Episode 77: Disruptive Feedback
Physicists: Victoria Scowcroft, Carolin Villforth

Transcribed by Denny Henke

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 fifty 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 birthright, an understanding of the universe. I've traveled 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 Physicist Podcast and I'm Ben Tippett, and now allez physique!

Ben: You. Yes, you. You're having a hard time, I know you are. But don't give up. No one has told you lately how much your bravery impresses them. How much your cleverness inspires them or how much they appreciate your diligence, and you are so diligent. We all see how hard you try and it makes us want to try just as hard. No one has told you because we just don't talk about these things to anyone, but you are an inspiration. I'm only telling you this because you're having a hard time right now. I know it hurts but don't give up. Keep trying, things will get better. Life keeps knocking you on your butt but we're cheering for you. Every time you get back up it makes us stronger. Every time you don't give up it makes us braver. You are an inspiration. Thank you for trying so hard. Thank you so much. Everything good that comes to us tomorrow will be because you were brave when it mattered. And because we didn't give up. Please don't ever give up. Rest when you need to. Take a break when you need one but you are good, you are so good and we appreciate your diligence and your cleverness and your bravery. I mean, look at a galaxy. All those hundreds of billions of twinkling stars and at the center a supermassive black hole. The galaxy of stars is your life and everything good and interesting. And the black hole is all of your hardships. But it's not the black hole that causes the galaxy even though it's bigger than everything and at the very center of things. The galaxy isn't there because of the black hole and you know what? The black hole isn't there because of the galaxy either. They are just two parts of the same thing. A galaxy's evolution depends on the black hole and the black hole's behavior depends, in part, on the galaxy. But you've gotta know that when we admire the galaxy from afar all we see is a network of brilliant stars. All your heroism, all your patience, all your kindness. We know that it's shaped by that big black hole at the center and we also know that you're so, so much bigger than that. So, never give up. Never stay down. Never stop shining for us. Today on the Titanium Physicists Podcast we're talking about the supermassive black hole at the centers of galaxies affects the formation of the galaxy around them and how the shapes of galaxies tells us about their history. Now, speaking of digging back into our history, our guest today is an archaeologist. She's also a web comic artist and a comic writer and letterer. Her web comic, *The League of Mad Scientists* has been going on for 10 years now and her writing and lettering work can be found at her website courtneybrookedavis.com. And we all look forward to her upcoming superhero miniseries *Physgig*. Welcome to the show Courtney Brooke Davis.

Courtney: Oh my gosh, thank you so much.

Ben: Before we go on I want to make a short note here that I've started a new thing at the Titanium Physicists Podcast. We're going to have listeners, regularly, on the shows as guests. So, if you'd like to know more, I'll give you the details at the end of this episode but the short version is, follow us on Twitter and Facebook.

5:00

Well, Courtney, for today's show, it's going to be magnificent. An old friend is returning and she's brought a colleague with her to join our crew. Arise Dr. Victoria Scowcroft. Dr. Vicky did her PhD at Liverpool John Moores University and she's currently a Prize Fellow at the University of Bath where she uses variable stars to map the universe. And arise Dr. Carolin Villforth. Dr. Carolin got her PhD at the University of Turku and she's currently a lecturer at the University of Bath where she studies active galactic nuclei. Now, alright everybody, let's talk about galaxies. Okay, Courtney.

Courtney: Yes.

Ben: Have you ever looked at a picture of a galaxy?

Courtney: I have.

Ben: Okay, good. Galaxies are big globs of stars out there in the universe, right?

Courtney: Yeah.

Ben: They're all stuck together with gravity. Just like a city of stars, they all live together.

Courtney: Mmmhmmm.

Ben: In today's topic we're going to be talking about how the super massive black hole in the center affects the growth and the shape of the galaxy. But, to go any further with that we need to talk about, like, the different parts of the galaxy.

Courtney: Alright.

Ben: The first thing you know about galaxies is they are made up of stars, right?

Courtney: Yeah.

Ben: There's more to a galaxy than stars but stars are the big thing that pops out when you look at them.

Courtney: Mmmhhhmm.

Ben: Let's take a galaxy like ours. It's a spiral galaxy, right.

Courtney: Yeah.

Ben: Spiral galaxies usually have two parts. There's a part called the disc which is a big disc of stars that move, kind of looking like a spiral. Right?

Courtney: Mmmhhmmm.

Ben: And at the center of it there's something called the bulge. Now, the bulge is a little spherical distribution of stars right in the center.

Courtney: Yeah, is the bulge then what we call the Milky Way part of our galaxy?

Ben: The disc is the thing that we recognize as the Milky Way.

Courtney: Oh, okay.

Ben: When we look at the Milky Way, it looks like a big streak, a big ribbon through the sky because we're looking at a disc from the edge on. Like, if you hold up a plate and then turn it sideways so that you're looking down the edge of it.

Courtney: Mmmhhmmm.

Ben: That's why it looks like a line

Courtney: Mmmhhmmm. Ah, okay.

Ben: So, the disc, its pretty big. 30,000 light years in radius. So, that means, traveling at the speed of light it would take 30,000 years to get to the middle. They're big. The bulge, it's about the 10th of the radius of the disc. So, the disc is really, really big. It's like a pizza plate and then the bulge is kind of ah, medium sized ball stuck in its middle. So, in addition to this, other aspects of astronomy have told us other aspects to the galaxy than just the stars. There is a supermassive black hole in the middle in the center. The super massive black hole in the center of the galaxy has about a .1% of the mass of the overall galaxy. Just so you know in terms of like, what weighs more, what has more mass, the supermassive black hole, it's a million times the mass of the sun but there are 100 billion stars. Or rather, our galaxy has a 100 billion solar masses worth of atoms and stuff in it. So, the supermassive black hole is huge in terms of human size. But, it's actually not that large in terms of the overall galaxy. So, if you want to talk about the stars in orbit around the galaxy, most of the stars in orbit around the galaxy, you can't say that they are orbiting the black hole at the middle. The black hole at the middle is a part of the mass that they are orbiting, but mostly they are just orbiting the collection of other stars in the galaxy.

Courtney: Huh. They are all orbiting each other, affectively?

Ben: Yeah. They're orbiting each other. So, the supermassive black hole is a part of that but it's not a huge part of that.

Courtney: Mmmhmmmm.

Ben: If Doctor Strange came along and made the supermassive black hole at the center of our galaxy disappear, it wouldn't affect how most of the stars orbit very much.

Courtney: Okay. It's...

Ben: It's not huge. So, in addition to that there's dust and gas. Not all the baryonic mass, the atoms, in our galaxy are in stars. Most of it is in dust and gas which is kind of shaped in a disc shape. Kind of distributed inside the disc where most of the stars are.

Courtney: Okay.

Ben: And that's not a coincidence. Because what happens, the way that galaxies form, is they start out as great big clouds of dust and gas and then over time they are kind of rotating and they kind of collapse down. They are feeling the gravity of all the other dust and make this big blob of gas that will kind of collapse down into a rotating disc. And then inside, once it is a rotating disc, the density of gas and dust there is big enough for small pockets to collapse and make stars. You're seeing the stars form where there there are dust and gas. The dust and gas are where the stars are not because the dust and gas likes the stars but the dust and gas was there first and the stars formed out of the dust and gas.

Courtney: Got it. They are the stuff that stars are made of.

Ben: Right. Last step. There's something called the halo. The halo is like a huge sphere of material that's kind of orbiting our galaxy but it's not, it's outside the disc.

Courtney: Huh.

Carolin: Though, it's not really around it, it's more like it's everywhere. So, rather, like if there were a big something squishy and then the galaxy would be in the middle of the something squishy.

10:00

Carolin: It's more like that. So, it isn't, like, surrounding it, it's all around and we live inside it, if that makes sense.

Courtney: Oh, okay.

Vicky: And there are stars there too. It's just a lot less.

Courtney: Can there be stars, like, outside of a galaxy? Like, it sort of detaches and floats off or something? Like there's a star but there's no galaxy around it? Is that a thing that can happen?

Vicky: I think they can get kicked out.

Carolin: Yeah.

Vicky: Like if they interact with each other but I don't know that they would necessarily form outside of a galaxy.

Carolin: They wouldn't necessarily form outside of it but they'd be very hard to observe because there'd be a single star far away from anything else so it would be very hard to see. But if you have galaxy collisions basically, some of the material would basically get thrown out. And they would just be somewhere outside of the galaxy. So, you wouldn't be able to observe like an individual one but they must exist.

Ben: So, the last aspect to this, is that the halo is much, much, much bigger than the disc. The halo is like 50 times wider than the disc. And also, in terms of mass, the halo's got a lot more dust and gas in it than the disc does.

Courtney: Okay.

Ben: So, it's kind of like coyotes. So, some of the coyotes are in the town but most of the coyotes are still running around in the countryside on their own.

Laughter.

Ben: I guess in England that doesn't make any sense but…

Courtney: I live in California so that makes total sense to me.

Vicky: They're like badgers.

Carolin: They're like badgers, yeah.

Ben: As many badgers as there are in the town and you see badgers a lot, there's still a lot more out in the countryside. Okay, so, these are the different things that are going to come up over and over and over in our talk. Essentially, there's going to be disc of stars, there's also the halo of gas around it. And you can usually see, like, ah, emissions from those and like, ah, radio waves and stuff. There's ah, the supermassive black hole at the center and then, ah, the thing that determines where stars go is kind of like where all the dust and gas is. Got it?

Courtney: Okay. Yeah.

Carolin: So there's these galaxies, ah, and this is basically until the 60s or so, ah, these components is what we thought galaxies are made of. But actually, there's something more exciting that can go on in the centers of galaxies and that is, in some cases, a black hole is accreting, meaning that a lot of gas is falling into the black hole. So what happens if you have a large gas cloud that gets near a black hole it will get disrupted and it will form what we call an accretion disc. So, basically, it will start rotating around a black hole in a disc like structure. So, like a little spinning blade, actually quite similar to disc galaxies, just much, much, much smaller. Um, and what happens is that within the accretion disc, ah, the gas will start to heat up to a very, very high temperatures. So it radiates, so it will become very, very bright and that is an accreting black hole.

Courtney: So, the black hole, instead of being black, it's got something around it that is like, shiny and bright?

Carolin: Yeah, very shiny, very bright. Yeah.

Ben: Have you seen the movie *Interstellar*?

Courtney: Yeah, I did.

Ben: Yeah.

Carolin: Yeah, that.

Ben: They take a little trip to a place with a black hole and it's bright. The little solar system there is super bright and the reason is, because you've got an accretion disc around the black hole that is shiny.

Courtney: Okay.

Ben: It's radiating light because it's really, really hot and that lights it up better than a sun would.

Courtney: Was that the one where like, there were these super high waves and stuff?

Vicky: Yes.

Carolin: Yeah.

Vicky: But the physics in that film were, like, legit. They worked with physicists to get all of it right. So, it's a really cool film.

Courtney: Accretion discs?

Carolin: Yeah, accretion discs. So, now we've got an accreting black hole and so that accretion disc around the black hole would actually be tiny. So, it would basically be, a few light weeks to light days across so that's really, really tiny area. But within that accretion disc, due to the black hole, a lot of energy is released. We say that a black hole is very efficient at creating radiation. Like, if you want to create light, you could burn something which is not very efficient at creating radiation. And then one of the things we, on earth, to create energy, would be fusion like what we have in the sun. If we say that the sun is our gold standard for releasing energy for mass, that has an efficiency of somewhere below a percent or so at releasing energy from mass, at, creating radiation from atoms.

Courtney: Huh, wow, the sun sucks.

Carolin: Yeah, the sun sucks. Black holes are so much better because black holes can release energy at about 10% of the rest mass. That is absolutely fantastic. So, if we had black hole accretion on Earth, all of our energy problems would be solved.

Courtney: Yeah, let's do it. Let's have black holes everywhere.

15:00

Laughter.

Courtney: I see no downside to this.

Vicky: Yeah, me neither.

Carolin: So, this 10% of rest mass energy means that this tiny, tiny area around the black hole, much, much smaller than the overall galaxy, can be a hundred times brighter than the entire galaxy.

Courtney: Oh wow.

Carolin: Yeah, it's absolutely amazing. That is basically, the black hole being so efficient at creating radiation. And so, if you have an accreting black hole at the center of the galaxy, it will basically outshine the entire galaxy.

Courtney: So, what's it like when you're on a planet and a star in that galaxy, like, you don't get night time or?

Carolin: That is a good question!

Courtney: I am a huge sci-fi buff so all I think about is like what it's going to be like for people on these planets. Like, that's nuts to me, like, it's just bright all the time.

Carolin: So, it would depend a bit, so one thing, you have the accretion disc, and that emits a lot of radiation but there's also other structures around it. So, one of the things that would matter for a person living in a galaxy with an accreting black hole is that there's a dusty torus surrounding the accretion disc. So, that's something that basically looks like a donut that's surrounding the accretion disc. And that's very dense dust and gas and so on and that means that if you're looking at a - at creating a black hole from the point of view where you're looking through that donut structure you won't see much of the accretion disc because all the radiation is absorbed there. So, if you sat in a galaxy and you've been looking side on at your donut then your night sky would possibly be kind of fine. If you were looking straight into the accretion disc, yeah, that would be quite bright. Yeah.

Courtney: So, just like in tv, location is everything.

Carolin: Yeah, location is everything.

Courtney: Wait, so, does our black hole have an accretion disc?

Carolin: No, no, it doesn't.

Courtney: Oh, okay.

Vicky: But yeah, so, we originally didn't know what these were and then they were like, what is this thing, why is it there?

Carolin: So, actually the whole quasar thing came about, I guess I'm doing this kind of upside down because now we already explained what an accreting black hole is and now I'm telling you how they were discovered.

Courtney: So, wait, an accreting black hole is a quasar?

Carolin: Ah!

Vicky: Yeah! Surprise!

Ben: So, astronomers detected these weird things called quasars which stands for quasi stellar radio source and were like hey, we see these weird bright things out in the universe. We don't know what they are but they are emitting a lot of radio waves ah, and we know that they are small.

Courtney: Yeah.

Ben: So, we know that they are not wide like a galaxy. They are small like, you know, a solar system. Okay?

Courtney: Okay.

Ben: Quasi stellar radio. Um, so, we called them quasars and we didn't know what they were. And so, what we've discovered is that quasars are the, when the black hole at the center of a galaxy has an accretion disc, that's what a quasar is.

Courtney: Oh, okay.

Ben: Okay. I mean, there are other black holes in our galaxy that might have accretion discs, but it's the big one in the middle that makes a quasar.

Vicky: Because we didn't know what it was, they gave it a name which is really not anything to do with what it actually was. And then they figured out what it was and it was tiny because you were just seeing the bit at the center that was outshining the entire galaxy.

Courtney: Right.

Vicky: And then once we got our observations they were like, oh actually this is what it really is.

Courtney: So, a quasar can only be the black hole at the center of the galaxy because it is a size thing?

Carolin: Yeah, yeah. So, you also have smaller accreting black holes, those are the black holes throughout the galaxy that accrete but they'll be like a solar mass and they won't dominate the emission of the whole galaxy and the structures around them will be slightly different. So, basically, quasars are, you need, like a super massive black hole, so, say more than a million solar masses or so and those are found at the centers of galaxies. So, that's a quasar.

Courtney: Can black holes get bigger?

Carolin: Yeah. So, all of the black holes that we see at the centers of galaxies, they have masses of say, like, millions to billions to tens of billions of solar masses and we know that they did not form at these masses. So, we know that those black holes were formed at the very beginning of the universe and they might have been at the very beginning, maybe 10 solar masses, maybe thousand solar masses, we really don't know. And then, through the history of the universe, they were accreting. And that accretion, accretion, we talked about, that creates all that radiation, is also something that feeds the black hole. So, that accretion disc, basically, as it circles around the black hole, once it gets near it, the matter will fall into it and then increase the mass of the black hole. So, while you have a quasar, that also means that your black hole is growing.

Courtney: Does that lend the possibility that black holes that aren't at the center of galaxies could eventually, given enough passage of time and things falling into them, like, turn into quasars?

Carolin: I guess, yeah. It would just take them a long time.

20:01

Ben: Um, it's possible for one black hole to eat enough to become a really, really, really big black hole. But it's kind of like, ah, for a black hole to eat something, the thing pretty much has to run into the black hole. And the probability that that is going to happen is pretty low. So, ah, the black holes at the centers of galaxies are really, really big because they formed and started accreting, started eating other things, started increasing their mass, back when the galaxy was forming and there was lots and lots of stuff to fall into them. And now there's less stuff to fall into things so if you have a black hole it's not going to get big fast the way the one in the center of the galaxy did.

Courtney: Unless a crazed super villain starts chucking stuff in there.

Ben: Yeah, that's right, yeah.

Carolin: But that black hole might be in a galaxy that already has a supermassive black hole in the center so as it's evolving, as it grows in mass it will also sink to the center of the galaxy and then just merge with the bigger black hole.

Courtney: Oh.

Carolin: Yeah.

Courtney: So, I was going to ask, why do some black holes accrete and some don't?

Ben: Okay, so, accretion is about stuff falling into the black hole, right? So, if you have a one solar mass black hole and you throw a 1kg bowling ball into it the black hole will grow and become a one solar mass + 1kg black hole, right? I mean, they only grow by having other material fall into them. So, when we talk about accretion and accretion discs, it's kind of like, you have a black hole and it's sitting there out in space and then a big cloud of dust that is kind of floating around minding its own business runs into the black hole and then it gets close enough to the black hole that it starts orbiting and starts falling into the black hole. And that's what an accretion disc is, it's just a wandering cloud of dust that bumped into the black hole. So, whether or not a black hole is accreting or not isn't really a property of the black hole, it's the property of whether something is wandering close enough to it.

Carolin: In fact it will depend quite a lot on the galaxy. So, the question then is, is there gas and dust around that will come near the black hole. And that depends on the properties of the galaxy. So, if you look at our Milky Way, the Milky Way is kind of stable. So, we said before that basically the black hole, you can't really feel the black hole. The black hole, while it is relatively massive it has only a minimal mass in the overall galaxy. So most gas clouds won't really be bothered by the black hole. So, mostly, to get something to accrete onto it you need to have some kind of instability in the disc or you might have some disturbance to the gravitational potential that would kick something to the center. And the probability of that happening will depend on your galaxy. So, say, if your galaxy is going to collide with another galaxy that is really quite a good way to disturb the gravitational potential, to really give gas a kick that would drive it to the center near the black hole so it can accrete. If you're a galaxy with not a lot of gas in it, the stars are not very keen to fall into the black hole because they don't have a lot of ways to, you know, get kicked around so then, mostly likely, not a lot of gas will fall into the black hole. If you are a disc galaxy like the Milky Way every now and then there will be interaction between gas clouds that drive gas to the center so you have accretion but the likelihood is not high. So, the answer to that question is, it's really complicated and this is an active field of research into what you're trying to figure out now. But really, it depends on the galaxy.

Courtney: So, does that mean our galaxy isn't all eventually going to get eaten up by the supermassive black hole at the center? Are we okay?

Carolin: Yeah, we're okay. We're fine.

Vicky: For now at least.

Ben: I have a stupid metaphor. Okay, so just imagine a toddler and then imagine a toddler eating a pudding. And so they are all covered in pudding. Being covered in pudding isn't a property of the toddler it's a property of the toddler being too close to some pudding. Okay? So, whether or not the toddler in the center of your house is covered in pudding depends on how much pudding there is in the house.

Courtney: Oh my god, I have a one year old niece so this is a perfect analogy for me. I can just imagine her covered in pudding.

Vicky: I feel like this doesn't just apply to toddlers.

Ben: Okay. To summarize, when the black hole starts eating gas you get an active galactic nucleus which people used to call quasars. Which is, essentially, when the accretion disc of the supermassive black hole shines so bright that it outshines the galaxy. It's a hundred times brighter than the galaxy. It's just really, really bright. So, if one of these is happening and you have your telescope pointed that way you won't see the galaxy anymore. The accretion disc of the super massive black hole will outshine the galaxy. Does that make sense?

Courtney: Yeah. You said they used to call them quasars. Is that term no longer used by the community?

Vicky: It depends on the age of the astronomer.

Carolin: Yeah, people still use it. It's just confusing… use it today.

25:01

Ben: I mean, quasar is the name of the phenomenon and then active galactic nuclei tells you what's going on. Which is the nuclei of the galaxy is active.

Carolin: Yeah.

Courtney: Okay.

Ben: So, before we go on, I want to emphasize something here. It's something we talked about at the very start when we talked about why the dust in our galaxy is in the same place as the disc. Which is that the dust was there before the disc was. All the new stars get made where the dust is densest. That's where the brightest stars are going to be made and that's where stars are going to show up most often. So, in some way, tracking where stars are made comes down to tracking where the cold dust is. In other words, tracking where stars are going to be, comes down to tracking where the gas is, where the cold gas is. So, you know, it's really important if you're going to talk about, you know, say, modeling galaxies. Trying to come up with ah, simulations that describe where and why a galaxy is a certain shape or size. It's really important to then track where all of the dust and gas goes.

Courtney: Okay.

Ben: As the galaxy evolves.

Courtney: Now, I have a question about the term cold gas. Why is it cold gas. I guess, why not just call it gas, I guess?

Carolin: Because it comes in different temperatures. Basically, throughout the galaxy, the gas will have different temperatures. If you're going to form a star you need a lot of material in, basically, a small volume. You need to make it very compact. If you have something that is quite warm, it has a high temperature, like, let's say, if you take a ball of gas and you heat it up it's going to expand because you're going to increase the pressure. So, if you want to make stars you want the gas to be cold because then it can be more compact and close together and make your new stars.

Courtney: Okay, I got ya.

Carolin: Does that make sense?

Courtney: Yeah, yeah, the density is enough to bring them together more.

Carolin: And to get a high density it needs to be cold.

Courtney: Alright, I get it.

Vicky: If it's cold it can collapse in on itself. If it's hot it won't let itself collapse.

Carolin: Yeah, and so basically in a galaxy you'll have this cold gas but then you'll also have this warm and hot gas so up to like a million degrees. And the cold gas will maybe be, in Kelvins I could say 10^{100} Kelvins or so. That's your cold gas that you need to form a stars.

Courtney: I don't know much about the Kelvin system so I'm going to assume that's cold.

Vicky: So, it's like -100 Celsius.

Courtney: Oh, trust me, I still understand -100 C is.

Carolin: Yeah, bloody freezing.

Vicky: Yeah, bloody freezing.

Courtney: Yeah, it's a little bit beyond what they'd call sweater weather.

Ben: You're familiar with absolute zero right? Absolute zero is when the thing has no temperature at all.

Courtney: Yeah, like everything stops moving.

Ben: So, we're talking about gas that's just a little bit above absolute zero.

Courtney: Oh jeeze.

Carolin: Yeah.

Ben: Luckily the universe is a pretty cold place. Like, the temperature of the universe is even closer to absolute zero. So, if you just have gas out in space it will cool down and reach those temperatures eventually.

Courtney: The universe is pretty cool you guys.

Carolin: Yeah.

Vicky: That's why we are the coolest people in the physics department.

Carolin: Yeah, I know. Not like these photonics people with their lasers.

Vicky: Okay, so, in the, like, the 90s and 2000's, they had models of, like, how galaxies evolved and they didn't really match up with what we were looking at in the observations. And they couldn't explain everything about galaxies, like, how the stars formed and how galaxies looked different when you looked at old galaxies and young galaxies and things like that. By that point we knew that AGN (active galactic nuclei) existed but one of the things that weren't going into these models and simulations was AGN. They were just like doing these simulations of galaxies but pretending that AGN didn't exist and just being like, ah, well a galaxy has stars and things in it but nothing about the black hole. So, then, what they did was put AGN in it to see if that would affect anything about the galaxy. And Carolin already said earlier that they are quite small in terms of mass and physical size, so you know that it's not really going to affect, like the orbits of the stars very much or change the mass. We would want to think about the other was that AGN would affect the galaxy other than things like gravity. So, that's when they had to think about what affect the accretion and the other physics would have on what was going on inside the galaxy.

Carolin: So, what was wrong with the galaxy evolution models was that they were making too big galaxies. So all the simulations they ran the galaxies were just way too massive so they were really over producing stars. So, what they wanted and what they got the AGN for, was, they wanted something to shut down the star formation. That's what they needed. Because otherwise those models weren't going to work.

30:04

And basically, I mean, they didn't just say, oh well, you know, something is broken, why don't we just try AGN. I mean, it didn't go like this because already, long before this, people thought about the fact that all that energy that was being emitted from the AGN was so huge, so fundamentally massive that if you could find some way, to basically couple that to matter in the galaxy, you could make a huge impact. So, basically, if you think about it, so there's this black hole here, it has this accretion disc and it's emitting all this radiation. If this radiation just escapes it will do nothing to the galaxy because it's just left the galaxy straight away. But, if it interacts with the gas and the dust in the galaxy, it can have an impact. And it can have that in several ways. So, one thing it could do is, basically, it could be absorbed by some dust or gas in the galaxy and it could heat it up. So, basically, a photon gets absorbed, you have more energy in the gas, it will now be hotter. It would add a lot and basically you increase the temperature.

Courtney: So, it's no longer that cold gas.

Vicky: Exactly.

Carolin: Exactly. We talked about this that we want the gas to be cold to form new stars. So if I'm pumping a lot of energy onto my gas and then warming it up, it will be less likely to form stars. The other thing I can do is, basically, try what we call, an outflow. So, all this radiation that is coming away from the accretion disc that might hit particles, like, say, dust or something. And that emission has a momentum, so basically, if it gets absorbed by a particle it will over-kick it a bit and if you now bombard some cloud of dust and gas enough, you basically give it quite a few kicks and you're starting to accelerate it and you can then drive it out of the galaxy and that is what we call an outflow. That's basically like a flow of gas moving away from the center of the galaxy. And if you do that, what you have, an AGN in your galaxy and you start driving an outflow, you're basically taking all that nice gas and dust that might be forming stars in the future and you're just removing it from the galaxy. So, both of those effects are methods to, basically, lower the star formation in the galaxy which is exactly what the theoreticians needed for their models. Yeah, there's also something else called jets. Yeah, but we ignore… So, basically, those outflows are something that can really affect the galaxy. And the amount of energy that is coming out of the AGN, we've had those calculations for a long time, it's enough to have a massive impact on the galaxy. This is what we call AGN feedback.

Courtney: So, galaxies that have AGNs are smaller? Does this happen with every galaxy with the black holes, cause you said about the AGNs, that's the accretion disc black holes, right? So, are galaxies with those black holes with accretion discs, then, smaller in general then, like, our galaxy?

Carolin: Um, so, that's difficult to answer because first of all, having an accretion disc is not a long term property of a galaxy. So, every black hole in the center of a galaxy, it will be on sometime then off again then might be on again in the future. They turn on and off.

Vicky: It depends on which pudding is in the house.

Courtney: Aw yeah, you ran out of pudding but then you went to the store, you got more pudding.

Carolin: Yeah, exactly. Yeah.

Ben: It's like, if everybody in the house was working on making stars, I guess. But then every time the baby got his hands on pudding everybody had to stop working because all the things they were working on were then blown out the window. Now we all have to stop star formation for a little while because the stuff we were building stars out of just got blown away.

Courtney: So, it's probably happened with our galaxy, that the black hole has had an accretion disc at times and this has affected the size of the galaxy and how many stars are formed.

Carolin: Yeah, so what the feedback does is actually very questionable. So I said, aw, you know it could do all of those things but its not like if the Milky Way black hole suddenly got active all star formation would shut down immediately. Because while there is a lot of energy coming out of the accretion disc it's only coupled to the matter around. So, we talked about that donut of dust earlier. So, basically the accretion disc has a direction. So, if you drive some kind of an outflow it will be, mostly away from the accretion disc.

Vicky: You've got your accretion disc like a plate and then, it's not going to go across the direction of the plate. It's going to go up or down, right? But it's not going to go horizontally.

Ben: I want you to think of a fan, okay? So, there's this thing that blows, in this case, photons. It makes lots and lots of photons but you can think of it like a wind going out, pushing everything away from it. If you're on the side of the fan you're not going to feel that much photon pressure. So, it's not going to disturb you much. Whereas if you're right in front of it you're going to get blown at hard.

35:01

And so, it's not a big spherical expansion of pressure, instead the pressure is big in some places and small in the other. And so, Carolin is saying that this is kind of a subtler effect on star formation. Essentially we're talking about gas getting heated up and blown around. And it doesn't blow all of the dust out of the galaxy instantly, some of it goes out but not all of it.

Courtney: Does this then affect the shape of the galaxy? Cause like, we said before, our galaxy is a spiral galaxy but not every galaxy is a spiral galaxy. So, does this, like, help determine what the overall shape of the galaxy is going to be?

Carolin: So, the reason it's a disc galaxy is because there is rotation. To turn a disc galaxy into not a disc galaxy you basically have to redistribute the kinematics of the stars. You have all your dark matter and all your stars and unless you change the distribution of that fundamentally the kinematics is not going to change.

Courtney: Okay.

Ben: We did an episode a few years ago about different types of galaxies and how there are elliptical galaxies and spiral galaxies. Ah, and the argument was that elliptical galaxies come about when you have two galaxies that smash together. Like the Andromeda galaxy and the Milky Way are going to collide one day. When they collide, galaxies are mostly empty space so it's not like stars will collide with each other. But what eventually happens is you get a big flow of gas and dust that hit the super massive black holes at the center of these galaxies. And so when two galaxies collide sometimes you get active galactic nucleus which is really, really, really big that then blow all of the dust and gas away. And in these situations, what we would call an elliptical galaxy is when all of the dust and gas is blown away and so you don't get any new star formation. What we call spiral galaxies are because all the dust and gas are in a disc so that's where all new stars, the new bright stars form. So, when you get two galaxies smashing together and the active galactic nucleus blows all the gas away you don't get any new stars forming and so you don't see any pattern of star formation. Instead, the galaxy is made up of all the other stars that are still around that are just kind of orbiting the center mass so you get a big glob shaped galaxy without any cohesive pattern to it. So, that's the extreme case of this, I guess, is what I'm saying. It can affect what the galaxy looks like in really, really extreme ways. But I guess what Carolin is trying to tell you is usually it's not that extreme. Usually the active galactic nucleus isn't so bright that it blows all of the dust out of all of the galaxy. Instead it blows some of the dust out of the galaxy and it blows the dust around and it heats up other patches so stars don't form there. But she's saying that for the most part it's not heating up or blowing away the entire disc so you still kind of have a disc, so, you still kind of have the new stars forming in a disc so it still kind of looks like a spiral galaxy.

Vicky: Should we talk about the halo now?

Carolin: Everyone loves the halo don't they?

Vicky: Especially Beyoncé.

Carolin: Yeah, especially Beyoncé. So, basically, let's say you've now made a really nice outflow and those outflows can be really powerful so if you have the AGN the gas will be moving away at like thousands of kilometers per second. So, it will clear away quite a lot of gas. And those velocities are high enough that basically mostly escaping from the galaxy so they're not directly falling back on. So, you're basically, like, pushing the gas away. But as it pushes away it will move into the halo. So, in the beginning we talked about this massive bubble of gas of various sorts that surrounds our whole galaxy and then basically outflow will go to join the halo. Um, and halo is very, very hot. So, gas in the halo can be like, up to a million degrees or so. There's also colder patches but generally it's quite hot. And the halo just sits there and what it does, annoyingly enough, so, if we now thought, oh, that will shut down star formation because we removed the gas in our galaxy and we pushed it up into the halo and we're fine, we're no longer forming stars. What the halo gas will do is it will cool back down and it will return gas to the galaxy in a nice cold form. So, your halo is basically some kind a reservoir that will keep feeding gas back onto your galaxy because you have just this massive bubble of gas and at anytime it's ready to return gas onto the galaxy.

Courtney: It's more like the timeout space.

Carolin: Yeah, it's a very, yeah, it's like a timeout space for the, so...

Courtney: Yeah, galaxy got too hot! Go cool down for a bit and come back when you're ready.

Carolin: Exactly. So, basically you pushed all your gas into the halo and it will come back down again. This is, I guess, quite disappointing in the forms of shutting down star formation and everything because you're just postponing it.

Vicky: Yeah, you're just like, well we shut down star formation, look, all my model's are great. But then it's like, oh no, here's star formation...

Carolin: It comes back down. But then again AGN also has a special superpowers, it has something we haven't talked about before which is the jets. So, jets are basically outflows from the black hole and they move, basically, at almost the speed of light.

40:01

So, our outflow is at like a thousand kilometers per second or so which is quite fast. But the jets will move at almost at the speed of light. So those outflows, they were relatively broad. They don't fill the whole sky but they fill some part of the sky. So, they have an opening angle or something like 45°, something like that, a bit larger. But the jets are very, very narrow so the jets will be a few degrees only. So, they are like little pencil beams going away from the black hole. And so those jets are very fast so they'll travel at close to the speed of light. Um, which is a lot faster than the outflows which are already traveling at a few thousand kilometers per second. Those jets just basically just pass through the gas because they are so thin they don't interact with it much in the beginning but as they reach into the halo at some point they'll basically crash into the halo gas and form massive bubbles. And those bubbles are basically large bubbles of gas where the jet deposits its energy and basically heats up the gas. So, we have this halo sitting there and the gas is kind of hot but it has the possibility to cool down and fall back into the galaxy. And there comes the jet crashing into the halo dumping in all this energy, heating it up again. And so what the jet basically does, which is absolutely fascinating, is it makes the halo less likely to return gas back onto the galaxy. So, when we had our outflows and we put all the gas out into the halo, the halo could say, oh well, I'm going to cool some of that down and push it back onto tho galaxy. But if the jet comes in and basically heats the halo back up again it is less likely to cool gas and return it to the galaxy so it's less likely to return gas for star formation later on. And this is another way for the black hole to influence star formation in the galaxy. So, where the outflows are basically shutting that star formation that was happening right now, the jets are a way for the black hole to keep star formation from happening in the future. By basically keeping the future fuel for star formation from coming back into the galaxy. So, even more ways for the black hole to (beep) up the galaxy.

Courtney: So, what makes a jet form?

Carolin: Ah, well, that's really difficult. So, so we know that jets exist. We see them all the time, well, not all the time, but they are quite common. How they formed is actually quite difficult. So, we know that we need the black hole, we maybe need the accretion disc, we will definitely need some magnetic fields and beyond that I think this is a scale that nobody knows. It's just very complicated physics. So, we have some amazing mechanisms that we think form the jet which basically, an accretion disc is rotating, so as it's rotating around it's basically spinning up the magnetic field and forming this kind of like corkscrew structure and then, like, material travels away from the black hole and all that. So, that is like the basic idea behind it. The details of it are complicated and poorly understood.

Courtney: Okay. That's cool. Always good to have more things to be figuring out. I mean, what are we going to do with ourselves if we can't be, trying to figure out the universe, right?

Carolin: Yeah.

Vicky: And it keeps us in a job so...

Courtney: That's right.

Carolin: Yeah.

Ben: Well, that was wonderful. Thank you Vicky, Thank you Carolin. You've pleased me. Your efforts have born fruit and that fruit is sweet. Here is some fruit! Vicky, you get a pomegranate. And Carolin you get a persimmon. Ah, I'd like to thank my guest, Courtney Brooke Davis. Her web comic and her comic works can be found on her website courtneybrookedavis.com. There's going to be a link to it on our website, thank you very much for coming on our show today!

Courtney: Oh my gosh, I had so much fun. This was great you guys!

Ben: Hurray!!

Well, that was cool. Now it's announcement time. Please listen carefully. We've got some cool announcements to talk about. So, first off, is always, please give us an iTunes review or tell other people about us online. Why? Because, well, lots of people love physics and lots of people want to know more but they don't know that we exist. And so the only way they can find out that we exist is if they stumble upon us randomly on iTunes or if, ah, one of their friends comes and tells them, hey, you want to know more about quarks and black holes? Well, my friend, give this podcast a shot. Second, ah, people keep bugging me to open the t-shirt sales again and so I have. Ah, the people who make our t-shirts only sell them in batches and so you have until March 11 to purchase them off of our website store. You'll find a link to our t-spring store off of our website, it's pretty easy to find. Third, I've decided to start doing a thing where, if I can't find a cool guest to introduce you to or if the planned guest cancels at the last minute, instead of just sinking everything, I'll just choose a listener of the show to sit in the guest chair and chat with us about physics.

45:15

It's pretty great because all of you listeners are actually really interesting and intelligent people so I'm happy to do this. Occasionally I'll put the call out on Twitter or Facebook that we need a guest. So, to be a guest you need to do three things. The first is to follow us on Facebook or Twitter and listen for the announcements. And the second is that you need to have a fast internet connection and a quiet room in your home or workplace so that we can record good quality audio. And the third thing that you need is to be available when we want to record it. That's it. So, follow us on our social media pages and you might get lucky and if you do we'll all be very happy to chat with you and meet you. Ahh, okay. Fourth thing. Thanks to the donations we've received over the last few years I was able to hire a professional designer to redesign our website. It looks really great and it should all work on your phones and tablets just as well as your web browsers on your computers. So, why don't you mosey on down to titaniumphysics.com and have a look. Some of the content on the website is ported over from our old- and might need a little bit of modification. So, if you want to poke around and send me a little bit of feedback about what might need changing or modifying I'll be happy to hear it. So, finally, we're still humbly soliciting your donations. Your donations go to paying for our server fees and our project to transcribe episodes as they come out. And our fancy project to buy people decent microphones. Ah, so, you can send one time donations through PayPal off of our website or you can go to our sweet Patreon website and give a recurring $2 donation.

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Clausen, a Mr. Devon North, a gentleman named Scott, Ed Lowington, Kelly Weinersmith, Jocelyn Read, a Mr. S. Hatcher, Mr. Rob Arizato, and a Mr. Robert Stietka.

So, that's it for Titanium Physicists this time. Remember that if you like to listen to shows where scientists talk about science in their own words there are lots of other lovely shows for you on the Brachiolope Media Network. Just follow the link or google us. The intro song to our show is by Ted Leo and the Pharmacists and the end song is by John Vanderslice. Good day my friends and until next time remember to keep science in your hearts.

Music

50:33

Courtney: I wonder what the night sky would look like if you were on a planet orbiting a star that wasn't in a galaxy.

Ben: Well, most of the stars we see in our night sky are in our galaxy.

Carolin: Aw, that's a good point, yeah.

Ben: Right.

Vicky: Yeah.

Ben: Galaxies aren't as bright as stars but you can still see theme with the naked eye. You can still kind of make out Andromeda with a naked eye.

Vicky: You can. I saw it from my back garden two weeks ago.

Ben: Oh cool. So, it would look like they were little patches around. Because there aren't any other stars making the sky brighter than them, mostly I think you'd just see these little patchy galaxies here and there.

Courtney: Little things here and there, huh. There's a bunch of little weird things there. Small and clearly unimportant, nothing to worry about.

Carolin: Yeah.

Courtney: Wait, do we name black holes? I feel like, if we name stars, we should name black holes.

Vicky: Um, yes, we name black holes.

Carolin: Do we?

Courtney: Good.

Vicky: Sagittarius A star.

Carolin: But that’s the only one.

Ben: Yeah, but that’s a misnomer right? Because it’s not a star. It’s a black hole.

Courtney: Oh, that’s right.

Vicky: Oh, controversial. Oooh, pun.

Carolin: Maybe we should start naming them.

Vicky: I don’t know.

Courtney: I feel like we should just give them names like Bob.

Carolin: No, Bob is a supernova.

Courtney: Oh, I’m sorry. It’s the Bob.

Vicky: Yeah, I can’t remember which galaxy it is in but it’s a typo in a supernova announcement that one of my colleagues did and now the supernova is named Bob.

Courtney: That’s amazing.

Vicky: Yeah.

Carolin: Really.

Vicky: Yeah. We should totally name black holes.

Carolin: Yeah, but then who would get the right to name the black hole? And how...

Vicky: Me and you.

Carolin: Me and you. You and me.

Courtney: Honestly, I think it's just the one of those things where like the first person to announce a name, like, everybody else is probably going to grumble a little bit but then they're not going to have anything else to call it so like, eventually, everybody's just got to go along with it so, do it!

Vicky: I think if we just go with it, people will have to stick with it.

Carolin: Yeah.

Ben: That's true.

Courtney: Yeah, be the first and they're going to try to argue with you and you were still first.

Carolin: Yeah. I just have to find a black hole I would like to name.

Vicky: Or just find one without a name.

Carolin: Yeah.

Vicky: And name it.

Carolin: Good point.

Vicky: I name the one at the center of 4258, black hole Gary Barlow.

Carolin: No. Oh no. No.

Vicky: It's official now.

Carolin: No, no, not Gary Barlow.

Ben: Hold on, hold on. I need to know if that's a fun...

Vicky: Are you googling him?

Carolin: Oh, you just offended Vicky. Because you don't know who Gary Barlow is.

Courtney: I don't either. Sorry.

Vicky: Oh dear god.

Ben: I'm like, is Gary Barlow one of those British celebrities that nobody's heard of?

Carolin: Everyone here has heard of Gary Barlow.

Courtney: I have not!

Vicky: He is the lead singer of "Take That". A boy band that is, has stood the test of time.

Courtney: Take That? I have never heard of this band.

Vicky: Oh dear god.

Carolin: Sort of a fun side story, there was a paper recently about how the high energy radiation from that could wipe out all life in the galaxy. But I'm not sure if we want to talk about genocide... in this episode, genocide by black hole.

Vicky: We did the maths to work out if you would, like, at what distance you would die and I can't remember what conclusion we came to.

Carolin: Yeah, I think we had to recalculate it because we thought they ignored something. But possibly, we are fine. So, I think we, in our location in the galaxy, we're kind of in the outskirts, we're far enough away, we'd be fine. Again, location is everything.

Courtney: If the ones that are shooting out the radiation stuff, if that goes on for long enough, like, couldn't potentially, life evolve to deal with that level of radiation right? Like, I bet tardigrades would survive that, right? They said those guys can survive anything.

Carolin: Um, I know nothing about biology.

Courtney: Those are the little, like, tiny microscopic creatures, I think their other name is like water bears?

Vicky: The water bears, yeah.

Ben: Yeah.

Courtney: They're real ugly and supposedly they can survive, like, being shot into space and stuff.

Ben: If you're close enough to a really, really intense source of really, really high energy radiation, like, if you were to throw a baseball at the sun and got to close to the sun, the radiation from the sun, the photons from the sun would break all of the molecular bonds holding the baseball together, holding the atoms of the baseball together, and I don't think a tardigrade could survive that.

Courtney: Alright.

Ben: So, ah, if the, if you're close enough you'd ionize and that's not surviveable.

Courtney: Okay, so it's, that's tough to evolve for but also I want to throw a baseball at the sun now.

Vicky: I think that was one of the things in the paper though. They might have sent in bacteria that they worked out could survive it. I vaguely remember looking it up to see what it looked like. It was really ugly.

Carolin: It was really ugly, yeah.

Courtney: Oh, I bet the tardigrade…

Vicky: It wasn’t tardigrades because I wanted to see if it was a tardigrade.

Courtney: They are so ugly, yeah, yeah, no, they are beautifully ugly. I love them.