Episode 21:
Black Hole Questions Answered

Fraser Cain: So three weeks ago we did Episode 18 on black holes, and as predicted we received a big load of questions from the listeners wanting clarification, so let's clarify!

First up: Jim Payne wants to know how (and I'm paraphrasing here) how we know when a voraciously feeding super massive black hole is changing the rate that it's feeding - so when it goes from active to less active? How do we know that?

Dr. Pamela Gay: Luckily, black holes tend to leave behind crumbs, you might say. When we look at black holes, especially nearby ones like the one at the centre of our own Milky Way Galaxy, we can see light echoes surrounding them. These are shells of light left behind from when the black holes were feeding in the past. They emitted lots of light, and when they stopped feeding that light continued to travel through space and its like hitting an on and off button in a show of light. You see it start, you see it stop, you see how thick it is, and the thickness corresponds to how long the black hole was feeding for.

Fraser: So you can actually see as the feeding goes on or goes off, then you get this reflection of light that's expanding in a sphere around the black hole. If we know how far away objects are from that black hole, we can see when things are balancing off of those objects as the light gets further and further away.

Pamela: Exactly. So as the light comes away from the black hole, it intercepts intergalactic dust and molecular clouds and the light reflects off of the particles and reflects back toward Earth, and we can see that light reflecting back toward us and use it to judge exactly when the black hole turned on and turned off. Black holes turn on and off as matter starts coming into them and stops coming into them. If things stopped falling in, the black holes don't exactly have anything to consume and they don't have anything to feed the light they give off.

Fraser: So would we be able to see, say, one of these light echoes rippling through another galaxy that the black hole has recently switched off from active feeding to quiet?

Pamela: Yes! In fact, we can see that in our own Milky Way Galaxy. We can see a light echo from a period in the past from when our own black hole was feeding. That light echo is travelling through our own Galaxy and can be imaged with the Chandra X-Ray Observatory.

Fraser: I know there was a recent story where an object, maybe the size of Mercury, got consumed and over the course of a couple of years there was a light echo really around the close neighbourhood of the Milky Way. But we can actually see one that's maybe tens of thousands of light years in the galaxy?

Pamela: There's several that have been seen, I have to admit I don't know their exact distances but that's something we can stick in the show notes for this episode.

Fraser: So that's how you know! You can see the light echoes as they move through the galaxy and know when those switches happened.

Okay, so we'll move on to the next one, and this one's going to give us all a headache: So Richard Holland, he wants to understand that if time slows down around the black hole when you're near it, it might seem - what seems like three seconds to you seems like 300 years to someone further away.

So is there a point in the singularity where time slows down all the way, completely. Does it just stop? Will the inside of the black hole experience time at all, compared to the rest of the Universe? What's going on here?

Pamela: Well there are two things to keep track of here. First of all there's how time is being perceived by the poor schmo who has the misfortune of falling into the black hole. That person sees time going at completely normal rates; they're falling in, they're getting stretched out, they're getting torn in half: life is not a happy thing.

But to people who are further away, and watching the black hole, they see that person who's falling in slow down and slow down. And eventually, appear to seemingly stop because time has slowed down so much that we can't in human lifetimes see anything happening.

Now in the very centre, our math breaks down. We might, in the equations find that "yes, time absolutely stops" but that isn't realistic in any way. This is one of those places where we're trying to figure out how to better merge together our theories of relativity and quantum mechanics and get a better understanding for what goes on at the amazingly high densities within black holes.

Within the short-shield radius, we aren't really 100% sure how to proceed mathematically. There are a lot of brilliant minds working on this. So while at first approximations might make it seem like time stops, that really doesn't make sense, so we're trying to figure out how to get our physics to give answers that are more realistic.

Fraser: So... we don't know?

Pamela: We don't know.

Fraser: Ohh, okay. Well, that's okay - we can't know everything- you can, you know a lot.

[laughter]

All right! Okay, so Ron Myers wants to know (and we got this question about three or four times): if a black hole were allowed to move about freely, to the extent that it was able to consume the entire Universe, how would that massive entity contrast with the Universe just prior to the Big Bang? Is that what might be what was before the Big Bang?

Pamela: So, here when you have a black hole you have a giant massive thing that's not generating any energy in terms of there's (as far as we understand) no nuclear processes going on. You just have, inside the short-shield limit, this really dense area that mathematics sort of doesn't get.

Now, the black holes that we see... they're not randomly forming new Universes. Or at least, they haven't so far, this is why we're able to exist.

So as I understand it, the difference comes in the fact that when the Universe sprang into existence, all that energy, all that mass, everything that is everything, was indeed squeezed down basically to a singularity. Same size as the inside of a black hole, as we sort of, kind of understand it, but that Universe that all of that energy and mass at the beginning times - it was the same size as everything else. That whole system was expanding out radically. As everything that has formed our Universe was expanding outwards and apart, all sorts of things were going on that we're still trying to understand. But, the energy itself was working to push things apart. The mass couldn't hold everything together, whereas in black holes the gravity from all of the mass is able to hold things together faster than anything inside the black hole is trying to push it apart. In fact, there's nothing inside a black hole that's trying to push it apart. The early Universe had something trying to push it apart, that's the inflation that blew up the Universe to what it is today. So unless you can trigger inflation inside of a black hole, you don't end up with a Big Bang.

Fraser: I guess that a way to test that would be if, black holes reached some amount of mass then maybe some pushing force took over, then maybe you would see (you wouldn't see) new Universes being formed as black holes kind of, you know, reached their limit. It hasn't happened yet, or doesn't appear to be happening yet.

Pamela: And here we're starting to get into the parts of science where you can do lots of speculation, lots of math to go to lots of different directions, but we don't have any ways to test those theories, so you start getting beyond what is testable science anymore.

As we understand it, there is nothing that would cause a force inside of a black hole that would go on to do the inflation that was necessary to get our Universe to get to be the way that it is today.

Fraser: I think that with cosmology, a lot of your intuition is worthless. You feel that there's an interesting similarity and you know maybe this is what's going on, but it's almost like with quantum theory.

Quantum theory, every point defies your ability to understand it, and defies your human intuition. Hawking says that we're living in a middle world where we evolve to understand things of our size and scale, but not to understand things of gigantic scale across the whole Universe and not of the really, really small. You get these connections that seem like they're similar, but in many cases it's really hard to follow your intuition any further.

Pamela: Everything suddenly becomes its own special case. You have the highest mass boundary values, the densities inside of black holes - that's a region we don't understand. The densities and energies and accelerations at the beginning of the Universe, that's again some place that we don't fully understand, so we keep hitting these boundaries where the most brilliant minds in the world are still working to map out the edges of the math that we use to define our Universe. It's sort of like these theoretical physicists are the mapmakers of the only truly unexplored territory that's left.

Fraser: All right. So, probably not - but we don't know.

Pamela: Our listeners are doing a very good job at asking us about the things that physics is still trying to figure out.

Fraser: Right. Okay, well then let's move on. This one should be easy:

[recording]

Hi, my name is Steve Mich and I have a question for you: I've always been interested in black holes and exactly what they are and I had always wondered what they look like. If you could, (and you were able to in the land of what-if), if you could actually go up to a black hole without being obliterated by it, I'm curious as to what it would look like. Would it look like a black sphere or point in space, or would it actually look like a swirling vortex?

[end recording]

Fraser: What would we see if we stood on a black hole? So like, not an obviously "what you'd see is your legs torn off and spaghetti-fied"

[laughter]

But let's say you could withstand that - what would it look like?

Pamela: Well, so let's look at two different places. Let's first imagine that you're standing on the short-shield's horizon. You're standing at that edge where if you go any closer you have to go faster than the speed of light to escape, and if you stay where you are you just might be safe if you move fast enough.

At that limit, you see things falling in, getting stretched out and stretched out and stretched out and slowing down. So it would sort of be like watching the most insane three-dimensional waterfall you've ever seen, because things are spiralling in, stretching out and things further away appear to be moving in faster than the things that have had a chance to go closer towards that undefined singularity in the centre.

As things are falling toward that undefined singularity, they're getting redder and redder and redder. They're also, as they get closer and closer, fading away into nothing. So it would be like you're watching things fall quickly, slow down, get red and then fade away. It would be kinda wild to watch.

Fraser: If there was a lot of material, it would almost be just a smooth blend of things all falling in, all slowing down and all turning red. And this would be inside the area around the black hole, which is outpouring in radiation with all the matter that's choking up.

Pamela: Exactly, so you have all the fireworks of all the particles coming in and out of existence. You have everything getting stretched apart. It would be sort of like the most insane horror film you've ever seen.

Fraser: There you go. Nice.

[laughter]

I like that. I think - I mean, when you see NOVA they always do these views of black holes, they always look like it's some kind of distortion, like moving and you go past it and you see it's not quite there, it's almost like a predator or distortion of space. But it sounds like that's not necessarily what you would see. You'd see something quite different.

Pamela: I can't remember exactly what cartoon it was where there was this ghost coming out and spiralling at the same time while screaming.

[laughter]

That's sort of my mental image of something falling into a black hole. It's getting stretched out, fading to red and spiralling in as it goes. Its top parts are falling than its bottom parts and everything's fading away and getting red as it fades away and its just kind of this... not right situation.

Fraser: So what if the black hole isn't feeding. What if it is just out there, in the blackness, maybe its going in front of stars that we can see. Then what would we see? It's not like mountains of material are pouring into it.

Pamela: If you're magically standing on the very edge of the event horizon of the black hole, you'd really see absolutely nothing. The black hole itself is not emitting any light other than its Hawking radiation, which in general its not that exciting, its small amounts of mass coming into existence, but that's - you can't really notice those extra particles.

Fraser: Would you see blackness around it, where the starlight is being bent into it?

Pamela: You would see a big blackness. It would be like going outside - if you go to the darkest parts of the world, when there's a cloud in the sky, the cloud is the dark place in the brightness of the stars and you can actually see the midnight blue of the background sky. The black hole would be a lot like that blackness. You would see the objects behind the black hole appear to be distorted as the gravity of the black hole causes their images to get distorted and twisted with gravitational lensing effects.

Now, you can't see individual light rays getting twisted into the black hole, so you'd just see the distortions and the background effects.

Fraser: Let's flip it around and say you're standing on the black hole and you're looking up.

Pamela: [pause] Oh, that gets much more complicated.

Fraser: MORE complicated?!

[laughter]

Pamela: Here you have the light is accelerating toward you, so everything appears more blue. That's just a little bit different.

Fraser: The wavelengths will be stretched

Pamela: You change the energy of the light, so it will appear more blue. So looking up you see a blue Universe, whereas normally you'd see a lot of red things and those red things are now blue and the things that are normally blue are now ultra-violet and the things that are normally ultra-violet you just don't see anymore. So everything would get shifted to the blue.

Fraser: All the light would still come in because --

Pamela: It would still come in.

Fraser: Yeah. Okay, so PhilM wants to talk about black hole evaporation. Once again he was not the only one - there were lots of questions on this.

He wanted to know if the particle pairs are randomly being generated and one goes into the black hole and the other isn't, how does it evaporate if its still gobbling up particles?

Pamela: Okay, so the particles themselves are being randomly generated. You can't predict where any one particle is going to come up and you can't predict exactly what mass or energy that particular particle is going to have. But the overall distribution of particles is actually directly related to the mass of the black hole. A bigger black hole will have what's called a higher temperature which leads to a higher evaporation rate. A smaller one is going to have a smaller evaporation rate, a lower temperature.

It's this temperature, the thermal radiation of the black hole that is driving this evaporation process. The math is kind of complicated and I have to admit that it makes my head hurt.

Fraser: Okay, I want to talk about the evaporation for a second just so we can get a sense of this. So these particles are kind of popping into existence, and then normally are recombining to each other and then disappearing, right?

Pamela: The particles that are popping in and out of existence are due to the temperature of the black hole itself.

Fraser: Okay

Pamela: The thermal radiation of the black hole that's causing these particles to come in and out of existence.

Fraser: So then, what's happening is if this particle pops up, and it has to be in exactly the right place, where one half of it escapes into the Universe while the other half gets sucked down into the black hole, you've essentially gotten a little bit away from--

Pamela: So the black hole itself is radiating away thermal energy that takes the form of these virtual particles where half of the virtual particle pair is able to escape just like you described it.

It actually works out that most black holes are actually receiving a lot more energy than they're giving off through this thermal radiation. You'd need a black hole that was 4.5x10^22kg, or about the same size as the Moon, for the black hole to be evaporating at the same rate that its receiving particles just from the cosmic microwave background radiation. Anything bigger than that is going to be taking in more energy than it's giving off.

Fraser: Okay, so you're saying even though the black hole is evaporating, it's getting radiation from the cosmic microwave background radiation, maybe still bits of grit and dirt are falling into it, so its still growing faster than its evaporating. So the evaporation process must be slow.

Pamela: It's a very slow process and in our everyday Universe, normal black hole (those formed by stars, those formed in the centres of galaxies through mechanisms we're still figuring out) are too big to be evaporating away. They are evaporating, but they're not getting smaller because they're taking in things. Just photons from the cosmic microwave background are enough for them to not be shrinking.

Fraser: Will there be a time when there's no photons left from the cosmic microwave background?

Pamela: Here's one of these things where you have to project so far into the future. Imagine a time when all the material available to create photons has been used up. All the stars have died and all the white dwarfs have cooled off so that they're no longer thermally emitting radiation. All of the neutron stars have cooled off. Everything that's out there has cooled off and what's left has just been zooming around the Universe sucking up the leftover photons from the cosmic microwave background.

I have to admit, this is so far in the future that I've never really worried about this physics. I can conceive of a time when the Universe has been essentially dead for so long that the number of photons leftover and the energy leftover in the photons from the cosmic microwave background is so small that all the black holes can be radiating away. But then the particles they're radiating away, I don't know how that plays into the equation, it starts to get--

Fraser: Do they just get sucked into different black holes?

Pamela: It starts to get into really fuzzy physics where I'm not quite sure what's going to be happening, so--

Fraser: Could there just be a day (a long time away)--

[laughter]

-- where all that's left is this diffuse spray of particles that are, thanks to dark energy, accelerating apart from one another and every black hole has evaporated away and all you've got is half of those virtual particles. After they've even been recycled several times, back and forth from black hole to black hole and all you've got is just this fuzz of particles accelerating apart from each other. It's a very sad Universe.

Pamela: It's a very sad Universe and part of my brain is not convinced that every single white dwarf out there will end up inside of a black hole because it just seems with everything accelerating apart that's not gravitationally tied together, it might be possible, for just one white dwarf star to escape falling into a black hole eventually, as our vast Universe dies and goes to ashes.

Fraser: Sure but then that white dwarf will eventually cool down, form a big diamond and just sit there.

Pamela: Yeah, so we'll have diamonds and--

Fraser: More than been recycled through a black hole, it will just be a dead piece of carbon.

Pamela: Yeah.

Fraser: This is the saddest show ever!

[laughter]

Pamela: I know, I know!

Fraser: All right, let's move on to something much happier.

Okay, this is good. Now, Mad Jack wants to know - in the episode you talked about the Earth as a "people hole", or specifically a "Pamela hole". The force of gravity is so strong that nobody, not even Pamela can escape. Obviously the Earth is way overcompensating. How big a rock do we need to actually have a "Pamela hole"?

Pamela: So, I am such a nerd that when I saw that question I actually sat down and attempted to figure out the mathematical answer.

Fraser: I *knew* you would! I *knew* it!

Pamela: So here on the planet Earth, you have to be going a little more than 11 km/s to escape from the surface. So if you have a velocity of a little over 11 km/s you can get into space. I figured, 'just how fast can I jump?' Using a base guess that I can jump about 0.7m into the air I figured that my velocity is - not a lot. Basically you'd need a rock that was the density of the planet Earth and about three kilometres in size to be able to gravitationally hold me down. It's kind of pathetic.

Fraser: There are asteroids out there that are three kilometres across.

Pamela: Oh yeah.

Fraser: So a three kilometre-sized rock is a human hole, that nothing, not even a human being can escape.

Pamela: Exactly. Yes.

Fraser: That's cool. See? That was happy!

Moving on. Himanshu Raj wanted to know where the angular momentum comes in. We talked about how the matter doesn't just fall straight into the black hole, it chokes up like it's going around a drain so material doesn't fall straight in. Why do they go round and round? How does the law of the conservation of angular momentum apply?

Pamela: If I have a velocity that is exactly going from where I am to the gravitational exact centre of a black hole, I can fall straight in. But in general my velocity won't be along that perfect line. If instead I have velocity that goes initially, as I'm far away from that black hole (or whatever object I'm falling toward) I will fall toward it but my velocity is carrying me off to, say, the right somewhere.

Imagine a situation where I'm standing and off 45 degrees from straight ahead of me is the high mass object. I'm trying to go in a straight line, trying to go in a straight line, but its gravity is pulling on me. So, I start off with this momentum that's carrying me forward and its force bends my velocity. If I'm actually physically running, and you grab my arm and try to pull me perpendicular to the direction I'm running in, you're going to cause me to spiral.

The exact same thing is going to happen with particles falling into this high mass object. They're trying to run in a straight line, trying to fly in a straight line and gravity bends their trajectory. It has to bend them around and pull them closer and closer and closer as they go. It's your original velocity having to get bent in new directions that causes things to spiral in.

Fraser: I can imagine, if you think about in terms of regular gravity objects like the Sun and a comet going around the Sun. The comets go on these strange elliptical orbits around the Sun. They don't bend in and go straight into the Sun, they have their orbits. A black hole, although it's very crazy, IS a centre of mass in kind of the same way, right? So objects can be orbiting black holes just like they can be orbiting the Sun.

Pamela: Exactly.

Fraser: I guess at some point something happened that they cross into the short-shield radius. That's where they start getting torn apart and sucked in. I guess there could be situations where there's so much of it going in that it has to take a number.

[laughter]

It has to wait for its turn to get destroyed.

Pamela: And as the stuff falls in, it starts orbiting and the orbits between two different particles can be so close to one another that there's friction built up between the different orbits. It's that friction that slows down the material and when the material slows down its allowed to finally fall into a black hole.

The initial velocity of a single particle might cause it to simply go into orbit. You have to build up lots and lots of particles that are interacting with one another and slowing one another down to get them to fall onto the heavy mass object.

Fraser: So, it's almost like, to answer the question then, all objects falling into the black hole are going to have some momentum off the direction of straight down into the black hole and if there's a lot of material coming that all just adds up and you get this material backing up.

So we've got one last question, and this is from the forum from Namcitsym (I think it's a forum name) wants to know if there's a limit to how much material a black hole can devour? I'm guessing no.

Pamela: No. Black holes are vacuum cleaners with infinite sized bags. The limits really come on what gets close enough to the black hole to be consumed. If you have a black hole hanging out in an empty section of space, then it's not eating anything. You have to get something that comes on a path that brings it close enough to the black hole that the black hole's gravity is able to change the direction of that thing's orbit, that thing's velocity and suck it in to consume it.

For instance, in our galaxy, our black hole in the centre isn't eating anything right now. If some star on a highly elliptical orbit from the outer nether-regions of the galaxy went shooting towards the centre of the Milky Way on its regular path, it might get close enough that the black hole changes its velocity and sucks it in and eats it.

In general, black holes hang out. They're kind of mellow that way. They're sort of like how you can end up with Anacondas sitting on the centre of a jungle floor just waiting for something to walk up to them and get eaten. Black holes are the anacondas of space - they just hang out, waiting for something to get near enough to get eaten. Anything that gets too close is dinner.

Fraser: To use another animal analogy, it's almost like if you're chasing a herd you have a much better chance of picking one out. If there's a whole lot of material falling around the black hole that its going to interact and bump and change its orbits and some of it is going to fall in and some of it's going to get swung out. If you've just got single objects coming and looping around the black hole, chances are they're just going to treat it like a point of gravity and move back out again.

Pamela: Exactly. It's when you start getting wild interactions such as you get with quasars or galaxy merger events where all sorts of different stars and gas clouds and everything else is interacting together and ejecting matter in all different directions that the random distributions of all these different motions end up sending things into the black hole into the feeding range of these monsters in the centre of galaxies.

Fraser: All right, well we're out of time so I guess this completes part one of our black hole questions answered series of shows. I can imagine us next dealing with the questions from the questions of our questions answers, so we'll be doing this every couple of weeks I'm sure. If you have more questions, send them in, we'll queue them up for the next black hole questions show and go from there.

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