Astronomy Cast Episode 73:
Questions Show #8

Fraser Cain: We've been so crazy following our own whims through the universe that we've neglected your questions. That ends today. It's time to dig deep into our overflowing email box to retrieve the puzzling questions our listeners have sent in.

Let's start with what I think is our best question ever.

[laughter]

This is it, this is the greatest question. Justin Craig sent in an awesome email. He says, "I was wondering, if you had enough anti-matter and you put it into a black hole with an equal mass, would the black hole disappear or just become twice as heavy?"

Now, before we go into the actual answer of question, let's give the listeners background on anti-matter. I don't think we've done a show on anti-matter, so what is it?

Dr. Pamela Gay: Anti-matter is basically the "Spock has a beard" universe of matter if you've watched old generation *Star Trek*. An electron of antimatter has the opposite charge. It has all the opposite physical characteristics that a regular electron has. So you have an electron and a positron, take one and turn it inside out in every way you can (except for the mass – you can never have negative mass, it's always a positive quality), and it's exactly the opposite. Opposites often annihilate one another.

Fraser: This isn't just some crazy, calculated theory. This is real stuff – you can calculate it in the lab, you can smash it together, it annihilates and produces a gigantic amount of energy. This is real stuff.

Pamela: Yeah, we've produced positrons – I think they've even put together anti-matter hydrogen and helium anti-atoms in various laboratories. You're just very, very careful to suspend them away from everything else while you're working with them. But we can create these things.

Fraser: So this isn't some theoretical concept. Astronomers see the presence of antimatter out in the universe, being produced naturally. In fact, it was recently announced there's a cloud of antimatter in the Milky Way.

Pamela: There's a bunch of natural processes that it's just part of how energy settles out when it's becoming matter. If you take energy and you say, "okay, let's change it into matter" you're going to get a regular matter particle and an antimatter particle. Everything is created in the yin and yang, in terms of you have to have a positive charge and a negative charge. All of these things have to balance out in these energy goes into matter reactions. In some cases it can actually create clouds of antimatter.

There's a cloud here in the Milky Way that we detect because of the very specific gamma ray light it gives off, that has a colour that you pretty much only get when you have these matter/antimatter reactions. We think this is perhaps coming from low-mass x-ray binaries that are creating this cloud of antimatter.

Fraser: All right. We know there's antimatter, but just creating clouds which are annihilating instantaneously. We're not actually clumping together gigantic quantities – enough to say, create a black hole. But let's say we could. We've pulled it all together and fashioned it into a ball of antimatter with exactly the same mass as our target black hole. Then we smash them together.

Pamela: Here's where I said it's really important that mass is always a positive quantity. If you take a pile of matter and a pile of antimatter, they're both going to have the same gravitational effects on things, they're both going to have the same style event horizons… they're going to have the same everything.

The thing is, with a black hole, you can't tell if it's matter or antimatter.

Fraser: Whoa.

Pamela: Yeah.

Fraser: Right, of course. So an antimatter black hole would, in all cases, feel identical to a regular black hole, if you're trying to orbit it or whatever.

Pamela: If you basically went around with some sort of antimatter vacuum cleaner and collected antimatter into a bigger and bigger and bigger pile until the pile had enough mass (regular mass with antimatter characteristics), that it condensed down to a black hole… it's a black hole. When you take an antimatter black hole and a matter black hole and throw them together… we don't know what's going on within the event horizon. From the outside perspective, you just made one really large black hole. Which is kind of cool.

Fraser: Hold on, let's break this down a little bit. Say we have our antimatter black hole and we're streaming planets and asteroids at it, they're just disappearing into the antimatter black hole. Now, there would've been an explosion going on as these asteroids are striking the antimatter, right?

Pamela: The problem is you're starting from the assumption the matter inside a black hole is normal. It's not – at least, we can't think of any way that it's normal. So the whole idea that you have electrons goes away. The whole idea that you have protons goes away.

What you have is some surreal quark soup that all the different bits and pieces that make up both matter and antimatter are slammed together and forced into these really small volumes. Things lose their identity in the process.

Fraser: We'll get that question in a second – we've actually got another question on that identity and information. I guess my question – sorry to not let go here – let's imagine you had your antimatter black hole and your regular matter black hole, wouldn't your antimatter black hole be the exact same configuration as the regular black hole, just the antimatter version of that/

Say it's some kind of soup of particles which no longer look like protons/electrons/whatever. Wouldn't they just be anti-versions of whatever's in the black hole, and wouldn't that still create the explosion?

Pamela: How do we know, because it's in the event horizon, that these particles are able to hold on to that level of identity? How do we know they haven't turned into pure energy as they cram themselves in there?

Fraser: Let's say we do know. Let's say they do remain as a mere version of the particles that are in a black hole. What happens then?

Pamela: Well, it's just energy being released, but that energy can't get out because it's a black hole.

Fraser: Well that's the question isn't it – the energy can't get out because it's a black hole which would stop even energy. So obviously you're not going to have an explosion of chunks of things because they would just be sucked down. You're not going to have radiation because it's going to get sucked down. You're not going to get sound…. Anything. There may very well be an explosion, but you wouldn't know it happened. Is that right?

Pamela: Exactly. Basically, what goes in stays in and we can't find out anything beyond that. Since the antimatter systems have positive mass, you just have a bigger black hole.

Fraser: Right. Wow.

All right. I think that's it – I guess, that's the question at the heart of it. The hope was maybe the two would cancel each other out and you'd be able to break past black hole-ness, right, and the whole thing would explode and turn into a release of energy. Even energy can't escape this black hole, so even if there is a release of energy, no one's the wiser.

Pamela: Exactly.

Fraser: Awesome question. Best question ever.

[laughter]

Let's get on to some other best questions ever. Let's go with that – continuing on the information.

We had a question from Maureen Egan, and she wants to know, "in terms of information not being able to escape the gravitational pull of a black hole, what exactly is information? When I imagine information I think of data like that stored on a floppy disk or CD."

I think astronomers do use that term quite loosely – all the information is lost, so who knows what happens to it. But what is information?

Pamela: I'm not sure so much that we use the phrase loosely as we just throw it around a lot without ever telling anyone what it means.

Fraser: Oh, fine – yeah.

Pamela: Which is a little bit more evil on our part.

Fraser: Yeah, no – I just throw around, "information's gone – moving on"

[laughter]

"Stop, what does it mean?" So really – what does it mean, information loss?

Pamela: It's an idea that came out of quantum mechanics. It's this whole idea that particles have varied states in them. If you take an atom – let's talk about helium, which is nice and simple. In a helium atom, you can have two different electrons. One is going to have spin-up and the other will have spin-down if they're both in their lowest energy state. This is something that comes from the poly-exclusion principle, which says you can't have two electrons with the same spin in the same orbital.

The fact that one is spin-up is information. The different states particles take on, or the different wave functions, all of this is different types of information. It's the quantum states that are tied up in particles that people try and figure out how to take advantage of in building the next generation of hard drives where we store information in the spins of electrons.

How do we figure out how to tap into this so that we can build atoms that store the genetic code of the human genome, or something crazy like that. I don't think you can actually do that one.

Fraser: Maybe we could do an analogy in star trek, like where you hop in a transporter and you're going to be teleported from where you are to the moon down below. You want to make sure that the teleporter can rebuild you, atom by atom, and for it to be able to do that it's going to be able to put an atom here with this quantum state, an atom there with that quantum state, etc. It's got to get it exactly right or you won't be you anymore. You'll be somebody else, or even just a mess.

Pamela: All of this can include information such as what the polarization of a photon, what is the orientation of the waving of the electric and magnetic fields of that photon as it passes through space.

Fraser: So there's any number of ways you could measure an atom or a photon or a particle or anything and that's the information that is thought to be destroyed when it goes into a black hole.

Pamela: It's the most basic way of putting this is what are the quantum states of the particles – that's the information the particles carry.

Fraser: So the thinking is that if you could somehow pull that stuff back out of the black hole, there would be no way to re-create that information. No way to ever know what its quantum state was.

Pamela: Yeah.

Fraser: Why is that bad?

Pamela: Well, we like to think that no information is ever lost. Ever particle in some way, holds its entire past inside of it. It couldn't exist if a whole series of different things hadn't existed. You take energy and that energy has to split into a positive and negative charge, different spins that are conserved… you have all these different things that have to get conserved in the creation of matter and reactions and there are very specific processes that are the only allowed atomic processes, as particles decay from one to another through time.

If this information could get lost, it's sort of like erasing the history of the particle, which is kind of sad and also implies that there's information about our universe that gets lost forever.

Fraser: Right, but astronomers aren't boo-hooing about lost information. This information loss breaks something, right?

Pamela: Well, one of the tenets we start with is no information can ever be lost or destroyed. If black holes can lose or destroy information, there's one of our basic tenets gone, and that makes people uncomfortable.

Fraser: Okay, I think we could talk about this all day. Hopefully that gives you the information you were looking for, Maureen, and we'll come back around and talk about information in black holes… that's a whole show, I'm sure.

Pamela: Yeah. The short answer is, as near as we can tell, black holes don't eat information – it has ways of escaping. But that's for another entire episode.

Fraser: Right, right. Okay. But when they're talking about information, that's what they're talking about – the quantum state of the stuff that gets consumed.

Let's move on and go to our next question. This is from Mark Maultby. "If gravity is the force of interaction between objects, what is the smallest object that could noticeably be said to have gravitational attraction?"

I just want to set some scale here. If I have the Earth, with the Sun... Here we are on the Earth, feeling its gravity. If I go across the universe, to the other side of the universe, I'm still feeling the effect of gravity from the Sun, right?

Pamela: Oh yeah.

Fraser: Now, not much, obviously.

Pamela: Not noticeably.

Fraser: It's so miniscule you can't even have numbers to describe it, but it is there. Every piece of matter in the whole universe is interacting gravitationally with every other piece of matter in the whole universe. That's true?

Pamela: That is exactly true.

Fraser: Okay. All right, and then that doesn't matter for any size – for a planet, a moon, a proton, an electron, a neutrino… anything, there's still a gravitational force that's being done across the universe. I guess the question is, is there some point where that doesn't happen anymore?

Pamela: No. It's either you have mass – and if you have mass, then you affect things with gravity. Or you have no mass, in which case you can fly across the universe at the speed of light.

Fraser: Is there a minimum amount of mass you can have/

Pamela: Nope.

Fraser: But, we had this conversation just a couple of weeks ago about the Higgs-boson. I know there's the concept of gravitons. Is there some number where, if you're smaller than the Higgs-boson, then you won't have mass? Like, you need to have one Higgs-boson to have mass – I'm speaking gibberish, right?

Pamela: That's one of the crazy things. Higgs-bosons have a fair amount of mass.

Fraser: Theoretically.

Pamela: Or at least, they have a fair amount of energy (and energy and mass are kind of interchangeable, which makes the way we talk kind of confusing). The real question comes down to what is the least massive particle that we know about? That's probably quarks. Three quarks combine to make a proton.

I think the real question is what the particle is with the smallest mass out there. Here you have to start remembering there's quarks, and they combine to create protons and basically have mass (in a sort of weird kind of way). Electrons have mass, neutrinos have mass. Then there's this stuff called dark matter that we don't know what the heck it is. It has mass. It gravitationally effects things.

I'm not sure we know, yet, at this point in time, exactly what the smallest particle out there is, because we're still discovering particles. We're still trying to figure out what this weird stuff called dark matter is. But it's basically, when you start getting down to these… this is a single lepton, a single boson, a quark… these individual units have slightly different masses, but these are the smallest things (smaller than atoms), that are capable of gravitationally affecting other things in the cosmos.

Fraser: But that kind of feels like you're not quite answering the question.

[laughter]

You're kind of saying that these are the smallest particles that we know about – that we know exist for sure – and we know that those particles have mass, and therefore they can gravitationally attract. If you had one quark on one side of the universe and another on the other side of the universe, if they weren't being expanded away from each other, they would eventually come together, over a long time.

But the question is, is there some theoretical limit where you just can't have any less mass?

Pamela: When defining the smallest possible things, we often say, "there's the Planck unit of time" (the smallest discernable unit of time), or there's the Planck length… You'd think there'd also be a Planck mass, which would be a limit to how small mass could get. But there's not.

As far as we know, there may not be a limit to how small something can get in terms of mass, but we're still figuring out the particle world. We still haven't found the Higgs-boson (if it exists). We still haven't found the graviton (if it exists). There's this whole realm (potentially) of different particles that don't interact via the electromagnetic force like electrons and protons do, that are making up dark matter. For all we know, the least massive particle out there is also the most common particle out there and happens to be whatever it is that makes up dark matter.

We're still learning. Particle physics, the standard model, these are things we're still working to define. As far as we know, no – there is no mandated-by-the-cosmos boundary on how small a mass we can get. We're still exploring.

Fraser: I guess the question will maybe help to be answered by upcoming work with the Large Hadron Collider.

Pamela: Yes.

Fraser: We don't really know. That was a good question too.

[laughter]

Pamela: These are the ones that stump me.

Fraser: I know, I know. Let's move on. Something I think is a little simpler – this comes from Sabre Rosewood and the question is: "since the tides on Earth are part of what causes our moon to slowly move away, what will happen once the oceans are gone? Will the Moon stop moving away from the Earth?"

We talked about this in our show "Where Does the Moon Come From?" and discussed that – the Moon is slowly moving away from the Earth. What's the cause of that?

Pamela: It boils down to conservation of angular momentum. The Earth isn't a perfect sphere: it has mountains, it deforms itself due to the gravitational pull of the Moon. As the planet rotates, it bulges out so that part of it bulges toward the Moon and part of it bulges in the opposite direction because the gravity is not so strong over there.

This deformity basically gives the Moon a gravitational handle to hold on to our planet and say, "no – don't rotate past me, keep the bulge pointed this direction!" The rotation of the Earth is constantly trying to carry the bulge past the Moon. Gravity grabs that bulge and pulls it back. This pulling back on the bulge that's trying to rotate past the Moon is slowly, slowly, slowly, slowing the rotation of the planet.

Fraser: You're talking about a bulge that's coming from mountains or one side of the Earth is a little more bulged than the rest of it. Oceans move huge distances – more than the mountains ever move. There's a gigantic amount of ocean on the planet, so does that play a significant role in this?

Pamela: It plays a significant role, but it's not the only role. So, 50 million years from now, when our oceans start to evaporate away, we're still going to have these tidal effects. We're still going to have this planetary flexing that prevents us from becoming a perfect sphere ever. This planetary flexing is going to continue to slow the rotation of the planet until eventually we're completely locked so the same face of our world is always facing the same face of our moon.

Fraser: And the moon will stop moving away.

Pamela: It will stop moving away.

Fraser: Right, so the oceans are part of the bulge on the Earth, but they're not the whole thing. Eventually, even when the oceans boil away, the Earth and the moon will still go through this dance until they figure it out – until the Earth and moon are facing the same side toward each other forever and always. Which I think would be longer than the lifetime of the Sun, right?

Pamela: Yeah, that's what we think right now at least.

Fraser: It'll be a red giant before it happens.

Okay, cool question. Let's move on. Paul Barnett asks "Since the universe is expanding and we believe that matter cannot be created or destroyed but only changed from one form to another, I'm curious to know where the new matter comes from to occupy the new space that's created. Is there new matter being spontaneously created?"

Now, let me try and rephrase the question, because I think he made a couple of mistakes there. We talk about the universe expanding, the expansion of the universe, both from the big bang but also from the additional dark energy that's helping to push the universe apart. We're getting more space in between the galaxies and galaxy clusters and interstellar space. But we're not necessarily getting any space in between the galaxies because they're held together.

I guess the question is, let's look way out into the most unpopulated part of the universe where space is expanding apart and we can measure the density of how many atoms per cubic kilometre there are out there. As the space is expanding from dark energy, is there any more matter coming into existence?

Pamela: No, that's the cool thing. The universe is basically diluting itself over time.

Fraser: So it's like you're pouring water into something that was quite thick, and it's just making it more and more dilute – more and more thinned out.

Pamela: Or, the way I like to think about it, if you imagine blowing up a balloon, the balloon has very thick walls when it's small, but the more and more you blow it up, the thinner those walls get, the fewer atoms there are per square centimetre of area on the surface of that balloon.

Fraser: Until it pops.

Pamela: Until it pops.

Fraser: Our universe isn't going to pop, is it?

Pamela: No.

Fraser: Okay.

Pamela: But it's going to get pretty empty.

Fraser: Right, and that's it – there could be some point in the far, far future where everywhere you look, there's no atoms around. Right now, I forget – did you mention how dense space is?

Pamela: It's on the order of nothing per cubic meter?

Fraser: Right, okay. The occasional particle per cubic meter, but you could eventually get to the point where there's one particle per light year.

Pamela: What's weird though is this is true of atoms of normal matter. There's this thing called dark energy, and near as we can tell, dark energy is constant at all times. When we look at how much energy there is per cubic meter of space, it works out to a few protons worth of energy at all points in time, even though the total volume of the universe has increased.

That means the amount of energy, the amount of dark energy in the entire universe, is somehow increasing as the universe gets larger, because its staying constant as a function of volume. This gets confusing.

Fraser: I've got a zinger for you now, then. We always talk about the fact that matter and energy are interchangeable. So, is dark energy interchangeable with matter? Could you freeze it into matter?

Pamela: As far as we know, no. Dark energy is this weird enigma, currently. We don't know what causes it. As near as any theorist that I can understand has gotten, dark energy is basically a field of energy that permeates all of space and time. If you can imagine this mesh of energy that is everywhere, all at once, and not getting all metaphysical on me… if you can imagine this lowest possible energy state (that isn't zero) it permeates everywhere. One of the fears is something will come along and trigger that wave, that field that permeates everywhere to crash down to zero and no one knows what will happen.

Fraser: Now you're freaking people out here.

[laughter]

Pamela: Theorists do scary things with their mathematics sometimes. Like I said, we don't really understand it right now. So, give us a few years.

Fraser: Okay. To summarize then, with the expansion of the big bang and the addition of dark energy, the universe is growing but the amount of matter in the universe isn't changing, so it's really just getting diluted. So, back to the question where's the matter coming from, it's not coming from anywhere – there's no additional matter. All the matter in the entire universe was created in the big bang, and that's all we've got.

Pamela: That's all we've got.

Fraser: All right. Speaking of all we've got, there's one more question. This is a good one too, in fact this is a question I was going to ask you about and I never got around to it.

This one comes from the forum, the Bad Astronomy & Universe Today forum. "I can't wrap my head around the physics of gravity assist. Why does travel in the same direction of an object's orbit speed something up, while travel in the opposite direction slows it down? I keep thinking the approach push and depart pull would cancel each other out either way and not change the speed at all."

This is great – I've thought about it too. You've got a spaceship going toward Jupiter and it's going to get a gravitational assist to pick up velocity and go much faster. As it approaches Jupiter, Jupiter is speeding it up. I get that – it's velocity might be changing as it's falling into Jupiter's gravity well. As it does its fly past, and starts to move away from Jupiter again, now Jupiter's pulling back on it. It should be slowing back down. Shouldn't you just end up with the same velocity? It's like going down a hill and then back up it on the other side, shouldn't you end up going the same speed you were going before?

Pamela: That would be exactly right if the object you were having the gravity assist from wasn't moving.

The key is you are gravitationally falling into the gravity hole of some object in motion. If it's not in motion, you go in, come back out and your energy hasn't changed at all. If you imagine a completely frictionless, gently curved valley in the road. You go down a hill, up a hill, no friction occurs so you're going the same speed on both sides of the hill even though you speed up going in and slow down going up… it all cancels out in the end.

The catch is, if the object's moving, the amount of time that it is either able to gravitationally pull on you to speed you up or gravitationally pull on you to slow you down changes. If you're moving in the same direction as the object that's giving you the gravitational assist, as you're moving toward it, it's saying "yes! Catch up with me!" and pulling on you to get you to catch up to it. So the whole time, you're approaching it, it's running away from you. As it's running away, it's pulling on you to help you catch up.

Once you catch up to it, you've gained all this velocity, so you're able to zip away from it with extra velocity you didn't have before, because the extra time you had catching up with it lead to you getting some of its velocity and spending extra time falling in and not extra time falling out.

Fraser: So, you're slowing down Jupiter by a teeny-tiny little bit, to slow it down in its orbit, and its speeding you up to pull you up to its speed.

Pamela: Yes.

Fraser: Right. So the amount that you get falling into it and the moving back away from it do cancel out, but it's that process where it's pulling you up to its speed in the orbit which is what adds to your velocity.

Pamela: If you're going in opposite directions, then you end up putting the extra effort into slowing down to meet its speed. Then you end up going slower on the other side. Same thing.

Fraser: Right, and I know the MESSENGER space craft is using that method to be able to go into orbit around Mercury.

Pamela: Yes.

Fraser: They're using this process to be able to slow themselves down, as well – if you just go the opposite direction, you slow yourself down.

That totally makes sense. I honestly didn't have it thought through, so thank you.

Pamela: It's a really cool affect.

Fraser: You know what, I said that was the last one, but we've enough time for one last, quick little question. I think this is a quick one. Rich from New York wants to know “if the Sun were to suddenly vanish, would we feel the effects of gravity instantaneously, or would it take approximately 8 minutes, just like light?”

Pamela: It would take 8 minutes, just like light. Fast enough?

Fraser: The speed of gravity is the speed of light. If the Sun disappeared, we would see the light disappear and we’d also suddenly feel the gravity disappear.

Pamela: It would appear as if all of a sudden all the stars became visible and they’re moving in the wrong way. That’s kind of cool.

Fraser: Yeah.

And that effect works the same for us moving around the Milky Way, the Moon going around the Earth… it waits for the speed of gravity. Cool.

I think that plays into our recent show about gravity waves, that’s what the whole trick is about. You’re watching as waves of gravity are released from objects as they wash over the planet. That’s it – that was quick.

Pamela: Cool.

Fraser: Perfect. I think that covers everything.

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