Astronomy Cast Episode 26:
The Largest Structures in the Universe

Fraser Cain: Last week we covered our galaxy evolution show, talking about how galaxies start from nothing and turn into something. This wee we're going to continue our journey and learn how these galaxies come together to form some of the biggest structures in the Universe.

Let's get a bit of a re-cap. Where were we last week?

Dr. Pamela Gay: We started off with how little things come together and gracefully form big pretty things like spiral galaxies. The Universe started off after 400 thousand years of forming hydrogen, helium and a dash of lithium and beryllium. It was a pretty smooth, continuous surface of matter.

Luckily, it wasn't completely smooth, slight irregularities in the density distribution of material collapsed and formed bigger and bigger things. The dark matter collapsed first and then drug into it the luminous matter. As the luminous matter fell into these dark matter gravity wells, stars began to form and small collections of stars, baby galaxies, irregular galaxies, began to form. These came together to form, at first, irregular, strange shaped things and over time we ended up with spiral galaxies and elliptical galaxies that we see today.

Fraser: That process of little things coming together to form bigger things is still going on.

Pamela: That is still going on. Our own Milky Way Galaxy is in the process of consuming many things right now. We're a wee bit cannibalistic.

Fraser: Let's talk about how the Milky Way is continuing to grow.

Pamela: The Sloan Digital Sky Survey has given us an amazing understanding of the nearby Universe. We have been able to trace out trails of stars left by dwarf galaxies as they've gotten shredded and fallen into the Milky Way Galaxy. We call these trails of stars tidal tails, because the gravity of our Milky Way Galaxy tidally distorts the small galaxies and then shreds them in much the same way that the gravitational pull from the Moon distorts our own Earth's oceans.

Fraser: I need some evidence here. How do we know that the stars we see in the sky are the tail from a dismembered galaxy, as opposed to just stars in the sky? How can we tell the difference?

Pamela: We look at what the stars are made of. Stars that formed out of the same blob of gas and dust are all going to have the same composition. They're going to be formed out of the same recycled supernova material; they're going to be formed out of the same proportions of original material from the Big Bang.

When we look at different systems, we often find a different fingerprint of atoms. We find a different fingerprint created by a different set of supernova that exploded to form that system of stars.

When we look out, we look at the stars to find out, "How old are they and what are they made of?" The 'how old are they?" also falls in because in a lot of little tiny systems you'll get pretty much all the stars forming at the exact same time. If you look at one of the smallest nearby galaxies, the Ursa Minor Dwarf spheroidal galaxy, you see stars that were all made out of the same material and all formed within a short period of time in a single burst of wild star formation.

Fraser: So we'll look at the sky and analyse all the stars in a collection of stars that we see. We'll analyse what they're comprised of and then it's almost like connect the dots.

Pamela: Exactly.

Fraser: You'll say, "this one's similar, that one's similar – oh, I see a trail here" so chances are those stars all formed together in a galaxy and now it's just wreckage.

Pamela: This is how we've found the, now pretty much shredded, Sagittarius dwarf spheroidal galaxy. If you look out to the other side of the Milky Way, there's this concentration of stars in the disk that are made of the wrong stuff. Our Milky Way's disk stars, stars like our sun, predominately are metal-rich, they're (in the grand scheme of things) fairly young, but this collection of stars is metal-poor and they're all pretty much the same composition. So when they were first found, astronomers went "oo, this is weird" and started looking around and were able to piece together that there is a dwarf galaxy falling into the disk of the Milky Way and as it falls in, it's getting gravitationally torn apart and sucked into our own galaxy.

Fraser: Are we consuming the Magellenic Clouds as well?

Pamela: It's unclear. Depending on who you read, the Magellenic Clouds may be just passing through and getting distorted as they pass through, or they're getting gravitationally sucked into the Milky Way and will eventually be shredded and consumed. So we're still piecing together the evidence for that. Most of the evidence, in my opinion, points toward they're eventually going to fall into the Milky Way. There are dissenting views, dissenting interpretations of the data.

Fraser: What's our next big collision going to be?

Pamela: The next truly big collision for the Milky Way is going to be for the Andromeda Galaxy. When that happens, we're going to be toast. I can't say for certain what's going to happen to our own star – by then our own sun will have consumed the Earth or at least heated it to the point that life will no longer exist. We probably won't be on our planet to observe what's going on, but our galaxy is going to have itself torn into patterns that we can only imagine in computer models right now.

Fraser: I think you're going to freak people out. So as I understand (not that we really have to worry what's going to happen in 500 million years from now), when two galaxies collide although the galaxy structure itself is totally obliterated and totally mixed-up, the actual stars themselves don't bonk into each other, right?

Pamela: Exactly. Occasionally you'll end up with a section of stars that will get flung into the supermassive black hole in the centre of galaxies, so you can get things gravitationally disrupted and sent on a suicide mission to the centre of the galaxy.

Fraser: Right, but the chances of the individual stars actually colliding are really remote. They just pass right through each other and then continue orbiting until you have a new formation.

Pamela: So in about three to five billion years, the Andromeda galaxy and our Milky Way galaxy are going to gravitationally fall into one another. As this happens, our dark matter halos are going to hit first, and this is going to send shocks back. These shocks are going to distort the shapes of our spiral arms. Clouds of gas and dust that haven't yet been used up forming stars are going to light up and start to form new generations of stars in a wild star-forming frenzy.

As the galaxies fall together, some of the streaming arms, the trailing arms that are behind in the merger are going to get left behind and stretched out, grasping out toward the rest of the local group around us. The cores of the two galaxies are going to fall together and tangle. The supermassive black holes in the centres of the two galaxies are going to light up as gas and dust also falls into the supermassive black holes and we end up with active cores.

Fraser: Are those two supermassive black holes eventually going to merge?

Pamela: That's going to take even longer, but yes, that is the eventual fate. The two supermassive black holes will eventually themselves merge together into, I guess a more super-supermassive black hole: an even larger supermassive black hole. When that happens, gravitational waves will be sent rippling through space.

There's going to be some pretty amazing fireworks when this happens. We can actually get a preview of what it might look like by looking out at the antennae galaxy (and we have images of the antennae galaxy both in the enhanced version of this podcast as well as in the show notes for this episode).

Fraser: So you're going to get two great big galaxies coming together, they're going to make a mess and you're going to end up with a much bigger galaxy? Is it going to have spiral arms in the same way that –

Pamela: So, the resulting galaxy is most likely going to be an elliptical galaxy. Whether it's going to be a flattened or perfectly spheroidal galaxy, models are working on figuring out, but time will actually be the final one to tell us. Two spiral galaxies are going to go away and after that initial mad dash of star formation, star formation is going to drastically taper off because there'll be a lot less gas and dust available to form new generations of stars. We're going to end up with where there were two star forming, pretty galaxies, one much larger elliptical galaxy that is red and basically dead of star formation.

Fraser: and then…?

Pamela: And then we hang out until something else come along and we eat it too or it eats us.

Galaxies have this cannibalistic tendency. It's kind of interesting, because galaxies (like people) don't like to be alone. For a variety of different reasons, galaxies tend to be found in pairs and groups and clusters and super-clusters that can have up to thousands of galaxies gravitationally bound together, rotating madly about a central gravitational point where there's often a giant, what we call cD elliptical galaxy located.

In these different environments, galaxies periodically get too close and then consume one another. In smaller groups like our own Local Group, which doesn't have that many giant galaxies, we've been allowed to hang out and be spiral and be blue and form stars for billions of years. We have another 3-5 billion years that we're going to be allowed to hang out and continue doing this. But eventually we're going to merge with Andromeda, and eventually Andromeda and us and whatever you want to name that new galactic version of our two systems -- I can't think of any way to turn Andromeda and Milky Way into something like "Brangelina" or "Tom Cat")

Fraser: "Milk-dromeda way?"

Pamela: Exactly, something like that. I like "Milk-dromeda".

So whatever you want to name that new system, we'll eventually end up colliding with other galaxies, interacting with other galaxies.

Fraser: So there are other galaxies moving in our direction?

Pamela: There are other galaxies that we're gravitationally interacting with. So, eventually we're going to just keep interacting, but it's a slow, slow process. We live in a small area and gravity in our area is holding us together with the other galaxies in the group, but it's not whipping us around at high velocities.

Fraser: Can we see some examples of places where there was a lot more material and a lot more mergers happening?

Pamela: Lately, Hubble has been taking some really spectacular images of galaxy clusters. These are regions of space where hundreds and thousands of galaxies are all gravitationally bound together. With all of this gravitational pull in one location, you often get some really neat effects like gravitational lensing, which takes the light from background objects and twists it out into weird patterns that will be a topic for a different show.

In these beautiful images you often see galaxies that are distorted and misshapen and you often don't see a lot of really pretty blue spiral galaxies.

Fraser: So that's how you know that we won't necessarily have a spiral galaxy shape in the future. All of the big clusters forming are all misshapen elliptical galaxies.

Pamela: Exactly. What happens with these big systems is they have so much gravity that they're causing the galaxies that are all orbiting together to orbit really fast. If you imagine a room full of people, if you tell them to walk around kind of slow and make sure they don't slam into one another, they're not going to slam into one another. Even if you tell them to close their eyes and walk really slowly, it's going to be a while before all of them have collided with somebody else.

If instead, you take a room full of people, tell them to close their eyes and run around madly, it's going to be a very short period of time before everyone's collided with at least one other person.

These galaxy clusters are the situation with a lot of people running as fast as they can with their eyes closed. The galaxies are whipping around quickly, pulled by the gravity of all the other different galaxies in the cluster, and as they're zipping past one another, they're what's called "harassing" one another. The gravity from one galaxy whipping past another galaxy tugs on that other galaxy's stars and gas and mis-shapes the other galaxy.

You also end up with, as galaxies fall into these rich clusters, they hit the gas and dust that has already been stripped out of the galaxies and now basically forms a media between the galaxies. So one galaxy hits this diffuse cloud of gas and dust and gets shocked. That shock knocks the gas and dust out of it, adding more gas and dust to the material between galaxies.

So in our own little, tiny group, there is material between us and Andromeda and the other galaxies in the Local Group, but it's not a lot of material. If instead, you look at one of the really rich, really beautiful ones, they're called "Abell Clusters" because most of the nearby ones were found by a man named Abell (and astronomers aren't that creative). If you look at one of these giant clusters of hundreds and thousands of galaxies, these clusters are rich in gas and dust between the galaxies. In fact, there's so much gas and dust and the galaxy is so strong that we can see the gas and dust using the Chandra X-Ray Observatory, because the gas and dust has been compressed and heated to the point that it's so hot it gives off x-rays.

Fraser: So, the two galaxies (or multiple galaxies) are coming at each other and this material in between is kind of piling up and you get a bump effect in between them as it – it doesn't have any room to go anywhere and starts to heat up as well. Do you get star formation in these regions in between the galaxies?

Pamela: Star formation is harder to get to because the gas is so hot. When gas is hot, the individual atoms move around really fast and it's hard to get hot gas to condense down into stars. So mostly you just have this hot, diffuse gas everywhere.

Fraser: Right, that's sending out x-rays that we can see.

Pamela: Exactly.

Fraser: So what's the future of this, then? In this case you have galaxy clusters with hundreds of thousands of galaxies coming together. What will that look like down the road? One big, elliptical galaxy?

[laughter]

Pamela: Over time it is possible that all the galaxies could end up falling into the centre, the friction from all of the gas in the system is affecting their ability to continue whipping around forever.

What's neat though, is if we look at these big clusters today and we look at similar, really big clusters in the past, they look very similar. Everything in them is red and shredded and dead. So, big, dense clusters, at all points in time, are big and filled with shredded, destroyed objects. These are basically collections of galactic carnage. This is where the gladiator battles of big galaxy against big galaxy have all taken place and the galaxy that has managed to destroy the most galaxies and consume them sits in the centre as a bloated cD galaxy.

Fraser: I'm going to use a really weird analogy here; it's kind of like the rat race. Say you live in a big city – say you live in New York City. You're going to work really hard and spend a lot of money and burn out really fast and so these big galaxy clusters are all interacting with each other and very quickly causing so much star formation all of their excess gas and dust is just gone and they turn red and that's all they've got left for material.

A galaxy like, say, the Milky Way has a lot less of a really crazy environment, life's a little more laid back here in the Milky Way, so we can have star formation go at a more leisurely pace at a longer period of time.

Pamela: That's a really good way of looking at it. Adding on to that same analogy, New York City is one of the oldest big cities in the United States and it's always been a rat race. There's still some small towns in America that are just as old as New York City (I grew up in one of them, Westford Massachusetts) and these small towns that have been around forever are still pretty much small towns and they've evolved a little bit over time. Some of the farms have gotten turned into bedroom communities for bigger cities, but they're still small towns.

There are also intermediate situations. Some of the middle-sized cities that have grown and grown and grown over time to the point that you now look at them and they're pretty much big cities coming into their own.

If we look out at galaxy clusters, there are these middle-sized systems that, in the past had active star formation, had spiral galaxies and things were whipping around but they hadn't had enough time yet for everything to collide. While they were whipping around, they weren't whipping around at huge velocities. So they had time to just hang out and be, and be blue and do their thing. Now, as time has passed, enough time has passed that the galaxies have had time to shred each other.

Things that were little in the past stayed little stayed blue. Things that were big in the past stayed big and stayed red – they very quickly ended all star formation. Things in the middle started out blue, stayed blue for a little while and gradually, over time, as things interacted, got redder and redder and redder, such that these middle sized clusters today consist of primarily red and dead galaxies, and in the past consisted more of blue and pretty spiral galaxies.

Fraser: I think I should mention that the title of this episode, where we're talking about the largest structures in the Universe, these are these gigantic galaxy clusters consisting of hundreds of thousands or even millions of galaxies. What's the biggest thing we can see?

Pamela: As we look out there are superclusters. These are nodules at the corners of the large scale structure of the Universe where galaxy clusters are coming together and multiple galaxy clusters are forming superclusters. What's neat is some of the largest things, the great attractor, are hidden by our own disk, so we can't look out of our galaxy to see exactly what's there. We can see galaxies and galaxy clusters streaming towards this great attractor that's hidden behind the gas and dust that we can't see through.

Fraser: What's the great attractor then? Is it the centre of a lot of gravity – something big?

Pamela: The great attractor is most likely a supercluster that exerts massive gravitational attraction on the space around it and it's sucking in other galaxies and galaxy clusters toward it, but we can't actually see it. It's sort of as though you have a house with an ocean view and you know there's a beautiful island off in the ocean but you can never see it because of where your neighbour built their house.

Fraser: So if our galaxy was pointed in any other direction, we'd be able to see what the great attracter is?

Pamela: Yeah. Exactly. We're sort of stuck.

Fraser: Oh. That's… that's ironic. Okay.

[laughter]

Pamela: There's other stuff we can look at. There's the coma cluster, there's the Virgo cluster. All of these things out there tracing out the large scale structure of the Universe. So, we can look out and see what looks like a sponge-like structure of voids and walls and the intersections of walls that are all traced out by the places where there are and aren't galaxies and galaxy clusters.

Fraser: Do they all connect if you zoom back out far enough does it look like they're all together in lines or are they in fairly big clumps with big distances in between.

Pamela: Basically, just imagine the structure of a sponge or a bunch of soap bubbles where you have the intersecting places where there's going to be a lot of soap or a lot of sponge material, and then there's empty voids that might have a few galaxies in them but not a lot, and then there's thicker walls that trace out the edges of these voids. It forms this growing network, this growing three-dimensional spider-web perhaps is the way to think of it, where we're not quite sure exactly if you keep going larger and larger – we want to think that if you look at a large enough sample, everything's going to look the same in all directions. Right now we just see, basically, a small corner of a sponge made by all the galaxies.

Fraser: If we look into the future with the impact of dark energy (which is accelerating the expansion of the Universe) what will it eventually look like?

Pamela: If you look at a really cheap sponge, it has little tiny air pockets in it and then fairly thick walls between the air pockets. Imagine taking that sponge and pumping it full of air, sticking it into a vacuum, so that he bubbles inside the sponge, the empty spaces inside the sponge, grow, and the walls of the sponge get compressed smaller and smaller and smaller.

What's happening over time, is our Universe is ending up with emptier, larger voids and thinner, denser walls and larger junctions between all of the walls where they come together.

Fraser: I guess eventually all those bubbles will pop – I guess pop isn't a really good term for it -

[laughter]

The connections will start to come apart and I guess it will just start forming big spheres of galaxy cluster stuff?

Pamela: Exactly. Another way to look at it is a loaf of bread. You can have really dense bread, or bread that has really big air pockets inside of it. As you watch the bread rise, as the yeast creates larger and larger air pockets inside the bread, that's sort of similar to what's happening within our own galaxy as it both grows and the material condenses into higher and higher density regions.

Fraser: And eventually you've just got air and little pieces of bread.

Pamela: Exactly.

Fraser: Wow, so is there anything else, then, that you thought might be relevant for this episode? I think I'm all out of questions.

Pamela: I just think it's neat that we talk about galaxy-on-galaxy violence using the scientific term "galaxy harassment".

Fraser: (laughing) Galaxy harassment. Is that the technical term?

Pamela: That is actually the technical term. When two galaxies sweep past each other and their gravity deforms one another, that's galaxy harassment. It's one of the few times when we got humorous in how we name things in astronomy.

Fraser: That's great Pamela. That's a full two episodes of galaxy evolution, from the small to the super big, the biggest there is. I think that was great.

This transcript is not an exact match to the audio file. It has been edited for clarity.