Astronomy Cast Episode 280 for Monday, November 12, 2012: The Cosmological 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! So we are actually recording a second episode on one day to catch up from all of your madcap travels.

Pamela: And we're actually getting ready to do madcap travel together in like two weeks, three weeks?

Fraser: Three weeks – yeah! We're going to be cruising the Mexican Riviera, looking for evidence of the world ending on December 21, 2012.

Pamela: We're going to be looking at really cool [missing audio] architecture.

Fraser: Mayan ruins.

Pamela: Yeah, yeah.

Fraser: It's going to be really fun.

Pamela: And we know a bunch of you who are going to be with us, and we are working on getting Zelda a list of you so we can contact you.

Fraser: Yeah, and we're going to try to do some…we're going to do some official stuff like recording some episodes of Astronomy Cast, and maybe we'll do a …we've got a couple of talks that we do, so maybe we'll do that.

Pamela: And there will be unofficial stuff like "office hours" in public spaces that include, like, junk food and stuff like that.

Fraser: Yeah. Going for dinner and hanging out…a lot of hanging out.

Pamela: Yeah.

Fraser: So this is going to be fun! I think this is going to be a really neat experiment to see if we can start to pull together fans of Astronomy Cast, and fans of space and astronomy in general and maybe do more events like this.

Pamela: I hope so.

Fraser: I would love to do something in Hawaii where we could actually, you know, pull some strings and see some observatories, and...wouldn't that be cool?

Pamela: Yeah!

Fraser: Yeah. Yeah…but anyway, so that's what's happening, so if you're going to be there, we'll see you soon, and if you're not going to be there, we'll see you the next time we do this.

Pamela: We're always on line.

Fraser: [laughing] We're always on line…yeah, and once again, we're recording this episode as a live Google plus hang-out, and if you want to be able to watch us record the episodes live, just circle Astronomy Cast page on Google plus, and then it will circle you back, and then you will start to receive notifications in your calendar when we're about to record, especially when we do non-standard ones, but normally we record every Monday at 12 noon Pacific time.

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Fraser: In order to allow for a static universe, Albert Einstein introduced the concept of the cosmological constant to make the math work out. Once it was discovered that the universe was actually expanding, he threw the number out calling it his "biggest blunder," but thanks to dark energy, the cosmological constant is back with a vengeance. Alright, Pamela this is another kind of half history/half math episode?

Pamela: Well, and it's also one of these there's history as it works out mathematically, and history as we explain it when we're too lazy to explain the math, and that's kind of a weird concept, but everyone starts just like you just started with the "Einstein created the cosmological constant to make the math work out," well, that's a great, hand-waving statement that says absolutely nothing.

Fraser: Right.

Pamela: And when you look at the math, if any of you schmoes out there have had the same educational system I have, you at some point took Calc. I, and learned to integrate and differentiate, and…I guess that's really Calc. II is where you integrate, and when you integrate an equation in Calculus, there's a constant -- and it can be anything! I, at one point, while frustrated and taking Calculus in Russian as one does as a foreign exchange student, I decided to just like start putting smiley faces. The cosmological constant is that constant that comes out of integration that you can set to whatever you want, and when Einstein originally set it, he was working from the philosophical premise, not the mathematical premise, the philosophical premise that our universe was static, and so he set it up to stay our universe.

Fraser: OK, so I guess when Einstein started to go down this road, what was the generally accepted thinking about what the universe was like?

Pamela: Well, we had two competing confusions. One was there was Olbers' paradox, which said when you look up, the sky is dark (kind of stating the obvious), but then the next step of Olber's paradox was stating, well, if our universe is infinite in both size and time, the sky shouldn't be dark because everywhere you look, your view will end in a star, but since the sky is dark, then the universe has to be finite in either time, or size, or both. So there was that – we knew that, but then there was also the idea that things are forever, and our universe is static, our universe is unchanging, and it was that philosophical notion that our universe is static and unchanging that led Einstein to think, well, when we look at the universe we shouldn't see it expanding, we shouldn't see it contracting, we should see it be.

Fraser: Right, but I guess one of the ideas, you know, once you start to understand gravity a little bit, you look out to this universe and wonder why all of these galaxies weren't, I guess, starting to clump together with gravity. Why was it…?

Pamela: But why should they? And you're also assuming that they knew what galaxies were at that point.

Fraser: Gravity… sucks?

Pamela: But the planets don't fall into the Sun.

Fraser: Right, because they're orbiting. The orbit, the orbital velocity is balancing out the gravity, right?

Pamela: The idea is if our universe is great enough, if our universe is expansive enough, this galaxy over here is pulling on this galaxy, but then there's a galaxy over here, and there's another one up here, and everything is able to swarm, everything is able to move so that the combined motions lead to no expansion and no contraction. That was the belief system, and you can get there mathematically.

Fraser: And so you might get situations where these galaxies are going to collide and sweep past one another and orbit one another, but they're all just doing their thing, buzzing around in this static universe.

Pamela: Yes, and that was the idea is it was a static universe.

Fraser: And so then the question was: was this static universe infinite, or was it finite?

Pamela: They knew somewhere along the line that it was finite, and I hate to say this, but it was the age where Christianity in many ways…when in doubt, resort to the Old Testament, and that works for all the great religions except for Hinduism actually, and so you got back to that whole Garden of Eden, there's a zero point in time from when the universe emerges, and that was enough to fix Olbers' paradox. So you could have a static universe, spatially infinite, finite in time…right.

Fraser: As long as it wasn't infinite in time. Right. OK. So you've got… it's ::snap:: boom! There's a universe, and as long as that…there's a certain amount of time for when that happened, then you're not going to get this situation where the sky is completely white because there's a star in every direction at some point. OK, great! So this is the universe as, I guess, you know, cosmologists understood it at that point, so then what changed everything?

Pamela: Well, basically observing. So it started off…and Einstein, he was the one that came up with the equations, he was the one that used that constant that comes out of integration to stay the universe, but there were other theorists like Lamontre

, who said that the universe could be expanding. And it was Hubble working, as we talked about in the last episode, to measure the velocities of galaxies as a function of distance to figure out our universe is expanding, and this introduced the astronomy that people our age learned in school, which is we live in an expanding universe that, depending on how much stuff is in that expanding universe, is either going to expand forever, is going to basically expand to a stop asymptotically, or crunch in on itself, and those were the only three options that we were given in our textbooks, but then in 1998 everything changed.

Fraser: Right, but let's go back a bit, though, because I think Einstein, I guess, learning Hubble's discovery that in fact we live in an expanding universe, he had to throw out…so I guess he had introduced the cosmological constant to support that static universe idea, so what was the role of that?

Pamela: Without the cosmological constant, you have a universe that is quite happily expanding. That's where the math goes naturally.

Fraser: Really?!

Pamela: But when you add in the cosmological constant, well, you can set that value to anything you want, so you can stop the universe, you can slow the universe, you can expand the universe...

Fraser: It could be a negative number and have the universe come back together again.

Pamela: Why not?

Fraser: Sure! I just did.

Pamela: The math doesn't care. This is where observing becomes so important. And so it was with the observations initially -- we had Vesto Slipher noting that more galaxies are moving away from us than moving toward us. Hubble then figured out using Cepheid variables that as a function is distance, objects appeared to be moving faster ("appeared" is the key word there), and this matches the idea of an expanding universe, and then it came down to trying to figure out, well, is the universe expanding due to the entire universe at one point was smaller, or is it expanding because new stuff is coming into the universe? So this is basically the question of: do we have a finite amount of stuff that started out smaller, or do we have an increasing amount of stuff over time? And we now know, thanks to observations, that it's that big Bang notion of finite amount of stuff getting spread out over greater amount of time as the universe expands.

Fraser: But I think that's a really interesting, funny anecdote that Einstein had done the math, and then had gotten to a conclusion, and his conclusion predicted an expanding universe, and then to constrain it to what was the…I guess, the philosophical expectation for what the universe should be like, he had to throw in a fudge, and then…

Pamela: It wasn't a fudge! It was a mathematically allowed constant!

Fraser: I understand. Right, but it wouldn't have even occurred to him if he had known the universe was expanding. The fact that he had done it, right, was to go, "Oh! The math predicts expansion, but we know it's not possible for there to be expansion; therefore, I'm going to do this thing that the math allows," but this is the point, but then the Hubble announcement comes out and he goes, you know, "Oops," and then calls it his "biggest blunder," which I think is quite an interesting…

Pamela: …overstatement.

Fraser: Well, after the fact, as he turns out to be right again, but during the time, I think it was a very humble thing for him to do. You don't get a lot of scientists who just kind of go, "Oh! My bad…totally wrong."

Pamela: Well, I'm pretty sure he didn't do it instantaneously, but yea, he was fully willing to say, "Observation says this, and I need to work," and he worked with so many other great minds in his time. There's this whole group of people who were working to define relativity and cosmology that made huge progress, and he was part of that international dialogue in letters and journal articles and conference proceedings that defined the shape of space and time. Now, the problem was that when they were done, they defined a variable system of "we don't know," but what was interesting is they only had those three options that we mentioned: the expand forever, expand to a stop, contract in…and they discussed how it was possible that we had multiple geometries of space, and there were certain assumptions made, and when I took cosmology, it was: you can change the geometry, but we're going to assume…we're going to assume certain things, and one of those things that we're going to assume is that the rate of expansion is either slowing, or stopping, or shrinking, but accelerating was not an option that we learned, and in fact the mathematics is much, much uglier when that becomes reality.

Fraser: Right so pre-1998, the future of the universe was either: the expansion would go on forever, that there was enough momentum for the expansion to overcome gravity, right?

Pamela: The way to look at it was there wasn't enough mass to stop the expansion.

Fraser: Right, and so either you were going to get this situation where it's going to keep on expanding and expanding forever, slowing the drift, but not enough for it to…you know, it's like shooting a rocket off the Earth. When you give it enough velocity, it's going to make it into space, and then this other idea is that it would just reach this perfect balance point, and you would almost end up with that static universe, right?

Pamela: In infinite time asymptotically, so it never quite stops; it just slows.

Fraser: Right, and then there was the idea: well, there's tons of mass -- way too much mass -- and you get to this point like a rubber band, and then snap back down together again .

Pamela: A big crunch…

Fraser: And where did most people feel that the evidence was taking them?

Pamela: Well, we really didn't have…it was opinion. I actually remember when I was grad student, one of our faculty inadvertently led to me having much strife with some of the students that were in both his class and my class, after teaching there are three ways for the universe to end, he wrote on an exam the question, "How do you believe the universe will end?" Never use the word believe, just avoid the word believe…and he wanted students, of course, to pick, to decide how did they -- if they were able to choose of these three options -- how did they want to see the universe to end? And of course, when you say the word "believe," you're going get people who believe something other than those three options, and are going to happily discuss it, so don't use that word in an exam, professors and teachers out there. But we just didn't know, so it was valid to say, "Here are three options, pick one to talk about that is your preferred method for scientifically ending our universe," and yeah, mathematically, the mathematics worked out best if you had a universe that was asymptotically stopping with a linear geometry, fewest variables to deal with, least crying involved in solving the equations, easiest to program into a computer, so let's go with that one.

Fraser: I like the math, so that's my choice. Yeah, math is easy. OK, so 1998, which is so recent.

Pamela: The year the math got harder…

Fraser: Yeah, which is just so recent – I mean, I started Universe Today one year after that discovery, so this is all so fresh in our history.

Pamela: And what's awesome is they have already given the Nobel Prize for this, so back in 1998, there were two different competing supernovae teams, and there's one type of supernovae, the type 1A -- these occur when a white dwarf star carnivorously munches too much atmosphere off a nearby neighbor star and bloats itself up until it basically becomes a nuclear bomb and it explodes. And just like you'd expect a certain amount TNT to always give off the same amount of energy when it blows up, the white dwarf, when it hits that detonation mass, it's always going to have the same amount of stuff exploding. So same amount of energy given off, assuming we understand all of the physics correctly – you have to start somewhere. And so since these are standard-sized explosions, when you see a type 1A go off, you can say, "I know how much light it gave off; I can see how bright it appears; I can calculate its distance." And so there were these two different supernovae teams that were working to measure supernovae to ever greater distances, trying just to measure the expansion rate of the universe. They were just trying to get at the Hubble constant, and they knew that there was the chance as they got to greater and greater distances, they'd be able to see the linear relationship between velocity and distance fall over, that they'd be able to see the deceleration of the slowing universe because…

Fraser: And they could calculate that, and then figure out is it going to expand forever or…

Pamela: …is it going to crunch?

Fraser: Crunch – yep.

Pamela: And at the same time, we were working on figuring out the microwave background, there was a lot of research going on. Well, both of these supernovae teams observed and went to publication at similar points in time. They both observed that the universe isn't actually slowing as we anticipated, that the amount of expansion going on per megaparsec isn't shrinking as we get to nearer times, but rather it's growing, and the…Holy expletive-of-your-choice, Batman! The universe is accelerating itself apart! This was not something any of us had been taught to…

Fraser: "D. None of the above."

Pamela: It was a mathematical reality the equations allowed this to happen, but nothing…we weren't prepared. This was not an option of anyone's choice, and I remember seeing Chris Impey giving a talk at the AAS and he basically said, "Who ordered this? This makes the math harder. This isn't something anyone would have chosen!" And it's an example of how, if you do good science, and if you have solid observational results with sufficiently low error bars, and in this case, we had two competing teams with matching results, if you do your science well enough and you present your results concisely and clearly, everyone will follow you down a road of mathematical Hell no one wants to go down because that's the reality of our universe.

Fraser: Yeah. Reality bites. So, right… so what does the cosmological constant look like today? Now, I know astronomers refer to it as "lambda," right?

Pamela: Yeah, that's just the value that Einstein threw into the equation when he did his integration. You need a letter, lambda was a good one, he picked capital lambda, we use capital lambda today…

Fraser: What does lambda look like? It's like a little upside down "V," isn't it, kind of?

Pamela: Yeah, it's the letter that they use as an "A" in The Stargate.

Fraser: [laughing] I was totally thinking about Stargate actually! You're right! So it's the A in Startgate. Perfect.

Pamela: Without the circle.

Fraser: Without the circle in it at the top, upside down "V" – lambda. And so the math is complicated, right? So what do you have to do with lambda now?

Pamela: Well, it just basically adds extra terms to all your calculations. So every time you add extra terms, if you've ever had to solve quadratic equations, yeah, you can do it, it's harder to solve a quadratic equation than it is to solve x+3=9, so it's still doable, it just takes longer, there's more chewing required to process your equations, it makes it harder to code everything into a computer, so mostly it's just we're all at our heart of hearts lazy. We can solve it, but it just added extra terms to all of the equations.

Fraser: And is there sort of number, like what is the…in the last episode we talked about the Hubble constant, and we sort of zeroed in on 77-ish km/second/megaparsec, so is there a similar number, and what is that measuring?

Pamela: So this one gets nastier. We don't actually normally quote lambda as a stand-alone value. Yeah, you can chew through the equations and get to a value of lambda. Lambda=0 is no cosmological constant, but the rest of the time, we tend to talk about lambda in terms of the mass/density of the universe, we tend to talk about it in terms of what is the energy intrinsic in every cubic meter of space because it's that physical parameter of, well, how much energy is there in a cubic meter of space? It's that physical…

Fraser: How much energy is there…?

Pamela: It's actually a couple protons' worth. It's not much, but that small amount of energy -- some people call it vacuum pressure, some people refer to it as a force -- it's enough to push apart the universe because every cubic meter has that same energy density, and the creepy part that leaves a lot of us going, "We don't like this," is as the universe is expanded, that amount of vacuum energy per cubic meter has stayed constant, so this means that the amount of energy in the universe is actually not constant over the observable universe. So yeah, this sort of breaks the whole when you look at conservation of energy over closed systems, but it's not a closed system. It's an observable system, and that causes an escape clause for some people, especially those who'd like to think we're uniquely positioned in the center of a big bubble of mass that is lots more mass out there than in here, and thus that extra, but that requires special geometries. It's all confusing. People are coming up with excuses for what we observe, but the reality is we don't know. This is the great new mystery.

Fraser: Right, but I guess the point…what they're getting at is the amount of pressure that's being generated per…

Pamela: Force.

Fraser: Cubic something megaparsec/meter squared…

Pamela: Yeah…there's so many different ways to phrase this. Some people look at it as a force, some people look at it as a pressure, some people look at it as an energy density, but what it all gets down to is when you look at the composition of our universe, there's the normal stuff -- the baryonic matter, which is everything we see via light basically, and that's 4.6% in the universe, then there's all that weird non-baryonic stuff that we call dark matter.   This is the stuff that causes the outskirts of galaxies to move faster than anticipated, that causes the velocities of galaxies in clusters to be greater than anticipated. That's 23% of our universe. Now, that's only a small fraction when you add up all of that matter – the barionic and non-baryonic matter, and everything else -- that's the dark matter, that's…

Fraser: The dark energy.

Pamela: Yeah, dark energy – sorry. That's the dark energy, that's the 72% of our universe that is pushing everything apart, and that push is, well, it's the acceleration, and it manifests itself as an acceleration.

Fraser: And so…right. As we're getting more universe, we're getting more of this acceleration, but I mean, we measure acceleration in what? Meters squared, right? Meters per second squared?

Pamela: Meters per second squared.

Fraser: So do we measure this dark energy in kind of the same way?

Pamela: So the way to look at it is with the Hubble constant, we have km/sec /megaparsec of space, so take a megaparsec and then you have the rate at which that megaparsec is getting bigger, given in km/sec. The acceleration of that is given in km/second/second, and that number changes over time as dark energy becomes more and more important, as the stuff gets spread out, and gravity… we switch from being a matter-dominated universe to being a dark energy-dominated universe, and the crazy thing is this value could also be increasing. We don't know.

Fraser: Well, that's the question, right? That's the really interesting possible ramification of this. This is one of the big unknowns is: is this amount of acceleration constant, or is it increasing? Because if it's increasing, then we get this idea of the big rip.

Pamela: Well, we have the big rip anyway; it just becomes more dramatic. It's a matter of: do you poke through the universe, or do you just simply abruptly shred it?

Fraser: In the distant future, we'll get into a situation where the acceleration is so strong, where galaxies are starting to get torn apart, and then solar system are getting torn apart, and then planets are getting torn apart.

Pamela: I think everyone thinks that everything is going to evaporate and be consumed before that happens, and we're basically going to have proton decay, hopefully – we're still working on proving proton decay, but the universe will simply decay away before anything starts getting shredded, so no one being terrified of this, no scare.

Fraser: Yeah, trillions of years in the future, but isn't there a dark matter spacecraft that's really trying to really hone in on the…? Or sorry, dark energy.

Pamela: I don't think we've launched yet. There are plans in the decadal survey, here in the United States, lists as a priority building a mission to try and understand dark energy. The question is: how? So this is where you get a lot of people struggling with trying to figure out how exactly do we understand this beyond looking to earlier moments in the universe and making sure as we measure the expansion rates in those early days. Well, do those expansion rates correspond with the constant lambda value? Do they correspond to there always being that same couple of protons of energy per cubic meter of space?

Fraser: Cool. Alright, well, I think we've covered the cosmological constant so thank you very much, Pamela. That was great!

Pamela: My pleasure.

Fraser: Alright, we'll talk to you next time.

Pamela: Talk to you later.