his h-alpha filter that only allows the light from that one transition from hydrogen to pass through, well, if those nebulae were moving away from us at great velocities, their light would be a completely different color, and they'd disappear from the images.

Fraser: And so is that one of the filters that astronomers use is to look at this at that wavelength?

Pamela: So what we actually do with galaxies is we don't constrain ourselves to just one wavelength generally. First of all galaxies are kind of faint, doing that you're not going to get very much light in, so what we do…and we also don't know what velocity they're at, so if you don't know what velocity they're at, using a narrow gun filter isn't useful, so we take all the light and spread all the light out, and we'll look at as much of the wavelength as our individual instrument allows. Some of the best instruments out there allow you to get all the way from infrared to low ultraviolet spread out in this continual spectrum where you can see dips created from magnesium, you can see dips created from the different hydrogen lines. We see all sorts of different things as we look at these galaxies – calcium lines... And we use all these different lines to figure out the shift created by the velocity of the galaxies.

Fraser: So Slipher, which is the best name ever I think, had sort of laid the groundwork for this next discovery by Hubble, right?

Pamela: Right, so the thing with what Vesto Slipher did was he couldn't actually measure the distances to the galaxies, so all he knew was a bunch -- a statistically improbable number -- of the galaxies that he looked at were shifted so that they were moving away from us; they were red-shifted. Well, what Hubble was able to do was he took deep, deep images, ones that allowed him to see individual stars, that allowed him to carefully resolve faint objects in many of these galaxies, and he took a time series of them so that he was able to identify individual stars called Cepheid variables. They change in brightness over time, and as they change in brightness, they do it in a very systematic way, so that one that changes over one period of time…we know it gives off one amount of light. One that changes over a very different period of time, we know it gives a different amount of light, and so he was able to use this beating of the pulsating variable stars to say, "I know how much light this star is actually giving off, more or less." That was part of the confusion, but I know, more or less, how much light is actually given off. I can measure how much light I see, and this allows me to calculate the distance the same way when we see a motorcycle headlight, we know roughly how bright that should be and we can gauge the distance to the motorcycle based on how bright the headlight appears.

Fraser: And what did he discover? He was able to find these stars, these standard candles in all these galaxies around him? He's able to accurately measure the distance, which is great.

Pamela: Accurately is a stretch.

Fraser: He was able to in order of magnitude…

Pamela: I'll go with that -- with large error bars.

Fraser: He was able to "measure-ish" the distance to these galaxies, and what did he discover?

Pamela: Well, what he found… and the problem with his accuracy, he could tell the relative distances, but he couldn't tell the actual distances, so he was able to say, "This system's farther away than this system," and when he made those measurements, he realized those systems that are further away are moving significantly faster than the ones that are nearby, and that is consistent with looking at an expanding universe. If you imagine yourself in a theater and all the chairs in the theater are moving apart from one another a centimeter per movie, well, at the end of one movie, the chair next to you is one centimeter away, the chair next to it is two additional centimeters away, and each movie, well, that one that's two chairs away, two movies later it's going to be four centimeters away, three movies later…this just keeps increasing as you see that more distant chair appears to be moving faster. Well, it's not that it's moving faster, it's that the spaces between the chairs is increasing at a constant rate that makes things that are further away appear to be moving faster.

Fraser: Right. Right. OK. And so he makes this amazing discovery, you know, to calculate these distances and this velocity, and sort of stumbles upon one of the most important discoveries in all of science.

Pamela: And there had been people who predicted this might be the case. Einstein's theories of General Relativity and Special Relativity, when he chewed through all the numbers, when he examined our universe in detail, one of the things that came out of relativity is the idea that when you do the calculus of space/time, there can be a constant involved that makes our universe Steady State, but at the same time if that constant doesn't have the exact right value, our universe is either expanding apart or collapsing in on itself. It's not a static place, so Einstein originally tried to use his cosmological constant to stay the universe, but there were folks like Lamantre who said, "No, no, no! Our universe could be expanding!" and put these ideas forward, and so the theories were there that when Hubble put together the pieces of Vesto Slipher's spectra and his own photometry of the variable stars, when all those pieces came together, there was a complete picture in one very special moment in history.

Fraser: And so they had…he came to this…I mean, did he actually come to this conclusion and say, "OK, so we live in an expanding universe; therefore, the universe had to have come from a single point in the ancient past?"

Pamela: That wasn't in the original paper. Now, I clearly was not alive when this was happening, so I can't say what people were arguing at the conferences, I can't say what letters were getting floated back and forth, but in the literature, that original plot of distance vs. velocity lays out the case for an expanding universe. Now, the two theories that emerged over time was the notion of a Big Bang, but also what's called the Steady State model of the universe. This is a model that we now know isn't true, that observational data doesn't support it, but it took a while for us to realize that, and the Steady State model basically says that there's new stuff coming into existence that's pushing the universe apart, so this is the idea of that movie theater that has stuff coming into it vs. the stuff in the theater expanding, so you can imagine ooze pushing the chairs apart vs. just what already exists pushing the chair apart.

Fraser: New chairs…new chairs pushing the chairs apart.

Pamela: Right.

Fraser: So specifically what did he calculate this expansion to be? How did he describe this?

Pamela: It's just a plot! That's the awesome thing is this is a very clean, simple-to-look-at result with a lot of error bars in the initial stuff. It was just a plot of distance vs. velocity showing as distance increases, velocity increases. Now, it was noisy, it was ugly, we were still…we only had fairly small telescopes by today's standards, we couldn't see very great distances, he ran into problems when he started observing galaxies in the Virgo cluster because that's a gravitationally-bound system. Galaxies in an individual cluster -- that cluster isn't expanding, it's the separation between the clusters is expanding.

Fraser: Right. We get that question a lot, right? Which is, "Is the actual galaxies expanding? Are the solar systems expanding? Are we expanding?" I know you guys have Thanksgiving shortly, so…so you might be expanding.

Pamela: I'm not going to answer the question "Are we expanding?" in general. In the specific case of the cosmological constant, no, it bears no effect on the human body.

Fraser: Right, it's about the…I guess before the concept of dark energy, it's really this, you know, you have two cars driving away from each other, and those two cars are going to be driving away from each other, and they're going to be moving apart, they're not going to be…the cars themselves aren't going to be expanding as well.

Pamela: But you have to be careful. It's not the objects that are moving; it's the space that's expanding.

Fraser: Right. The road is growing with the cars on top of it.

Pamela: The road is growing, and they have their emergency brakes on. They have no velocity.

Fraser: Yeah. They're stopped. But how did he actually describe this? I mean, you say it's a plot over time, but like, I know there's like a certain number of megaparsecs per…

Pamela: Well, back then we were still trying to figure all that stuff out. So the poor guy in his initial measurements…we had problems; we didn't exactly know how to calibrate the distance to Cepheid variable stars, so when your meter stick is severely broken, you end up with the wrong number. So he originally ended up with the universe expanding at roughly 500 km/second/megaparsec, and what that says is every million parsecs of space…

Fraser: How big is a million parsecs of space?

Pamela: So there's roughly three-ish light years per parsec, so…

Fraser: Like 3 million light years, so distance kind of here to Andromeda-ish because Andromeda's like 2 million light years away from here.

Pamela: Something…Yeah, but then we're going to mix our units and add km/second in there just to throw everything off, so it's not that huge an expansion given the size of our universe, but the thing is it can be measured. Now, the problem is that in order to measure it accurately, you need to be able to measure distances accurately, and that's where everything falls apart. There we're trying…none of the variable stars are close enough that we can use parallax to measure them, so we've had to use all sorts of broken ladders to build our way out to the nearby universe, and we did an entire episode on distance scales, but…

Fraser: Yeah. So 500 km/sec/megaparsec, and so that means that if…

Pamela: He was wrong.

Fraser: He was wrong, but that was his initial calculation. So in other words if an object is one megaparsec away, then it's going to be moving at 500 km/second.

Pamela: Right.

Fraser: And if it's 2 megaparsecs away, then it's moving away from us at 1000 km/second.

Pamela: The space between us is expanding at…

Fraser: Yes, at a rate to make that other object appear as if it is moving by 1000 km/sec, and if we're 3 megaparsecs, 5 megaparsecs, 10 megaparsecs away…OK. Great, so he did these initial calculations and they were mind-bending, but not super-accurate, right? But I know that astronomers have been working on this number like crazy, and in fact, we still report on it, we still write articles, astronomers refine…

Pamela: Between 66 and 74…

Fraser: 66 and 74 km/sec/megaparsec. Right, which is sort of almost like a factor of 10 less than he originally anticipated.

Pamela: And what's kind of awesome about this number is for decades there was this horrible cat-and-dog argument between Allan Sandage and Gérard de Vaucouleurs about whether or not it was 50 km/sec/megaparsec, or 100 km/sec/megaparsec, and it was just this entire community -- people picked sides, and they mocked each other, and it was ugly, and I remember as an undergrad one of my professors he was not going to pick sides, he simply said use 100; it's easier. Move on.

Fraser: Right, because it doesn't really matter because they're big numbers and chances are everybody's wrong, so it doesn't matter.

Pamela: And it was only after Gérard de Vaucouleurs died that people were finally able to start settling down on the answer. The kind of crazy thing is the answer turned out to be roughly 70 – midway between 50 and 100, so both dudes were wrong, and unfortunately, like so many arguments in astronomy, the real work was only done after one of the people who made it a heated, contentious ordeal had passed away, and now we know the Hubble key project has done awesome work trying to refine our distance scale with Cepheids, trying to figure out the supernovae problem, and we're getting there. And what's awesome (and we've talked about this in other episodes) is there are so many different lines of evidence that we're able to look at -- from using the Wilkinson Microwave and Isotropy Probe (WMAP) to look at cosmological values to measuring supernovae to…we still use Cepheids to ground us.

Fraser: Now, I know – and this has always baffled me, and I tend to sort of avoid it when I write articles, which is that astronomers reference especially in their research papers the distance to objects using a "zed" value, a redshift value, zed=5 or something like that. What on earth does that mean?

Pamela: When we started this conversation, we talked about how Vesto Slipher had measured the Doppler shifting, the red-shifting of the galaxies, and the mathematical way of translating this is if you take the wavelength of the light that you observe, and you subtract off the wavelength of where you expected the light to be, and then divide all of that by where you expected the light to be, this gives you a fractional offset, basically, and that value mathematically is called "zed," "z" -- pick a term.

Fraser: For you Americans out there you could say "z" sure.

Pamela: Redshift is probably the best way to confuse fewer people.

Fraser: Yeah.

Pamela: And so this redshift value is just the fractional shifting of the wavelength of the light. It's what you can observe. To get beyond this fractional shifting of the light requires you to make assumptions about space and time. It requires you to make assumption about how the universe is expanding, so when we work to translate that fractional observed shift in the color, we have to say, "OK, so what value of h [missing audio] are we going to accept? What mathematical value for the density of mass in the universe are we going to accept?" The omega value…and it's only once you make assumptions about those values that you can translate that redshift into a distance. Now, the easy way to think of it is anything greater than 1 is really far away. What's kind of amusing to me is when I started grad school, I observed the high redshift universe, I looked at things that are redshift of 1.2, 1.3, and a galaxy at a redshift of 1 has a look-back time of roughly 7.5 to 8 billion years…

Fraser: Wow.

Pamela: …depending on how you look at it, so you're looking back to more than half the age of our universe.

Fraser: Right. I mean, compare that, as I mentioned, to Andromeda at 2½ million light years away, you're only looking back 2½ million years ago. Other objects in our supercluster, 10 to 50 million years old, so you're seeing galaxies that are 6 billion, 8 billion light years away, and that's just…that's considered a low redshift?

Pamela: Well, so z of 1 is now considered a moderate to low redshift. It all depends on whom you're talking to. Supernovae people…they're starting to push out further than that, but the majority of what we see is in that z=1, but it's kind of crazy the way we can never get all the way back to the beginning. So the high redshift things that we look at, they're at a redshift of order of 4. Some of the highest things that we've looked at are estimated to have redshifts of 6, and this is where we start looking at light that came from more than 12 billion years ago.

Fraser: Yeah, I mean, galaxies are being turned up now using, like, gravity lensing that are only 500 million years after the Big Bang.

Pamela: Right. And so > 4 means that you're looking at the first one to two billion years of our universe, and it's been amazing to me to see how our definition of high redshift observing has changed from z > 1 is high redshift to z > 4 is high redshift, and 1 is nearby. As our technology has increased, as we've pushed out further, it's like with racecars. The definition of a high speed racecar has changed since the 1920s. Well, now our definition of observing the high redshift universe has changed as well.

Fraser: And there are some calculators out there, I know [missing audio] that can convert that sort of thing, so you can put in the z ratio and you'll get a …

Pamela: The best one out there is Ned Wright's. He's at UCLA -- just type in cosmological calculator, it will take you to his javascript page, it has perfectly reasonable default values. I know lots of scientists who…I remember the first time I had to calculate this stuff, I sat there and I wanted to cry after they discovered what we're talking about in our next episode, which is the cosmological constant, and Ned Wright just programmed all of it so no grad student ever needs to cry over doing this again.

Fraser: Right. You do it once, and then you use his calculator.

Pamela: Yes. Yes. You prove you can do it, and then you move on with life. It's like long division.

Fraser: So as I mentioned, you know we're still reporting on stories and we did one, like, must have been like six months ago about "Astronomers Narrow In, Decide, Calculate the Most Accurate Measurement for the Expansion of the Universe Ever," and then, you know that number you just quoted, so you know… how big are the error bars now? How much farther do they have to go to really get to the bottom of this?

Pamela: It depends on which way that you look. So some of them have 15% error, some of them have 5% error, but what's awesome is that all of these overlapping error bars are, in fact, overlapping, so when you put all of the pieces together, it looks like we're probably good to +/- three km/sec/megaparsec, which is kind of awesome.

Fraser: It's pretty amazing. Hubble would really appreciate that precision.

Pamela: Yes.

Fraser: Since he was probably off by a factor of 10, but...cool! Alright, cool! And so as you mentioned, next up we're going to talk about the cosmological constant, which is Einstein's biggest blunder. Way to go, Einstein.

Pamela: Blunder and discovery.

Fraser: Blunder and discovery. Well, thank you very much, Pamela.

Pamela: OK, I'll talk to you later.

Fraser: Talk to you next week. Bye.

Pamela: Bye-bye.