Astronomy Cast Episode 11:
A Universe of Dark Energy

Fraser Cain: So last Thursday NASA announced new research from the Hubble Space Telescope. According to astronomers, dark energy has been with us here in the universe as far back as nine billion years ago. So this week we're going to try and explain about dark energy, because we got so many questions about it, what it is, and where it started. So, Pamela, you're not going to like this, but it's going to be another show where I'm going, "what is this?"

Dr. Pamela Gay: and it's going to be another show where I'm going, "We're not quite sure."

Fraser: Alright, well, what do we know?

Pamela: What we do know is that when you look out at the universe you find that there's gravity trying to pull things together but there's this other mystery force, this mystery energy, this dark energy, that is causing things to actually go apart from one another. So we have gravity pulling things together and we have this dark energy pushing things apart, and we're not entirely sure what it is.

Fraser: Ok, so how was it discovered then?

Pamela: Well, back in 1998 there were two teams looking to find high red shift supernovae, this was the supernova cosmology project led by Saul Perlmutter and the high red shift supernova search team led by Brian P. Schmidt, and these two teams were trying to find out what the Hubble constant is at large distances.

Fraser: what's the Hubble constant?

Pamela: The Hubble constant is an expression of how gravity is changing the rate at which our universe is expanding. So right now the galaxies that are nearest to us that aren't gravitationally bound to us are moving away from us at a rate of about 70km per second per megaparsec of distance between us and them. And that number changes as we go back to earlier and earlier times in the universe. These two teams were trying to measure the rate at which the universe is expanding at different periods by using supernova as trace particles floating in the expanding universe, and they can measure how fast they're moving, and assume that the rest of space is moving at the same rate.

Fraser: this kind of goes back to our show last week, where we talked about how to measure distance in the universe because if you can get a really good fix on the Hubble constant, then you can have a really nice yardstick for how fast various galaxies are moving away from us, to get a sense of their distance, right?

Pamela: That's exactly what's going on, and what they expected to find was that gravity was slowing down the expansion rate of the universe, and they didn't. What they found was that there's something that was causing the universe to increase in the rate at which it's flying apart.

Fraser: I want to dig into a little more detail here. So they were looking at these supernova and getting a sense of what their distance was and they were finding that the actual distance at which they were seeing the supernova at was now that they were expecting?

Pamela: What they were finding was that the distance related to how fast they were moving wasn't what they were expecting. Basically, if you think that the expansion rate of the universe is slowing down then when you look back at things you tend to see a certain relationship between recession rates and the distance of an object where the recession rate in the past would be a higher number than if this were a constant acceleration. Now if, instead, you find that the supernova are going slower than you expected at a given distance, that means that somehow we are accelerating ourselves apart.

It's one of these things where you expect supernova at a certain distance to be going a certain speed if the expansion rate stays constant. If the expansion rate is slowing down over time, you expect them to have a different speed. If the expansion rate is speeding up you expect to look back and see yet a third speed. So they're doing all kinds of complicated math that explains how the expansion rate is changing with what distance what object should be at if it has a given speed. And they had a certain set of expectations, just like the rabbit going through the rabbit hole with Alice following and everything got turned on its head, it wasn't quite what anyone was expecting.

They found that the universe is accelerating itself apart and this was a completely revolutionary idea, and the fact that two teams, working in competition with each other, both had the same head scratching got the entire astronomical community to look up and go, "oh! This is new. We need to pay attention to this. This is exciting." It also meant that the way we looked at the universe had to suddenly be changed, because things that we'd been setting to 0 for a long time or setting to negative values for a long time had to change to incorporate these results, all of our the universe had to suddenly account for a completely unexpected observation.

Fraser: in the past, astronomers thought that after the big bang there was a certain amount of velocity, a certain amount of gravity, and maybe the universe would coast to a stop, maybe it would collapse back in on itself in a big crunch, or if it had enough outward velocity it would continue expanding, slowly coasting but never quite stopping. But, no, it's like somebody turned on the accelerator, and is speeding up the expansion.

Pamela: Imagine that you start pushing a car up a hill and you let go of it and instead of rolling back over you, it decides to accelerate up the hill. It's just not what anybody expected to see and it's what we saw. Our universe which we thought was basically expanding up a hill and slowing down was instead accelerating up the hill.

Fraser: now, even though it was discovered in 1998, that's not the first time people had been thinking about this, right?

Pamela: No, this was the first time we had solid, observational evidence, but as far back as when Einstein first came up with this theory of relativity people have been looking at ways that the universe might be accelerating apart. For Einstein it was a matter of his world view told him that the universe was a stationary place where the galaxies were held in place forever. And when he looked at his theories it showed that gravity was causing them to move, and either the universe was accelerating apart or collapsing together depending on the amount of mass and that didn't fit his world view.

But there are different times in mathematics where you're allowed to just add a constant and it's completely mathematically legal. And he looked at his math and it was legal for him to add a constant, so he did and what he said was there's this cosmological constant that acts in opposition to gravity so while gravity is trying to collapse things in it is working to push things apart and thus the universe was held in perfect equilibrium. But it wasn't a stable equilibrium, as a rather uncomfortable way for the universe to be. It's sort of like it's one thing to be hanging from a rope underneath a swing, where your rope is actually a piece of solid metal steel, now imagine instead that you flip yourself up and your balanced on the end of this solid metal swing, exactly above the bar of the swing, and you might be stable there but if you sneeze you're going to cascade off that point of equilibrium. He had the universe held in that unstable state between his cosmological constant and gravity and it just wasn’t' a comfortable place to be.

Fraser: he later called it his greatest mistake

Pamela: a few years later, Hubble, working out in California, discovered that galaxies are all moving apart from us once you get past those that are gravitationally bound to us. The only way you have them all receding is if you have an expanding universe and when those results came out Einstein basically took back his cosmological constant. But once you put an idea out there, theorists love to chase ideas, and so there were theorists who were trying to figure out what if there is a constant, and it's just small so we don't see it affecting locally the expansion rate of the universe.

What if it is out there, what if there's some sort of a field, what if there's some sort of a vacuum energy, and these different possibilities were kicked around and people came up with beautiful theories for how, in a vacuum, any energy in it can condense into particle and anti particle that exist for a moment and then annihilate one another and there's this constant boil in space of particle and antiparticles forming and destroying one another and the energy of this entire vacuum particles annihilating one another and coming to existence is a background energy that works in opposition to gravity.

Matter and energy are just two forms of the exact same thing so just as you can say gravitational mass draws things together, you can say that the gravitational effects of energy can draw things together or push them apart depending on the sign of the energy, it just works out that the energy has a negative pressure, the energy is working to push things apart.

Fraser: Hasn't this been detected in the laboratory?

Pamela: it's kind of hard to detect. Basically we're looking for the energy of thirty proton masses per cubic meter. You need to be looking in really big chunks of space to see the effects of vacuum energy. There are people out there who claim they've detected dark energy in the laboratory, I'm not sure I buy it, I'm not sure I'm also qualified to buy it or not buy it, but it's not the same, hit you on the head sledgehammer results that you get when you look at the universe as a whole.

Fraser: you've already beat to my question, which is what is it? So, the first concept of what could possibly be accelerating the universe like this is this thought of this vacuum energy bubbling up in everything square meter or cubic meter of space in the entire universe and more and more energy is kind of pouring out of this, but how does that expand the size of the universe?

Pamela: This energy has a repulsive characteristic, it has what's called a negative pressure and it's working to push things apart, well our universe is expanding. The more the universe expands, the more space there is for this vacuum energy to bubble. The more space we have for this vacuum energy to bubble, the more repulsive force it's able to put out. So it's sort of like the bigger space gets the more vacuum energy we have, the more the universe is pushing itself apart. IF there's more of it than there actually is, then our universe would have actually torn itself apart in the first moments. Atoms wouldn't have had a chance to form, everything would have been completely shredded, but luckily it's a small thing. It makes up seventy percent of our universe, but the amount of mass energy contained in the vacuum energy is small enough that our universe was allowed to form and exist and expand without shredding itself.

Fraser: so what are the other theories for what this could be

Pamela: There are other theories, one of them is something called quintessence, which is basically field theory that says that there's a very light field that tracks through all of space and the way the field works is that it's causing things to expand. It's not a thing that currently has a lot of proponents, current observations are leading people think more in terms of vacuum energy, but we don't have concrete results. One of the problems with vacuum energy is that the theorists working on it are having trouble getting their numbers and theories to match what we observe, and it's a big problem.

Fraser: it probably shares the same problem with dark matter that it all just depends on us understanding gravity

Pamela: it's even more subtle than that. It depends on us understanding the particle world. It requires us to know what's out there, what energies different particles that we haven't even discovered necessarily have.

Fraser: Sure, but I mean, we're calculating the distance or the amount of gravity that objects of large scales should be affecting on one another, and if we don't understand gravity at those long distances…

Pamela: That is part of it, there are a group of people who believe that dark energy is just a matter of not knowing how gravity works at really large scales, but with the vacuum energy we also have to understand the entire subatomic world, but there are still subatomic particles we're discovering. There's a new boson type particle and that's too much detail, but there's a new particle discovered just last week and depending on what particles you put into your calculations, you can get results that say that the universe should have dark energy that acts ten to the a hundred and twenty times more than it does. That's a lot.

Fraser: so it's almost like we're going to find out more about dark energy with some of the new supercolliders than we will looking at it with out telescopes.

Pamela: With our telescopes we're able to say, "ok, so we know that there was dark energy at five billion years ago, and at that point it started to dominate." We start to have the effects of the acceleration being more powerful than the effects of the deceleration from gravity. Now with the new results we can look all the way back to nine billion years ago and our universe is only thirteen point seven years old so we can look way back into the early childhood of our universe and say nine billion years ago it was there and it was effecting things, it just wasn't a dominate player in how our universe was expanding at that point.

Fraser: what is this hold for the future of our universe?

Pamela: well, it means that we're just going to keep expanding forever. It means that eventually our universe is going to die, basically, an energy death.

Fraser: So if it just keeps expanding forever, right now we can see all these other galaxies. Will there be a point where we just can't see any other galaxies?

Pamela: Here the catch is that the longer the universe is around the more light years we can see things but the light that's being generated by the other galaxies is going to cease to be. Over time all the stars are going to die, we're going to left with black holes with neutron stars that start out hot enough that just by being hot they're going to be giving off light. We're going to have white dwarf stars that start off just by being hot, they give off light. But over time they're going to cool off and stop giving off light. Over time we're just going to have a universe that's basically consisted of dead chunks of former stars, galaxies.

Fraser: accelerating apart from each other.

Pamela: it's a kind of bleak future

Fraser: until some new great discovery

Pamela: until we figure out how to change the physics of the universe using a giant computer. But that's the story of Isaac Asimov, and it's hard to figure out how to do that when most of the time I can't even get my computer to stay stable for more than three months/

Fraser: What are people doing now and what's next?

Pamela: There's three different directions. There's the let's keep measuring supernovas as far back as we can. The more data we have the more constraints we can put on the theorists. There are a variety of different ways people are planning to map out the universe. They are all point of the joint dark energy mission that is part of NASA's beyond Einstein program and is supported by the US Department of Energy. They're looking for ways to map out supernova at higher and higher red shifts at larger and larger distances.

Some of the programs that they're looking at are the advanced dark energy physics project led by Charles Bennett at Johns Hopkins University. There's Destiny, the dark energy space telescope led by Todd Lauer at the National Optical Astronomy Observatory in Tucson. Again, it's going to be looking at type 1a supernova like we talked about last week, and then there's the supernova acceleration probe which is led by Saul Permutter one of the people from the original 1998 discoveries. He's out at Lawrence Berkeley National Laboratory, and again, that's another program to look at supernovae.

So by finding supernovae at larger and larger distances we can map how the universe's expansion rate has been changing over large chunks of the history of the universe. By carefully seeing how the different values play against each other, we can first of all say, "ok, so, have the dark energy characteristics changed pretty constant as a function of volume?"

Fraser: what do you mean, "has it changed?"

Pamela: Right now, if you look at what we think is vacuum energy, you find that there's the equivalent of thirty proton masses of energy per cubic meter. What if, in the past, it was only ten proton masses of energy? What if it was instead a hundred proton masses? We know that's probably not true, but different amounts of vacuum energy in a different volume would imply different physics are at play.

We need to figure out if this is just boiling virtual particles, is this something else, and figuring out exactly what is going on means we need to be able to trace the expansion. Think of it this way. I'm going to keep returning to this raisin bread analogy, you take a thing of raisin bread, throw it on your counter. If your room stays the exact same temperature and moisture, the entire time the bread is rising the yeast will behave in a consistent manner and cause the bread to expand in a consistent way.

But what if part way through the rising of the loaf of bread your heat goes out and the room plunges down to zero degrees Celsius for some reason. Your bread will stop rising. What if a plague blighted the yeast halfway through. It will also affect how it rises. We don't know what factors in the early universe might have effected how dark energy was working to push apart the universe/

Fraser: if the amount of this dark energy in each meter of space was actually increasing, then that could have a dramatically different effect on the future universe, and maybe the physics at play.

Pamela: imagine if at the beginning of the universe there was no dark energy and we're slowing getting more and more dark energy over time.

Fraser: as well as more space.

Pamela: That's two different things that are working to accelerate the universe apart. That can have rather dire consequences on our future. In the future could shred itself apart. We don't see evidence for that right now.

Fraser: you could get so far that the amount of energy was so strong that it was pushing galaxies apart, and even be able to push planets apart from the stars and able to push atoms apart.

Pamela: in the most extreme circumstances my desk could just tear itself apart.

Fraser: that's what they call the big rip

Pamela: yeah. We see no evidence for that, but it's still kind of neat to think about.

Fraser: what is the latest evidence form Hubble tell us?

Pamela: It tells us that dark energy didn't just mysteriously appear. Over time how gravity and dark energy have interplayed has changed. It's sort of like if you start a game of tug o' war, and initially everyone's pulling as hard as they can and the rope is holding on structurally it's ok, but as the people get more and more tired, they're pulling less and imagine it's an elastic rope it might be able to start pulling the people together as they get more and more tired. With the inter-play of gravity and dark energy, it works in the opposite direction.

As objects move further and further apart, gravity doesn't get more tired, but it does get more weak. Gravitational force is inversely proportional to the square of the distance, which means if we took the moon and moved it twice as far away, the gravitational force between the earth and the moon would be four times less. Now, as the gravity gets less and less effective at holding things together, the dark energy which was always there in the background, is able to exert more of a force on the stuff around it. It's force suddenly matters more.

With our elastic rope, it was always elastic, but you couldn't notice as much when people were pulling really hard. As the gravity gets less effective, the dark energy is able to overcome the gravity and start pushing things apart. That point at which dark energy was able to start pushing things apart occurred about five billion years ago, and it started to dominate then. But if you looked further back in time, we know that mass, that gravity, dominated.

Now we know that even though gravity dominated the dark energy was still there, it was still having an effect, it was just a small effect that it took a lot of results to be able to find. The new results rely on twenty three different distant supernovae. IT doesn't sound like a lot, but these things are hard to find. They're some of the faintest things that we're regularly searching out. We're looking for a little faint, firefly flare up in a distant galaxy, and it's impressive that they were able to find and carefully measure twenty three different supernovae and get these results.

Fraser: I think they also have a better handle on the amount of dark energy per meter doesn't seem to be changing over time.

Pamela: it seems to be holding constant right around thirty proton masses of energy per cubic meter.

Fraser: and hopefully with this next series of spacecraft and further research they're be able to tighten those constraints and more experiments with the supercolliders will help us understand what kinds of particles could be interacting with each other.

Pamela: the better the math, the better you can get from point A to point B. Our way of getting from point A to point B is by building a theory.

Fraser: I guess we have no answer for people this week, but I guess they can understand what people are talking about when they talk about dark energy. This is one of those great subjects that we're going to be able to watch it change in real time, and maybe within our life time we'll see the answer and know what it is.

Pamela: it's certainly a possibility with all these neat new missions going up in space. We may even find a more effective way than using supernovae. Like we said last week, there are people chasing gamma ray bursts, and maybe that will work, and maybe we'll be able to see back into the beginnings of time.

This transcript is not an exact match to the audio file. It has been edited for clarity.
Transcription and editing by Angela Coate.