## Astronomy Cast Episode 179
# Mysteries of the Universe, Part 2

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**Fraser:** Astronomy Cast Episode 179 for Monday March 1, 2010, Mysteries of the Universe, Part 2. 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's it going?
**Pamela:** It's going well. How are you doing, Fraser?
**Fraser:** Good! It's actually exactly the same as I was for the last show because we're recording 5 minutes after we finished recording the previous show, so whatever answers I gave you last time--they still stand. All right... so today we tackle more thrilling mysteries of the universe. And by tackle, we mean acknowledge their puzzling existence. Some mysteries will be solved shortly, others will likely trouble astronomers for centuries to come. Join us for part two. Alright, so this time we're going to focus on some massive problems--galaxies. We talked about the Milky Way, but now we're going to talk in general about some galaxies and their formation. So here's the first question--do galaxies form bottom-up or top-down? You threw that question into the mix, so I have no idea what you're talking about. So what is your question?
**Pamela:** So there's two basic ideas on how galaxies originate. One is you take giant clump of gas and dust and other material and let it collapse and you end up forming giant galaxy. The other is you take small spud... form small gas cloud... take another small spud... form small gas cloud... start throwing these things together... they merge... form something slightly bigger. Throw something else in there... it merges... gets slightly bigger. So the idea is either you have galaxies form all at once from the collapse of a giant cloud of gas, dust, and stuff, or you have bunches of little tiny things that collapse out gravitationally, and then together build bigger and bigger objects.
**Fraser:** Can I take a stab at it?
**Pamela:** Yeah!
**Fraser:** I think bottom up... let me tell you why. When you get really big spiral galaxies colliding together, they're coming at bizarre angles and you get these great big elliptical galaxies. So, if you collide two beautiful spirals together, you get a mush. And so if all the little galaxies were coming together, you would just get mush on top of mush on top of mush. So you would end up with just elliptical galaxies everywhere you looked. A spiral galaxy seems to indicate that one big gas cloud is all just coming together and turning into a spiral. That's my theory.
**Pamela:** Now you'd think that. And there's a lot of great papers out there saying that, but then when we look out there we can actually start to figure out how you make spiral galaxies. So, we can do both... and this is the problem.
**Fraser:** 'Course somebody would have thought of that, Fraser... duh.
**Pamela:** Yeah, yeah...
**Fraser:** Right. So you're saying that...
**Pamela:** You throw things together just right, and you get a disk. Now we're still trying to figure out where the heck spiral arms come from. These spiral density wave things are

kind of crazy. But they work! And they generate spiral arms... we just don't know where they come from. So, we know how to make disks... you just throw things together like pizza pie and spin them and they flatten nicely.
**Fraser:** Right, like a solar system... like the way our solar system formed from one gas cloud.
**Pamela:** Well, you can also do it by throwing things together... small clumps...
**Fraser:** Right. But it has to be small clumps that all came in on a common center of rotation, right?
**Pamela:** Well, it depends on the rate at which they come in. Things can get absorbed in. Things can shake themselves out and end up flattening the disk. This is where you have spirals that have warped structure but only for a little while. They ate something that was a little too big and it shook them up. But, over time they flatten themselves back out.
**Fraser:** Ok, so then the thinking then is you take a galaxy, and as long as it has enough time to spin, it's going to spin itself back into a nice roughly circular shape. It would be like me spinning a pizza pie--the crust--in the air, then adding a few more globs of dough to it and then giving it enough spins that it flattens itself back out again.
**Pamela:** As long as you don't hit it too hard... now you take that nice pretty disk and you hit it at a right angle with something else that's huge... and it's just going to get obliterated into nothing.
**Fraser:** And that's when you get your big elliptical galaxy.
**Pamela:** Exactly. So, we think in the modern universe... think... don't know for certain... think... this is why it's a mystery... that most galaxies are probably formed by little spuds coming together and building bigger and bigger things. But the problem is, as we look back at the early universe... we still find giant galaxies. And these giant galaxies haven't had time to form by little things coming together. So we think in the early universe, when you did have giant clumps of stuff floating around in these occasionally anomalously large over-densities, we think that occasionally you were able to have these giant collapsing clouds that formed all at once a giant elliptical galaxy.
**Fraser:** So is it option C... both?
**Pamela:** Yeah, that's what we think. But we don't know for certain! But this is the type of thing that we should be able to answer in the next few years, and hopefully we're going to be able to get a good handle on it with the James Webb Space Telescope.
**Fraser:** Right. And this is the telescope that's going to be looking at infrared, and so it's going to be able to see the earliest moments of the universe when visible light is red-shifted out to the infrared, and it should be able to see those either giant galaxies forming all at once or those smaller galaxies coming together. So would you be almost least-surprised to see it be both? To see big galaxies forming and small galaxies coming together?
**Pamela:** I'm aiming for both.
**Fraser:** You're aiming for both... huh...
**Pamela:** Because "both" gives you this one concept of giant cloud, where giant cloud has varying degrees of giantness, collapses to form something. Sometimes those somethings are really tiny and those tiny things merge to get bigger and bigger. But occasionally, you end up with giant elliptical galaxy all at once. And that's kinda cool.
**Fraser:** Yeah... I like that. Ok, well then let's move on to our next question then... now that we've solved that one. So which came first... super-massive black holes or their

galaxies? We now know that every galaxy pretty much has a super-massive black hole lurking at its heart and that the mass of that super-massive black hole seems to have some relation to the mass of the galaxy. Big galaxies have massive black holes, and small galaxies have less-massive black holes. So the question is do we get a super-massive black hole and then it's able to attract enough galaxy around it, or when you get a galaxy is it forming a super-massive black hole that's to scale at the center?
**Pamela:** And this is one of those things that we're still sorting out. As we look around, it's not just the size of the galaxy that the black hole is related to, but very specifically the size of the bulge of the galaxy. So in a spiral galaxy this is that round basketball that seems embedded in the center of the galaxy. In giant ellipticals, it's just the whole giant elliptical. And consistently, whether the super-massive black hole is millions of times the mass of the sun or billions of times the mass of the sun, consistently it's about 1/1000 of the size of that bulge in mass. And as we look further and further back in time, we eventually start to hit the point where the galaxies hadn't quite formed yet. And this is where it gets interesting, because the super-massive black hole had to come from somewhere. It had to eat something to get big, and...
**Fraser:** It had to accrete, right, it had to form star after star, gas after gas to get bigger and bigger and bigger.
**Pamela:** Right. The way we know things formed in the early universe is that you started with dark matter, and then the regular matter flowed into the dark matter, and what it's looking like is maybe... but we don't know if this was always true because we're working with an observational sample that you can count on one hand... but it's looking like maybe the black holes formed first, but what did they form out of... is it simply that you had all the material in one of these dark matter halos collapse down to form a super-massive black hole or is it just the ones we found so far are the naked ones, and as we keep looking we're going to find ones that are completely surrounded by material. We're just not sure.
**Fraser:** So then to give evidence one way or another... what would we be looking for? Would we be looking for a large galaxy that seems to have no super-massive black hole in it?
**Pamela:** Well, what we need to do is keep looking back and back and back until we find the smallest critters can be defined as a galaxy. And look to see do they still have this ratio of 1/1000 for the black hole to the galaxy mass. At the point that that ratio breaks down we should be able to say "Ah more mass, mass must have come first and mass collapsed into black hole, or ah, more black holes black holes must have formed first."
**Fraser:** So, it's that ratio... that ratio holds true in every galaxy we see around us right now... we just keep looking further and further back in time, further away, until we see it push off that ratio, one way or the other.
**Pamela:** And we need to consistently see with a sample size bigger than you and I can count on our combined fingers and toes.
**Fraser:** Right, because right now all we've got is gravitational lensing, these...
**Pamela:** There's a few examples where we're looking in the radio... but they're rare.
**Fraser:** Right. But once again, James Webb coming to our rescue should help us solve this one.
**Pamela:** Exactly.
**Fraser:** So, do you think this is another one that we should nail within... the next decade?

**Pamela:** I do, I do... I think this another one that James Webb is gonna... I think this one is a combination of James Webb and the Atacama microwave millimeter... ALMA I think it's going to solve that problem for us... Large Array.
**Fraser:** Right, and if you had to take a poll... I know this is pointless, but where would you come down?
**Pamela:** I'm going to.... oh God, I would give you a different answer on a different day of the week. I don't know. Based on the fact that I've been eating gummy bears I'm going to say black holes first.
**Fraser:** Ok. And is it possible that it's both? That the black hole formed as the galaxy formed around it in perfect lockstep?
**Pamela:** I actually wouldn't be surprised if it's some combination of the amount of dark matter versus regular matter in a specific over-density affects which happens.
**Fraser:** Right.
**Pamela:** And I don't know how those two play out.
**Fraser:** Ok. Alright, well let's move on to the next question. So, your next question, and this is another one that you threw into the mix which is where are the green galaxies? Should there be green galaxies? Because I thought that there really shouldn't/couldn't be green stars. Because it's the way the photons add up... with a star you're not going to get green. But would you get a green galaxy?
**Pamela:** This is a matter of green by eye versus green on paper. There aren't green stars by eye, but if you look at the color of stars on paper, mathematically, what is the wavelength of the peak color of light coming out of the telescope... green stars are out there. We just don't perceive them as green.
**Fraser:** Because we're seeing... even if they're mostly green... we're seeing enough on both sides of green that it looks some other color.
**Pamela:** Yeah, we see them as white, which is kind of annoying.
**Fraser:** They seem white to us...
**Pamela:** Yeah it's boring... Now the problem is on paper, you take galaxies and you do a plot of color versus luminosities and you get this beautiful red cluster... beautiful distribution of red galaxies. All the galaxies with dead stars... mostly ellipticals, not all... there are a very, very tiny rare, rare fraction of ellipticals that are blue... just to be surprising and odd. But, nice, beautiful red branch of galaxies. Then you have this cluster of blue galaxies in the same diagram...
**Fraser:** Right. With their furious star formation...
**Pamela:** Right. And some of them have less star formation than others... no big deal. So in this beautiful diagram, you can pretty much draw a line through the valley of green, where there aren't any.
**Fraser:** And yet these pretty charts predict them.
**Pamela:** Well, that's the thing... they're not really predicted. There's just no real reason that they shouldn't exist. What looks likes is happening is you have galaxies with lots of nice happy star formation.... star formation... star formation... blue galaxy... happy blue galaxy making stars. Then you have galaxies--no star formation. Red stars everywhere. But that intermediate that would give you this nice mix--it leads to green. There's a few examples in there, but mostly you just have this valley of nothing. So, for whatever reason, across all the different types of galaxies that are out there, star formation has this

tendency to just shut off abruptly. And when it shuts off, it's that abrupt shut off that leads to this valley of green.
**Fraser:** And it goes red...
**Pamela:** It goes red.
**Fraser:** It goes blue to red and it doesn't have.... and so I guess if we saw green, we would see sort of a slow turn-off of the star formation. We would see a mixture of star-forming and not-star-forming, and then we'd get that in-between stage, but we don't see that... it's as you said, it's a party, and then the party's over.
**Pamela:** Yes.
**Fraser:** Yeah. Hmmm. As opposed to something that's sort of in-between. Are there any examples at all? Or not?
**Pamela:** The valley of green isn't completely empty. But it is still this deep, deep valley in the color-magnitude diagram of galaxies.
**Fraser:** And so is there any reason? What do you think?
**Pamela:** Well looking at the things that trigger star formation and end star formation, we have... Quasars have the ability to strangle galaxies. First giving off so much light pressure that they clear out the region around them while at the same time hungrily eating at the beginning. That has some effects on star formation. We have galaxy collisions can cause rapid-fire star formation that eats up all remaining gas and dust in spiral galaxies, and when it's over, it's over.
**Fraser:** So, we have a lot of mechanisms that make star formation start...
**Pamela:** And, if you have a system that hasn't had one of these traumas... star formation is just going to keep going par normal. What we don't have is a mechanism that seems to allow a galaxy to just casually peter itself out... instead they like to die by collision, die by harassment, die by ram pressure stripping, which is just the dirtiest phrase a galactic astronomer ever came up with.
**Fraser:** So is there some mechanism then that turns off star formation as abruptly and violently as it's begun?
**Pamela:** It just... well in all these occasions where you end up with rapid violent star formation, that rapid violent star formation burns through all the gas and dust quickly or blows it out of the system, and it's usually a combination of the two. What we're missing is the opportunity for a nice normal galaxy like our own Milky Way galaxy to simply peter itself out. To simply slowly and aging with grace, run out of star formation. And so instead what we end up with is happy blue spiral, spiral that has had a hard life and turned red, violently blue spiral that is in the process of being destroyed, and nothing really in between.
**Fraser:** Well, let's move on then. Our next simple question is what is dark matter? And this is a good one because I think we're getting some pretty tantalizing evidence. Last show we talked about dark energy and you gave it a 50-50 chance that we'd figure it out in our lifetime. But dark matter... dark matter is getting close. Set the background, then, on what dark matter is or what we know... another place-holder name obviously.
**Pamela:** It started out as a place-holder name... it started out as the way we refer to whatever stuff it was that was causing galaxies to rotate as though they had a lot more mass than we could find with radio and optical and other forms of light telescopes. It was the word we gave for whatever it was that caused the galaxies in clusters to orbit one another too rapidly. All of these places as we look around the universe we see things

moving and acting as though there's substantially more mass than what we can see. That unseen mass we call dark matter.
**Fraser:** Right, and there were two theories, right? There was that there was a particle that didn't give off any kind of electromagnetic radiation...
**Pamela:** Or particles...
**Fraser:** Or particles, yeah, a collection of particles... a zoo of particles... but yet they could still influence one another and regular matter through gravity. The other theory being a modification of changing gravity as we know it... that over the long distances gravity acts a little funny. But I think now with the evidence that's piling up, you can sort of get rid of the second theory, right? We can actually see dark matter being separated out of galaxies... stripped away or condensed together... through gravitational interactions, so there's clearly some great big cloud of particles surrounding galaxies, influencing it through gravity yet invisible to electromagnetic radiation.
**Pamela:** Right, and not only invisible to electromagnetic radiation, but also just plain refusing to play nice with the electromagnetic force. So whatever this stuff is, and we call it generally... we think it's some sort of non-baryonic matter, stuff that isn't like protons and neutrons, whatever it is, it doesn't interact via the electromagnetic force, it doesn't interact via light or interact with light or do anything regarding light except gravitationally reach out and change the path of light. And that's how we find it. We can look through space and see how light from the most distance galaxies gets distorted by the gravitational pull of unseen stuff. We can map out the distribution of this stuff and this is where we've learned its distribution around colliding galaxies, this is how we've learned its distribution in clusters of galaxies. We've been able to come up with phrases that don't sound pretty... it's collisionless particles... particles so tiny in cross section that they don't generally interact with one other directly through collisions.
**Fraser:** And like we would experience air as particles colliding together... that's air pressure... particles banging into each other and banging into us, but this would be particles that don't even do that.
**Pamela:** Right, right. So, very small cross-section, doesn't interact via the electromagnetic force, just generally doesn't interact with anything. And we have experience with things like this... we just call them neutrinos. And neutrinos may actually be part of what makes up dark matter. There's a whole lot more out there and it's possible, if the theories of super-symmetry are right, that the Large Hadron Collider, as it does its experiments, will be able to detect the lightest of these super-symmetric particles that might be dark matter. So, we're getting there.
**Fraser:** But there have been more discoveries in the last... even this year, right?
**Pamela:** Right so we've been looking...
**Fraser:** Closing in on dark matter...
**Pamela:** Right, so we've been using the same types of detectors that we used to detect neutrinos to try to find dark matter. And there's been some results out there that look like maybe just maybe with more repetition and more crunching and more testing, maybe we're starting to detect some of these generally refusing-to-interact particles. Because even though they have a small cross-section, that doesn't mean that they're zero in size. So occasionally they will cause something to happen, they will cause something to flicker. And it's those flickers that we're looking for.

**Fraser:** And so it's interesting, even when we were beginning this show three years ago... almost four years ago, we would talk about it, lending a lot of equal credence towards particles modified...
**Pamela:** Modified Newtonian dynamics...
**Fraser:** Modified gravity theory... but now I think we're talking about particles, we're talking about certain characteristics of particles, what they're kind of like, the methods we're going to be using to find them, so it's interesting to see those theories evolve and so how do you like our odds?
**Pamela:** I think it's looking great. For me the turning point for me was when the Bullet Cluster images came out. We've also had the COSMOS project which mapped out dark matter.
**Fraser:** And for those of you that don't know, the Bullet Cluster--this is this example where you had two huge clusters of galaxies coming together, and the stars were passing right past each other, the dark matter was passing right past each other, but the gas was colliding and mixing in the middle, and so you got this separation like someone had taken a flour sifter to a galaxy, right, and you got the stars and dark matter on one side and you got the gas separated out from it. So clearly there's some thing that's there. It's just amazing.
**Pamela:** Yeah, it's so close. We're getting there... soon.
**Fraser:** Yeah, so there you go. What is dark matter? We don't know, but we hope to figure it out soon. Alright, well then as a relation to that question then, where are the dark matter galaxies? So if we do have this process where dark matter is being separated from galaxies, or perhaps they're just as formed after the Big Bang, could you end up with whole galaxies that are just dark matter?
**Pamela:** And that's one of the really, really interesting mysteries that we're still working to sort out. And the COSMOS project started to get us closer. It did a map of the distribution of luminous matter--the normal stuff we can see--and of dark matter based on gravitational lensing. And what they found was, there are places where we have over-densities... where we have extra amounts of dark matter and there isn't luminous matter there as well. We're not seeing the nice dense things we'd identify as a galaxy. Instead we're seeing these big amorphous halos, but new research is also showing that dark matter interacts weird when you start getting really dense gravitational wells. It doesn't seem to interact with black holes the way normal matter does. We're still sorting this out and I have to admit that I need more sleep to reread the paper to better understand the results.
**Fraser:** But the thinking is that dark matter doesn't even make its way into black holes in the same way. It just zips past. I guess the point is because regular matter has that larger cross-section, it's bouncing into itself around the outside of a black hole, and it's subject to tidal forces, but the cross-section of the...
**Pamela:** And there's frictional slowing...
**Fraser:** Yeah, but because this stuff... you could pile mountains and mountains of dark matter around itself and it's not going to really be bonking into each other. You're not going to get that frictional slowing.
**Pamela:** And it may be that you just can't get without a black hole in the center, the same sorts of density gradients that we'd recognize as a dark matter galaxy. It may be that we just can't get that nice super-dense center followed by either a surrounding halo or a

surrounding disk. But we do know that there are large amorphous boring-shaped but completely dark density areas of dark matter.
**Fraser:** So it's almost like you can get regular matter to do things, but you can't get the dark matter to do anything, and so you can separate out the regular matter, but you're still going to end up with a ball of dark matter that isn't going to collapse, that isn't going to form, and it isn't going to black-holify, and it's just kinda there... doing its own thing, not playing by the rules.
**Pamela:** So we need to look at more of the universe using gravitational lensing to try to find the distribution. We've only looked at a very narrow basically straw through the galaxy.
**Fraser:** But we don't see... so far we don't see dark matter of differing densities, is that what you're saying?
**Pamela:** Well, we see it of different densities, but we don't see any really high densities that look like galaxies, but we need to look more.
**Fraser:** As you said, we're looking through a straw and we need to do a better survey. Yeah, are there plans in the works for that?
**Pamela:** There are lots and lots of different survey teams working to look at these things.
**Fraser:** Right.
**Pamela:** It's just slow.
**Fraser:** Very cool. Well thanks Pamela. We'll keep rolling. I can see my list... there are more mysteries.
**Pamela:** Sounds good Fraser... I'll be talking to you later.
**Fraser:** Alright, I'll talk to you later.
**Pamela:** Bye-bye.