Episode 50: The Death of Spiral Galaxies with Kat Griffiths

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Ben: Never be afraid. There's nothing which is known which can't be understood. And there's nothing which is understood which can't be explained. For over 50 episodes now my team and I have brought you to the very frontier of knowledge in physics and astronomy. And still our mission goes on, to present you with your birth right: an understanding of the universe. I've travelled the world seeking out a certain type of genius, masters of not only their academic disciplines but also at explaining their research in understandable ways. And I've bestowed upon these women and men the title of Titanium Physicist. You're listening to the Titanium Physicists' podcast, and I'm Ben Tippett, and now allez physique!

[1:48]

Ben: If you want to make somebody who doesn't know anything about the cosmos feel small, you tell them that the world is a sphere that is spinning and he's standing on the surface of it. And every month the moon travels through the sky as it circles the earth. And this is kind of a crazy revelation because it means that there is an object, the earth, which is so large that you can't ever see how large it is. It's kind of a scary thing recognizing that there are objects so much larger than you that you can only think about their size conceptually. You can't imagine yourself next to them. It's more than humbling, it's horrifying. But you don't stop blowing his mind there. Then you tell him that there are other planets some of them much, much, much bigger than the earth and they're circling the sun. And the sun is big. It's so big; it's a hundred times wider than the earth is. It's huge! Now, before he can get used to his place in the universe, you tell him that the sun is one of three hundred billion other stars circling the galaxy, swirling around the center the way the other planets circle the sun, and the moon circles the earth. So then he kind of feels crummy about being so proud about his truck you know? But there's still kind of a finiteness to the thing he's comparing himself to. So he still has a little bit of pride. So you finish crushing his ego by saying that we can see like two hundred billion other galaxies, kind of like ours just floating out in space. "What are they circling?" he asks. Because as long as there is a center to the universe he can imagine his relation to that point, such is the way of all egoists. When you reply, "They're not really circling anything. I mean they kind of clump together here and there but they're just kind of spread out from here to forever. There is no center to the universe. And you are so small you can't even imagine your size compared to the first smallest thing we started talking about." So then he starts crying and the nerds win. So today on the *Titanium Physicists* podcast we are going to talk about galaxies. Awesome! Now let me just take a second to talk about fan podcasts. They can be wonderful things where a group of people talk about their favorite thing and if done right, you don't just learn new things, about your favorite TV show say, you also feel like you are a part of the conversation. And let me tell you, the *Verity* podcast does it right! The podcast is named after Verity Lambert an amazing person who was the founding producer of Doctor Who back in 1963. The *Verity* podcast consists of six women from around the world who gather weekly to talk about Doctor Who and it's probably the best Doctor Who podcast out there. It's engaging and entertaining and inclusive and the show is simply amazing. So today our guest is Kat Griffiths, one of the cohosts of Verity. Kat is a Canadian fan-queen and she does jiu jitsu and she writes fan fiction and we'll link to her blog on our website. Welcome to our show Kat!

Kat: Thank you. A fan queen. I've never been called that before.

Ben: So Kat, today I've assembled two of my titanium physicists. It's been a while since we've had them on the show together. Arise Dr. Sean Moran. Dr. Sean did his PhD at Caltech. He is currently at the Harvard Smithsonian Center for Astrophysics and he's an expert on galaxy evolution. Now arise Dr. Laura Hainline. Dr. Laura did her PhD in astronomy at Caltech. She is an expert in studying accretion discs around black holes and she currently works for a company which may not be named.

[5:06]

Ben: Alright everybody let's start talking about galaxies. Ok Kat, did you know that there are different types of galaxies?

Kat: I did know that.

Ben: Ok do you know what they're called?

Kat: No clue.

Ben: Ok well there's the swirly ones.

Kat: They’re spiral arms.

Ben: That’s right. There’s spiral galaxies and then there's ones that just look like big blobs of stars

Kat: And they're not called blob galaxies?

No. They're called elliptical galaxies because they look like blobs.

Laura: Well they look roughly spherical or elliptical like ellipses. We'd prefer to sound like we know what we’re talking about.

Ben: Well a blob is kind of an oval shape and the mathy way of saying oval is to say ellipse.

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Laura: Thus elliptical galaxies.

Ben: Thus elliptical galaxies. So the crazy thing I learned while preparing for the show is that spiral galaxies are bluish colored and elliptical galaxies are reddish colored. I thought they were all the same color because they are all full of stars. But they’re not and the reason for that is amazing.

Sean: So they're that color because the spiral galaxies which are always the ones in the best pretty pictures and stuff with these grand loops and blue colors and really cool stuff. Those are all full of young stars. There's tons of gas and dust swirling around with spiral arms and it makes them look cool and also that gas and dust is what condenses into these new stars that are always forming these galaxies and young stars tend to be blue stars. The brightest young stars are blue. And so they completely dominate what we see in the spiral galaxies but if you turn off that gas, turn off any new star formation all you end up with after a period of time are old stars. And old stars are dim and they are red. So you have these big old blobby galaxies were nothing much new is going on and they're all full of red old stars.

[7:01]

Ben: Okay, so there are two paths that we can go on. Would you like to know why an old population of stars is red colored and a young population is blue colored or would you like to go in for the explanation of why spiral galaxies have young stars and elliptical galaxies don't?

Kat: Umm…the second one.

Ben: You're knocking it out of the park Kat.

Kat: Well, it's far more interesting to me.

Ben: Okay. So to do that you kind of have to talk about, in the most general terms, how each of these galaxies form. Because the reason one makes stars and the other doesn't has to do with how dense gas and dust are in the two types all the galaxies.

Sean: So way back in the early universe when these things were just starting to form there was this soup of gas and dark matter in the universe and the dark matter sort of clumps together under gravity and start sucking in all this gas and stuff. And then you start condensing the gas. It starts getting into these clumps that fragment and starts forming stars. And you end up starting to make these galaxies full of young stars. And so you fast forward for a long time and you end up with the spiral galaxies where all the gas is sort of condensed into this little disc where they're all rotating around the center, you start to get this spiral structure. But then what happens if you take one of the spiral galaxies and slam it into another one, which happens from time to time. It's all gravity out there so sometimes these two big heavy things start slowly getting drawn towards each other and eventually they'll collide and smashed together. And what happens when you get one of those is all this nice spiral structure gets all stirred up and all the stars get flung in all directions. And a lot of the gas gets used up either in some intense final burst of star formation or even ejected. And you end up with this big blob. And then the question is: Why doesn't the big blob ever turn back into another spiral galaxy. So it goes back to all these galaxies have these big huge black holes in the middle of them and when you start merging galaxies together the black holes eventually merge too. Somehow, we don't know, we've never seen it happen, starts gets sucked in and heated up. And you end up getting all of this intense radiation coming off the black hole. And when you merge these two spiral galaxies together you often end up with a black hole that's putting out such intense radiation that it either blows any of the gas remaining in the galaxy completely out or it just keeps it super-heated and it never ends up being able to cool back down into one of these discs, into one of these clouds and stuff which is where we need to form stars.

Laura: And that's one thing Sean has left out is that stars form from cold gas not hot gas.

Sean: Yeah. That's right. You have to cool your gas and get it to settle down and get it to clump together densely before you can get a star out of it.

[10:17]

Ben: Alright, let's take that explanation and go through it a little bit slower. So Kat, at the very very early universe there wasn't any structure to it. I mean there weren't any objects. There was just really, really uniform gas. Everywhere you went - gas. You could go 100 million parsecs away - more gas, same temperature, same density. There was also dark matter. We don't know what dark matter is. It's probably some kind of weird particle that we don't know. All we know about dark matter is that it's dark. It interacts gravitationally. It was first detected when people were trying to figure out how much mass a galaxy had. You can do it in two ways: you essentially look at a big spiral galaxy. You can tell that the stars are orbiting the center of it as they kind of swirl around and we can tell how fast they're moving. And so each star in the galaxy is in orbit around the center. So we can tell based on how fast it's moving, we can tell how much mass is between it and the center of the galaxy, all the mass that it's orbiting around. And so you can figure out what the mass distribution is like in a galaxy as you look at how fast stars are moving around the center, as you go away from the center of the disc shaped galaxy. You can essentially do it that way or you can figure out how much mass there is by counting up all the stars. In our solar system the star has most of the mass. So you say well in a galaxy if the star has most of the mass we just count out the stars and figure out about how much mass there is and what the distribution of mass is. And when they do that calculation they don't agree. So the conclusion is oh there must be mass that isn't shining like a star. And that’s why we call it dark matter because it's matter, it's got mass, but it's dark because it doesn't shine.

Kat: I do want to ask in our galaxy, our sun is our star so when you're talking about counting up stars and stuff like that that would be like including our sun. That would be one of our stars in this galaxy.

Ben: Yeah. So 300 billion and one stars. Something like that.

Laura: We haven't actually counted. I think at some point they just extrapolate.

Sean: Estimate based on how much light they are emitting. Because we know how much light a star like the sun gives off. And we know how much light a star a little bit smaller gives off and a star a little bit bigger gives off. And we just sort of take our picture through one of these blue, green, or red filters and then from the amount of light we measure off of that we can figure out about how many stars are in that picture.

Ben: So the moral of the story is there's dark matter. And there is about 10 times more mass in dark matter than there is in luminous matter, which is interesting. But the real kicker is when people started doing computer simulations of galaxy evolution they found that you only get structure forming in the time scales, and you know with the range of sizes we expect, if the dark matter kind of collapses first. So the very first thing to collapse in the universe were just kind of long strings of dark matter and they turned into these little clumps. And these clumps were kind of the seeds of what each galaxy would be. So galaxies would collapse in on where these clumps of dark matter were. So all this dust, all this luminous dust, as the universe expanded and cooled, the gas cooled down and it could start collapsing in gravitationally. And there were large larger fields, like a 1,000,000 light years across, of dust and matter, would start collapsing in on one of these clumps of dark matter. So like our galaxy 10,000 light years across. So it's drawing in gas from a large area, and it kind of falls in. Now the deal is like the planets around our sun, if you're not going to fall into the sun you need to be in orbit. So the only dust and gas that wouldn't collapse down into the center, into the black hole in the middle of these things is the dust and gas that essentially can maintain an orbit. So you know gas and dust falls in toward the center of this and as it does it speeds up. And there's some statistical variation in their initial velocities so they're all traveling in slightly different directions. And it just kind of sorts itself out where it bounces in around itself. And eventually after a long time you end up with kind of a disc of rotating matter. And the orientation and direction it's rotating is random. But eventually in these systems inevitably you end up with a big pancake shaped cloud of dust and gas. That's rotating in the same direction around the center of mass. And you see these around black holes. You see them in clouds that eventually turn into planets, like all our planet's eventually formed from these disc shaped clouds of gas that was orbiting the sun. And that's kind of why all the planets kind of orbit the sun in the same direction in the same plane. And you see the same thing and essentially galaxies. Only instead of clumping down to form planets this dust and gas that's circling the center of the galaxy is going to clump down and form stars.

Laura: Did that make sense Kat?

Kat: It does. Yeah. It makes total sense.

Sean: So all the young stars when you have this cloud of rotating gas and dust it starts fragmenting and collapsing into all of these millions of stars. It happens over a long time, over a period of billions of years really. It's just sort of continuously churning through where the little clouds of gas collapse to form a new star, gas gets rolled up again, and more clouds collapse and form stars later. It happens for a really long period of time. But as long as that process continues to go on you're always going to have some young stars at any given point in the galaxy. And young stars tend to be bluer because...

Laura: We tend to see more of the brighter young stars. And as it turns out the brighter stars are heavier and they admit light that tends to be more blue.

Sean: Yes.

Ben: Ok. So there's a correlation between the temperature of a star and how heavy it is. The bigger heavier stars burn through their fuel faster and so they are hotter. You know you look at like a flame, the blue flames are hotter than the red flames. So just so in stars, the hotter it is the whiter and bluer colored it will be. So initially when clouds of gas turn into stars you get a variation of stars: big heavy ones that are bright and blue. You'll get ones that are kind of the size of the sun which are kind of white yellow. And you know ones that are less massive than the sun and they'll be kind of red colored.

Kat: So is our son a young star or an in between..?

Laura: It's in middle-aged star.

Sean: It's a Goldilocks star.

Laura: It's actually kind of considered an old star on the scale of astronomy time. It's considered an old star.

Sean: It's probably a billion years old which is respectable.

Ben: It’s been around the block a couple times.

Laura: The young stars because they burn through their fuel faster they have shorter lives. And as you decrease the mass of a star, as they get lighter, their lifespans gets longer. So the red stars and yellow stars tend to live longer than the blue stars.

Sean: Way longer.

Laura: Much longer yeah. Like billions of years as opposed to a few 100 million years.

Ben: It's kind of like how old people don't like rock n' roll and living fast because you know when they were young there was a sizable chunk of their population that liked living fast and dying young but they lived fast and died young and the only people remaining were like "no none of that rock music."

Kat: There's actually a correlation between that and with dogs. That really big dogs like Great Danes and St. Bernards and things like that have a lot shorter lifespans then small dogs like Chihuahuas and Terriers and stuff like that.

Sean: Well so when you have like a dog park if you have some huge dogs there they're probably going to be dominating all of the barking and the attention and trampling over the little ones.

Laura: And they are the young dogs. They might statistically be the young dogs.

Sean: And so while they are around really the only stars you see are these big enormously bright heavy young stars. But once you turn off that switch on forming new stars they disappear really fast by cosmic standards which is still...

Laura: A long time.

Sean: A long time. It's still like millions of years. But the other ones live for billions and billions of years.

Laura: And eventually the long lived stars are the only ones that are left. And that's what happens in the case of an elliptical galaxy because all of the heavier stars have gone off and died and the only ones that are left are long lived and small and they're red. So there you go.

[19:05]

Ben: So essentially what you have is, you take a cloud of dust and you let it collapse, and eventually it will form essentially a pizza shaped thing of dust that is slowly circling the center of mass of the galaxy. And then stars will coalesce out of that dust of gas. And long story short, if you let that happen long enough you'll get these spiral arms and it will be in a spiral galaxy. And if you take two of these natural spirally galaxies and you let them get close enough to each other they will fall together. And as they fall together stars will go everywhere and dust and gas will go everywhere. And part of the dust and gas will get dissipated. But the gas and dust that didn't get dissipating, lots of it will fall into the middle of the black hole. And essentially the black hole, as dusk falls on it, will radiate light.

Laura: Well it's not the black hole that's radiating light.

Ben: I know it's great! OK, there's a mechanism around the black hole that will radiate a whole bunch of light, that then melts all over the rest of the dust and gas and keeps it from being the type of dust and gas to make new stars. So crushing this nice spirally pancake structure by colliding two galaxies is what dissipates all the gas and makes the gas unusable. And that's why the new stars don't get born. So we can talk about that cool mechanism about why the stars melt the thing or we can talk about the formation of spiral arms because that's weird. Like why does it stop being a big pizza shaped thing of dust and why does it get all spirally.

Kat: Black holes. Always black holes.

Laura: A black hole is basically an object so massive that not even light can escape from its pull.

Kat: I've heard that exact statement multiple times. Yeah.

Laura: So therefore any light that would be coming from anything that will be say falling into it or coming out of it, we can’t see it because it can't leave. It's trapped. So that's why we can't see it. But the way we see black holes, as it turns out, if the sun were black hole the earth would still be in a normal orbit. So as stuff gets drawn towards the black hole it moves into orbit. It's not sucked directly in shall we say. And then so this material it's orbiting the black hole and it forms what we call an accretion disc. And it's usually just made of gas.

Kat: Yeah so it would kind of look like these things are all orbiting nothing, right?

Laura: Yeah, exactly. For some reason they're all orbiting something but we don't see anything there.

Sean: So you end up collecting this gas that's sort of spiraling down the drain which you don't see what's at the middle of the drain but you do see stuff starts to pile up. And when you have a big cloud of gas there's friction and it starts to heat up and rub against itself as it spirals down the drain.

Laura: And so that gas because it's getting heated up it starts to admit more light. It will emit like x-rays in fact and gamma rays instead of just the optical light that we usually see. So that's part of the reason why when we look at it with the usual camera we just see this stuff orbiting around nothing. But if we looked in x-rays we would see a small compact area that's just x-rays.

Sean: It's just blasting x-rays out in the middle of the galaxy.

Laura: But there's nothing else around it.

Sean: And so it's a tiny, really by the size of a galaxy, it's a tiny amount of gas that sort of swirling down the drain. But it's just blasting out this really hot light...

Laura: Creating tons of light.

Sean: And that goes blowing through the entire rest of the galaxy. And it's so energetic that any other bits of gas and dust that it encounters on its way out it heats up to really hot temperatures most of the time.

Laura: So when it heats up to those high temperatures it can ionize the gas. So that means it can strip away electrons from the nucleus and it can separate molecules. It can do all sorts of things.

Sean: And all of that is really bad if you're trying to form stars.

Kat: If I'm understanding correctly, I'm going to make a really bad comic book analogy. When the Flash goes like super-fast and all you see is a trail but you don't see him would that be kind of...

Sean: Yeah sure, you just see the glow.

Laura: So we know it's there because the stuff around it is glowing.

Sean: You don't see the drain but you see the stuff spiraling around it.

Laura: So yeah it's kind of like your sink because there's a cover over your sink drain and you can't see it but you can see the water swirling around the drain.

[23:30]

Ben: So there's a pretty simple explanation for why it gets as hot as it does because the material that's about to fall into a black hole gets hotter than almost anything else. It's almost like imagine you're standing on the ground out of the cabin and your body dug two wells. And one is 100 meters deep and the other is 400 meters deep. And you take two bowling balls, same mass, you drop one down the 100 meters deep, it hits the bottom bang. You drop the bowling ball down the 400 meter deep well and it hits the bottom of the well with so much more force. It's traveling so much faster when it hits the bottom of the second well then the first well. And essentially what happens is in a black hole you have matter that is falling in from really far away into near the bottom of a really, really deep gravitational well. So by the time the matter hits something else, the stuff that's spiraling into the middle of it, it's traveling really, really fast. And so those collisions nearby are very, very, very intense because stuff falling in from it has fallen from so high up relative to the black hole that the collisions between atoms involve enormous amounts of energy which is why even this far away from the black hole they still look like x-rays and gamma rays and they have the capacity to melt everything else because the stuff falling in is super-hot.

Laura: All of this is just going to tie back in to the black hole stuff because they are in the centers of galaxies. There is a black hole at the center of every galaxy. Did we leave that part out?

Ben: I think we did.

Sean: We might have.

Kat: Yes you did.

Sean: The ones that are in the center of every galaxy are millions and billions of times the size of the sun.

Laura: They're huge!

Sean: We have no freakin' idea where they came from.

Laura: But we know they're there.

Sean: We know they're there. And we know that they tend to be like in a big heavy galaxy that also has a big heavy black hole. So the size of the black hole correlates to the size of the galaxy. But we don't know where they came from. And we think when two galaxies merged the black holes must merge somehow to. Never seen it happen.

Laura: That's something that seems to be left out of every galaxy type book I've ever read, is that every galaxy has a black hole. Because they make them out to seem super rare.

Ben: Yeah it's kind of a new fact. People weren't sure that it was true when I was an undergraduate 10ish years ago.

Laura: To be fair, I don't know that they're sure. It just looks that way. It looks like they're very common. And so therefore by extension we might say that every galaxy has one.

Ben: Yeah and putting in a black hole at the very start of your simulation for galaxies as I understand it...

Laura: It makes everything come out very well.

Ben: It makes things come out a lot better.

Laura: It makes a lot more sense.

Ben: Yeah so it seems like they are requisite for the galaxy's to evolve in the way that we see them having had evolved.

Laura: On the other hand we can't tell you how they got there.

Ben: They don't start off very big at the very start right?

Sean: No not at all.

Ben: Lots of their mass comes from all the gas that falls in the course of creating a galaxy right?

Sean: Yeah but we don't know how much and we don't know what size they started as. Some people even think that they're primordial like they came with the universe and everything else started forming around these primordial black holes. Like even more important than the dark matter.

Kat: Came with the universe just has the best mental picture ever, like someone moving into a home and there's already a dog there. And it's like " well he comes with the home so..."

Sean: Well the universe already had all these black holes we might as well start building some galaxies around them.

Ben: That's right. We built the apartment building around the dog.

Laura: That might have been what happened. Sadly the astronomers were OK with that. We don't really know, but were not going to worry about that.

Sean: We're just happy we know a little bit now about how the black hole effects the rest of the galaxy, how it sends out this radiation that can turn off the star formation because it heats up all the gas so much.

Laura: Yeah. I think Ben, that's where the advances have been even in the last 10 years, is that what they've seen in a lot of galaxies you can see the effects of a black hole. For example, elliptical galaxies are extremely common and we don't have any other way to create them other than merging spiral galaxies together and then what happens in that merger that makes the star formation stop is the black hole.

Sean: Yeah it can almost only be the black hole. We don't have any other way of figuring out how to stop any more gas from turning into stars in these galaxies unless there's this black hole that's lit up in the center.

Laura: So therefore since we see so many of them and they can only have formed in this way it must be that they all have black holes. And it doesn't hurt that if we look at higher red-shifts which correspond to earlier times during the history of the universe we can see a lot of galaxies have these black holes in them. And we mentioned earlier how around a black hole you get lots of radiation and x-rays and gamma rays because the material is heated so much. It turns out we can see a lot of galaxies in the early history of the universe that were very bright in x-rays so that's why we know a long time ago many galaxies had black holes. Even if right now they're harder to detect.

Kat: Thinking about elliptical galaxies, they come about because of merger right? They never just start that way?

Laura: So we think. It turns out that there's a long history of a debate in astronomy between how they turned out that way and it looks like to the best that anyone can say, that yes, they came about because of a merger.

Sean: So most of the elliptical galaxies are bigger than spiral galaxies like you're typical elliptical galaxy is bigger maybe let's say twice the size of a spiral galaxy. So it's sort of suggest that they typically form by taking two spiral galaxies and smashing them together. But there also are some smaller number of little elliptical galaxies and we're much less sure where the heck they came from.

Laura: Yeah, they don't fit into the picture quite well.

Sean: They don't necessarily have the black hole involved as much in turning off the star formation. Sometimes a galaxy is just sort of off by itself somewhere and maybe it really just used up all the gas that was in the neighborhood. And so there's nothing left to form new stars.

Laura: But perhaps it's best to say to every rule there's an exception. We're not really sure where those came from so we're not going to worry about those. We'll sweep them under the rug. Let's just say for now that all the elliptical discs come from mergers of spirals.

Kat: OK. Yeah generalizations are fine.

[30:07]

Ben: Do we want to talk about galaxy distribution in the broader universe?

Sean: So we have galaxies sometimes merge and it's because they started out fairly close together. Each of them had their own little catchment area where they were sucking in gas from a wide area but they ended up being fairly close to each other in the end and then because the gravitational force between them, they would start feeling each other's presence and they start drifting towards each other and they maybe spiral around each other a few times and dance around a bit and eventually they smash together. Fine. Well what about on a larger scale where you have lots of galaxies. Let's say you're in the early universe and there's a big clump of dark matter. It's one of the largest ones that was around at that time. Maybe you start fragmenting into a lot of different galaxies and they all start out in sort of the same neighborhood. Once you start having such a big over-density of matter, the gravity is really strong there and it starts sucking things in from really a long way away. And so the galaxies start streaming in from all over and it's sort of a runaway process. You end up with hundreds or even thousands of galaxies all sort of being drawn towards each other and they end up in these huge clusters of galaxies and there are typically a 1000 large galaxies in a cluster. They often end up being elliptical galaxies in these clusters because they're all interacting with each other all the time as they get sucked closer and closer to each other. They're really much more densely packed than for example the Milky Way and our nearest neighbor Andromeda. We're kind of close to each other but it'll still be a few billion years before we have any real dust-up with Andromeda as it comes towards our neighborhood. But in these galaxy clusters the galaxies are much closer together and the tens of millions of years or hundreds of millions of years are always sort of zipping past each other really quickly sometimes merging and sometimes just grazing each other. So the centers of these galaxy clusters you have these galaxies stirring each other up constantly and you have the black holes in the center of all of them that are shining brightly. And you end up with the most intensely super-heated clouds of gas in the universe. These things glow really brightly in the x-rays. We launch x-ray telescopes and almost everything they see in the universe are these clusters. It's like the brightest thing in the x-rays in the universe. And it's because there's this big cloud of gas that gets so hot that it doesn't even stay bound to one galaxy. It's like the cluster's big hot gas cloud at that point. All the gas that is sort of left outside of the stars in these clusters of galaxies just gets strewn all around the cluster in this big huge really, really hot gas cloud. That's like to the nth degree of what you would see in one of these normal elliptical galaxies.

[33:05]

Sean: Yeah, so let's talk about the converse of galaxy clusters. Once you start having this big dense collection of galaxies everything starts streaming in. Well on the other end it leaves these big enormous voids in other parts of the universe where all the galaxies that may have been there at one point got sucked away to various clusters in different directions and there's nothing left in this huge section of space. It's just empty for hundreds of millions of light years or even more maybe. And so in between you sort of have...

Laura: Like a spider web.

Sean: like the galactic suburbs. Where there are little filaments where they're dotted with galaxies. And maybe it's sort of a stream these dots of galaxies along this line are sort of being slowly pulled towards the nearest galaxy cluster.

Laura: And there are big holes in between the filaments, in between the strings of galaxies. There's just nothing.

Sean: As galaxies are on these strings on their way to the big clusters they form smaller groups as they get pulled towards each other even as they're all falling in together. And you end up with these what we call the groups of galaxies and that's actually what we live in is the Milky Way and Andromeda is our nearest neighbor and we have a couple other small galaxies nearby.

Laura: We're called the local group.

Sean: The local group. We have a modest little suburban community here where we live.

Laura: But the local group belongs to the Local Supercluster.

Sean: Yes. We're way out in the outskirts of one these huge clusters. We're slowly on our way in ourselves but it will be some billions of years I think before we get there.

Kat: I was just marveling over the words "galactic suburbs" because one of my cohosts on the podcast her other podcast is *Galactic Suburbia*.

Sean: So a lot of these elliptical galaxies end up being formed as they are sort of on their way into these clusters.

Laura: Cluster center. And as you get further out you start seeing more spiral galaxies.

[35:10]

Ben: How's it going Kat? Is there any other questions you want to ask?

Kat: Just one kind of term that I hear a lot and I want to make sure I know what it is - a "nebula".

Laura: Ok, a nebula is basically a cloud of gas.

Kat: Ok, that's what I thought it was.

Laura: It can be any cloud of gas.

Sean: They're often glowing because there's a star nearby that is sort of lighting them up.

Laura: Yeah because the light from the star is exciting the atoms of gas and causing them to glow.

Kat: Ok because you get things like the Horsehead Nebula.

Laura: Yeah that's a star formation region.

Sean: Yeah so once you have these clouds of gas and you start turning on the newly formed baby stars they start lighting it up and they start blowing the gas around and it starts...

Laura: And sculpting it.

Sean: Sculpting it. And it starts getting pretty cool looking when you take a picture.

Laura: There are different types of nebula, nebulae.

Sean: Astronomers are terrible with terminology.

Laura: Yeah exactly. Seriously back 50, 60 years ago they called spiral galaxies spiral nebulae. All galaxies were essentially nebulae because they just looked like fuzzy clouds in the images.

Ben: About 100 years and prior to that we had some sense that we were in a galaxy and there are other stars beyond our sun. So you know we saw the Milky Way galaxy and it's full of stars. But our telescopes weren't good enough to resolve other galaxies. So we didn't know the universe was full of other galaxies. We called our galaxy the universe. And imagine that all these other galaxies just showed up like cloudy things. You have to resolve a picture for long time before it makes a nice spiral shape. They classified them as messy objects. And essentially we figured they were just clouds of gas out in space past our own little island galaxy before we realized that the universe is full of other galaxies just like ours.

Kat: Kind of humbling.

Ben: Oh man, it turns out we don't know anything.

Well that was fascinating. Thank you Sean. Thank you Laura. You've pleased me. Your efforts have borne fruit and that fruit is sweet. Here's some fruit. Laura you get a banana and Sean you get some peaches. I'd like to thank my guest Kat Griffiths from the Verity podcast. I had lots of fun did you have fun?

Kat: I had a ball.

[37:33]

Ben: Well that's it for this episode. Time for some closing remarks: first, I want to remind you that we've recorded over 50 episodes now. Have you looked up the one explaining quasars or the one about extracting energy from black holes? They're all relevant and they're pretty fun. Now second, we're accepting donations now. So go to the support tab at www.titaniumphysics.com. We accept Paypal, Patreon. You can buy an awesome t-shirt. We're doing it all. There are some nice rewards but the more help I get from you the better the show is going to be. Now third, a new podcast, it's called *Question Barn*. In essence, people send me questions and me and one titanium physicist will be answering them and I'll try to put it out weekly. So send your questies to Tiphyter@titaniumphysics.com. We'll answer them on our weekly podcast and it'll be really, really fun and I'll put it on this feed. So you won't really have to do anything. Now fourth thing, the *Titanium Physicist* podcast is a member of the Brachiolope Media Network. So remember, if you like listening to scientists talk about science in their own words give it a listen. It's fun times. We've got Science...sort of and *Astrarium* and a bunch of other ones. Just click Brachiolope Media Network on the itunes website. You can see all of the shows there, it's great. Now, this episode of the *Titanium Physicists* podcast is brought to you by a bunch of people: Joshua Walsh, Brian Brazzle, Keanan Arlin, Robert Shtetca, Rob Aberzado, Mr. S. Hatcher, Jocelyn Read, and Kelly Wienersmith. Thank you very much for your donations. Well that's it for this episode, until next time my friends. Good day and remember to keep science in your hearts.

[40:20]

Kat: Ok, when you're taking pictures of galaxies and stuff does the telescope or how you're taking pictures, does that affect the color of them?

Sean: Ah. It's our dirty little secret is that we only take pictures in one color at a time. So we take a picture with a telescope through a blue filter and it comes out black and white on our little CCD digital camera and then we put another green filter in front of our camera and take a picture through that filter. So it's more expensive but it's sort of like a piece of blue cellophane, a piece of green cellophane, and a piece of red cellophane. And then we only stitch them together into a real image afterwards. So it's all kind of by hand that we make the pretty colored images afterwards because you know color is sort of an art.

Kat: So it's easier to take the picture in black and white and then put the color back in?

Sean: Yeah, it's easier to measure how much light in a particular color when you limit yourself to only taking a picture with blue light at one time or red light at one time. So to make real scientific measurements it's really best to keep them as separate as possible and even to divide it up finer than that if you can. But sometimes it's nice to just put them all together in an image and look at them by eye.

Kat: Yeah because I'm assuming most of the pictures being taken are for actual quantitative study not because people want to see pretty pictures of the galaxies.

Sean: Exactly.

Kat: Kind of a byproduct. That makes sense.

[41:54]

Ben: As soon as someone is like “Hey Ben correct some misconceptions about black holes.” I’m off leash man. That’s the nice thing about editing this podcast is that I know nobody is going to have to hear my ramblings.

Laura: But one of the misconceptions is that as we were saying stuff gets sucked in. Ok so we just established stuff doesn’t get sucked in. We’ve also tried to explain why you can’t see a black hole but we do know it’s there. So what are other misconceptions that need to be cleared up?

Kat: I don’t know how much of an actual misconception it is or just the stuff I watch or read, but the whole concept of if you go into a black hole you either a) get squished down into little itty bits, which maybe you do or b) you go into another kind of… I guess treating a black hole more like a worm hole or something like that.

Laura: That’s some of the stuff we can’t answer. Some of that is imaginative, to say the least. But I thought you’d don’t get squished down in it, you got really stretched out.

Ben: Both.

Kat: It depends on who’s writing.

Ben: No, no, it both happens. First one and then the other. So essentially, you know about tides right? Like the earth’s oceans feel a tide from the moon. And the reason it is is that the earth feels a different amount of gravity from the moon depending where on the surface of the earth you’re standing because the earth is pretty big compared to the inside of the gravitational field of the moon. So if you’re on the back side of the earth you’ll feel less force than on the front side. And the deal is that water always kind of wants to live in a shape where it feels kind of no net force. Everywhere over the top of the ocean needs to feel the same net force. So moral of the story is tidal forces squeeze you together and stretch you apart. So it kind of squishes you like a football. It would squish a soccer ball into the shape of a rugby ball. And the deal is that tidal forces are pretty weak. They affect the oceans but only because the oceans are huge. But the deal is that if you get fairly close to a black hole your body will start to feel the effect of tidal forces. So if you're falling foot first into the center of a black hole your feet will feel a different amount of force pulling you towards the middle than your head will. And the overall effect is called spaghettification because these forces, the forces required to create a black hole, are much stronger than the forces that keep matter in shape. I mentioned that before. So what happens is as you're falling towards a black hole, these tidal forces become stronger than the atoms' in your body ability to maintain their shape. And so you get squished down into a spaghetti shape. And that happens before you hit the center. It will happen midway on your trip down to the middle of the black hole. Once you hit the middle of the black hole there is something called a singularity. And it's actually an honest to goodness mathematical singularity. I've got to do a show about it. One of the reasons Stephen Hawking's name will be remembered forever in the history of science is because he was the person who demonstrated that there's a mathematical inconsistency in the laws of physics, in Einstein's theory of gravity that happens at the center of black holes.

Laura: So when Ben says a mathematical inconsistency he means something like you end up with an equation that says one equals zero.

Sean: Or you divide by zero.

Laura: Or you divide by zero.

Ben: No, no. There's a logical inconsistency in the equations. So what happens is in a theorem you'll have various things that have to be true…

Laura: You get a bunch of things that should be true when you put them together but they aren't.

Ben: Yeah, you get something inconsistent. So if you're solving a detective story or something you'll put together everybody's story and there's always like one fact. And they can't all be true at once and you try to figure out what's inconsistent in there. And you're like "Ah, the butler did it!" His story doesn't match everybody else's. His story can't be true if everybody else's stories are also true. So when they do this with the laws of physics near the center of a black hole, they write down a few things that seem like really reasonable propositions as we understand the laws of physics today. They're essentially laws that are physically true. And when you reach the center of a black hole those laws all can't be true at the same time. And so there something flawed with Einstein's theory of general relativity at the center of a black hole. And what this tells us as physicists is that the model that we use to describe black holes can't be true. The physics are fundamentally inconsistent near the center. So there's somewhere around the center of a black hole where something else has to happen. And we don't know what the answer is. We just had no idea. I mean there's different people, string theorists try to talk about it, but nobody has any answers. You can essentially get a PhD in speculative mathematical fiction at this point in time.

Sean: Which we have.

Ben: Yeah and I have.

Laura: Well we didn't say you…

Ben: So essentially what will happen is if you hit the middle, when the matter that was once making up your body hits the middle of this, nobody knows what happens.

Sean: That's why it's so great for science fiction.

Laura: Yeah in science fiction they imagine there are other worlds, other universes, on the other side. You could really make anything up and we couldn't tell you that you were wrong.

Ben: Yeah because we know that we don't know what happens there, one of the solutions people do is they say well what if instead of collapsing down to the middle, what if you get shunted out somewhere else in the universe or in some other universe. And those are kind of worm hole theories and they're pretty fun but nobody knows for sure.

Laura: We can't prove that.

Ben: Yeah.

Kat: Yeah there's a fine line between science and fiction. And when they come together…

Laura: Science fiction.