# Astronomy Cast Episode 27:
# The Third Question Show

**Fraser Cain:** The first question comes from --

**Dr. Pamela Gay:** From your neck of the woods, actually.

**Fraser:** Yeah, this actually comes from my neighbourhood, from Surrey, BC which is just outside of Vancouver. Earl Williams has a question, so let's hear it.

[recording]

Light is crucial to astronomy, but what enables a photon to travel at the speed of light and to move endlessly? We know that to move particles in an accelerator we expend huge amounts of energy. My light bulb doesn't have much energy but I assume that if I put it by the window, some of the trillions of photons it produces will, in 2 seconds, be on the Moon and in time will clear the last vestiges of the Milky Way Galaxy. How is this possible?

[end recording]

**Fraser:** Why does light – where does light get all the energy to cross the Universe?

**Pamela:** It's this little thing that Newton came up with. An object in motion tends to stay in motion unless acted upon by a force. Light is this weird little packet of energy, it's both a wave and a particle all at the same time and that's all philosophically quite difficult (but quantum mechanics tends to break brains that way). This little mass-less packet of energy acts like a particle and obeys Newton's laws. As it chugs its way across the Universe, as long as no force acts on it, it's going to keep going at the exact same path forever.

When light beams pass close to gravitationally, pulling on objects – when they pass past galaxies, when they shoot past stars, their paths will get bent. This is where we get gravitational lenses. But that light just keeps going, it's just on a new direction. Light always travels at the same speed, it always goes at the speed of light. It's convenient that way.

**Fraser:** I guess it's not quite as surprising because in this situation Earl wanted to know about a photon, but you could almost ask the same question about, if I were able to throw a rock hard enough off the Earth or wherever and it went through space, it would be able to keep going across the whole Universe.

**Pamela:** The Voyager spacecrafts, they're leaving our solar system. They're going to keep chewing along – much slower than a photon – but they're just going to keep going until they get gravitationally sucked into something somewhere far away from our solar system.

**Fraser:** Right

**Pamela:** Things just keep going until you yank on them.

**Fraser:** It's all about momentum and inertia.

**Pamela:** Exactly.

**Fraser:** But does that really make sense? I don't want to break people's brains here or anything, but to say that photons have the inertia from when they're emitted to get all the way – to never stop – is it the same thing as an actual chunk of rock that's going at a different speed?

**Pamela:** It's pretty much the same thing. An object in motion, including a photon, is going to just keep going. With a rock, if it collides with something it's going to either bounce off of it, it's going to get absorbed into it and its direction is going to get changed. The total energy of the collision is going to get conserved. With a photon, the same thing can happen.

A photon can hit an atom and get absorbed and later on it will get re-emitted and none of the energy is lost. Now, if the atom has a higher energy level after the photon is emitted, the photon is not going to move slower. A rock, it might impart velocity on something and then it moves away with a slower velocity. With a photon of light, it changes colour. So, instead of changing velocity, photons compensate by changing colour when they impart energy onto things.

**Fraser:** So how does that mechanism work?

**Pamela:** There is a relationship between the energy of a photon and its colour or frequency and a constant. It's a nice, linear relationship. If I increase the energy by a factor of 2, I also increase the frequency by a factor of 2 which will make an object appear to be bluer. Anytime I change the energy of light, it's going to keep going at the speed of light.

Instead of thinking of flying rocks, it might be easier to think of sound waves instead. With sound, the velocity of sound through air (as long as the air stays the same temperature and density) the sound is always going to stay at the exact same speed. The amplitude of the sound can change – you can have a louder or softer sound – and that's part of where the energy gets tied up in the sound. In light, it gets tied up in the colour.

**Fraser:** So to wrap up for Earl, photons (like wood or spacecraft or rocks) have momentum and they're able to move across the whole Universe until they bump into something and that changes their direction or they get absorbed.

**Pamela:** Exactly.

**Fraser:** All right, that was good. I think that should wrap it up for him. Let's move on then. The next question here is about how many photons come off of stars and how we can see them.

[recording]

> I know any star gives off all this life as photons and these travel in a straight line forever through space until they hit something or are bent by gravitational fields. How many of these photons are being released, and how closely packed together are they so that we can observe them continuously millions of light years away from anywhere in space? If I move my head just a little while looking at a star, I continue to receive a photon stream from millions of light years away. How is this possible?

[end recording]

*(Editor's Note: This question was asked by Joao Frasco – sorry we missed the credit!)*

**Fraser:** This is a good question. There is so much light that we're able to see in the sky – so many stars – yet those stars are so far away. It's amazing that we can even see them at all. So they must be emitting a lot of photons.

**Pamela:** Oh, there's a ton of photons coming off. I did a back of the envelope calculation in preparation for this show. Our Sun gives off about 3.8*10^26 (that's 3.8 followed by 26 zeros) Joules per second – that's 3.8*10^26 Watts of energy.

Now, all sorts of different photons are coming off of the sun. Some are red, some are blue and they each have a different number of Joules associated with them. The majority of the photons coming off of the Sun are going to have the same wavelength. There's an equation that allows you to get at the maximum wavelength where the most energy is coming off that's a function of temperature.

When we look at this relationship, we can figure out that at this maximum wavelength, one photon is going to have 3.6*10^-19 Joules – that's 3.6 and then move the decimal place 19 places to the left and fill zeroes in between. So you have a lot of energy coming off with a lot of photons that have very small amounts of energy associated with each of them. When you work this out to find out (just assuming for back of the envelope purposes that all the photons have the same energy) you end up with 1 followed by 45 zeros worth of photons. 1*10^45 photons coming off the surface of the Sun.

**Fraser:** But I guess we have to put in for the fact that we're really, really far away from those stars.

**Pamela:** So all those photons spread out over space and by the time they get to the Earth and we consider just how many photons are entering our eye (not all the photons leaving the Sun at a distance of the Earth away, but just the number of photons that get intercepted by our pupil – I'm going to assume that's about 0.5cm squared in area). There, the number of photons entering the eye is going to be 1.9*10^17 photons. That's about the same number you get from a 100 watt light bulb held 10cm from your eye. So if you have one eye in a dark chamber with only a 100 watt light bulb 10 cm away from your eye, and your other eye looking at the Sun, both your eyes are going to be getting the same number of photons.

That's bright.

But what if we go a light year away? If you get a light year away, your eye is going to be intercepting 47 Million photons. That’s still a reasonably large number.

**Fraser:** That's still a lot of photons!

**Pamela:** But our eyes have to intercept a lot of photons for us to see something as bright. For instance, at 10 light years, that same Sun will appear to be giving off 470 thousand photons to our eye, but that's the same as a 100 watt bulb 200km away. So, our Sun at 10 light years and a light bulb at about 200km – that's the same number of photons hitting our eyes.

**Fraser:** So I guess for his question then, the short answer is that wherever you put your eye, there's that number of photons passing through that area.

**Pamela:** Exactly.

**Fraser:** So even if you move your eye to the left, right or look to the side, all that's going to do is let you intercept a different group of photons but the fact is the star is pumping out those photons in –

**Pamela:** Huge numbers

**Fraser:** -- in a nice tight sphere at huge numbers and its only that, because we're so far away, its not overwhelming.

**Pamela:** Exactly.

**Fraser:** Or alternatively, when astronomers detect quasars which are billions of light years away, you can just imagine how much energy they must be putting out.

**Pamela:** Yeah, you start running out of words for the number of photons coming out.

**Fraser:** Running out of zeros…

[laughter]

**Pamela:** Right.

**Fraser:** All right. So next up we have a two part question. So we'll play the whole question and then when we're done, we'll crack it in half and deal with it. Let's play the question:

[recording]

**Scott:** Hello Fraser and Pamela, my name is Scott Vonberger

**Andrew:** And I'm Andrew Spifmollen

**Scott:** And we're from the Thought-Provoking Discussion Podcast. Andrew and I have some questions that we figured you two would be the best to answer.

Astronomers have said that they can measure the speed of gamma-rays coming off of quasars. Sometimes these gamma rays coming off of quasars can reach upwards of 99% of the speed of light.

My question is, if the Earth was rotating toward this quasar that was emitting gamma-ray jets at 99% the speed of light, would the sum of the velocities of both the Earth and the gamma-rays exceed the speed of light and would the Earth rotation on the other side effectively decrease the relative speed between the two?

In essence, my question is, would the Earth rotating toward a gamma-ray jet at 99% the speed of light violate the laws of Special Relativity?

**Andrew:** And my question involves the speed of gravity. In 2002, there was an experiment made that used the data from the VLBI measurement of the retarded position of Jupiter, on its orbit during Jupiter's transit across the line of sight of a radio source. The conclusion was the speed of gravity is between 0.8 and 1.2 times the speed of light, which would be fully consistent with the theoretical prediction of general relativity, that the speed of gravity is exactly the same as the speed of light.

However, this experiment received a lot of criticism, the most common of which is that it did not actually measure the speed of gravity, but instead measured the speed of gravitational lensing as seen by the speed of light.

My question to you is: Is there any experimental data that would indicate the speed of gravity, and do you think this experiment actually measured the speed of gravity? If not, what do you think the true speed of gravity truly is? Thank you.

**Scott:** Thank you very much for taking our questions and keep up the great work on an excellent show.

[end recording]

**Fraser:** Okay, so let's tackle Andrew's question first. He said that gamma-rays are pouring off quasars and moving at 99% of the speed of light. But gamma-rays move at the speed of light, right?

**Pamela:** Gamma-rays move at the speed of light, but I think what he's actually talking about is cosmic rays, which can be for instance, just a proton hurled at high velocities across the Universe.

**Fraser:** Right. I think I did a story about that just a couple days ago about how quasars or the cores of supermassive black holes can actually act as natural particle accelerators. They've got these massive magnetic fields and they can whip up particles so they're moving almost the speed of light.

**Pamela:** And I think that's what he's talking about here.

**Fraser:** All right let's hope that's right. If we're wrong, Andrew, send us another one and we'll answer that one too. I think there's an interesting answer here as well. We'll do this one first and if it's the wrong one, we'll get the right one later.

So you've got a cosmic ray coming at the Earth at 99% the speed of light, and the Earth is turning and it's that speed you as a person on the Earth who sees it, who will be observing that cosmic ray, are we almost getting to the speed of light?

I could boost the question even further and say what if you fire your cosmic ray at me and I'm on another cosmic ray and they collide and both are moving head on at 99% the speed of light, what do you see?

**Pamela:** If you're the person riding the cosmic ray at 99% the speed of light, time slows down for you. You don't actually see yourself going quite as fast as everyone else sees you going because your watch has slowed down. You're still going to see light travelling at the speed of light and that's how we figure out how much your watch has slowed down.

If you're travelling at 99% of the speed of light and I'm just standing here and we both see a passing light beam going at the exact same speed, your watch has to have really slowed down. That's what allows us to work, the changing of time itself, the changing of the flow of time. As we rotate toward that cosmic ray, time slows down. As we rotate away, time's not slowing down. It's this flexibility in how we perceive time that prevents things from ever going faster than the speed of light.

**Fraser:** Let's come up with a few scenarios. You're on the Earth seeing that cosmic ray coming toward you but because you're moving as well, time slows down for you so it doesn't appear to break the speed of light. Not that the Earth rotates fast enough that its speed would match the speed of light with the cosmic ray – I think it would still have a long way to go before it would.

**Pamela:** Oh yeah.

**Fraser:** But I think that's the point. As the Earth is going the other direction and you're looking back over your shoulder, seeing cosmic rays coming the other way, time is not slowed down for you in the same way.

**Pamela:** Time is always adjusting itself to make sure that nothing goes faster than the speed of light.

**Fraser:** If I'm some 3rd party observer watching the person on the Earth come together with the cosmic ray, still it's not a problem because I'm not involved in the collision. I just see something moving 99% the speed of light hitting something else. It doesn't matter.

**Pamela:** Exactly.

**Fraser:** Nothing has moved faster than the speed of light from my point of view.

**Pamela:** Exactly.

**Fraser:** And if I see two cosmic rays colliding together at 99% the speed of light, it still doesn't matter because once again I'm outside of it. Both of them are coming together, nothing's breaking the speed of light, everything's fine.

**Pamela:** Exactly. You never move faster than the speed of light, and time adjusts to keep that true.

**Fraser:** Time is the thing that is willing to bend. That's funny.

Okay, so I hope that answers Andrew's question – if it doesn't, hit us again Andrew. We're ready.

Scott wanted to know what is the speed of gravity?

**Pamela:** Well, according to Einstein (and so far no experiment has proven Einstein wrong) the speed of light is the speed of gravity. It's all the same. Now, this can seem a little bit confusing, because if you just think about it, it would imply that if you yank the Sun out of the solar system it would take us about eight minutes before the Earth stopped orbiting the Sun even though the Sun wasn't there for eight minutes.

It also seems to imply that as we're moving through the solar system, there should be some sort of weird lag between "we're here now, we know which direction gravity's pointing in, but wait we moved – we have to wait for gravity to us". The thing is, gravity's already gotten there. We're sort of rolling around inside a gravitational bowl. As long as the Sun stays where it is, the bowl is going to stay where it is. So our bowl is defined by the location of the Sun. If you remove the Sun, it's going to take the speed of light for the gravity to travel and get rid of that bowl.

**Fraser:** I think in a show… I don't remember which it was, we talked about what would happen if you turned off the Sun. There would be this fear of expanding darkness because the light had already been emitted. I guess a sphere of expanding gravity-lessness would go with it as well.

In the beginning, Mercury would see the Sun and then –

**Pamela:** It would shoot off in a straight line.

**Fraser:** It wouldn't see the Sun anymore and – exactly. And no longer would it be rotating in a nice circle (or, ellipse) it would just go off in a straight line like you let go of a sling you'd been spinning around your head.

How could you test that? I guess that's the question. It seems strange to me that if we know gravity, and we know how it acts, it's amazing that we haven't been able to detect the speed. So what are the experiments that people have tried to do to figure that out?

**Pamela:** Well, the most definitive and consistently accepted experiment has been to look at binary pulsars. These are extremely massive, tiny, tiny objects. Objects more than 1.4 times the mass of the Sun that are roughly the size of Manhattan – so really dense objects – that are orbiting each other. We can get very accurate timing on their orbits because they happen to also be pulsating. These pulsar beeps in the radio allow us to time where they are and very accurately figure out exactly how their orbits are evolving with time.

With these high density systems, what we're actually finding is we can watch gravity radiate away. This radiation is predicted by special relativity. There's all sorts of really complicated, very scary math (that happens to intimidate me), that goes into describing how the gravitational radiation radiates away in terms of the amount of mass, the closeness of the orbits and all this other stuff.

If you work through all of the big scary math, it predicts exactly what we see. We see these orbits changing over time and it all works. None of it would work if gravity didn't travel at exactly the speed of light. You have to have within 1% to get the results we see. So the Universe seems to be following a theory that requires the speed of gravity to be the speed of light.

Now there's also a highly controversial experiment a few years ago where a group of scientists looked at quasars in the distant parts of the Universe as the planet Jupiter passed in front of one of them very closely – it wasn't exactly an eclipse, but they passed very near one another. Gravity affects light, we talked about that with an earlier question.

The idea was, as Jupiter put itself roughly between us and this background quasar, it would change the position in the sky where we saw the quasar as the light got bent. This change was seen. It was interpreted by some to be a way to measure the speed of gravity. You measure when you see this change in position in the quasar and if it behaves in a certain way, you've measured the speed of gravity. Other theorists have come along and said, "no, no no, you've actually proved something else".

So, how to interpret this observational result that yes, we did see the position of the quasar move because of the gravitational effects of Jupiter on the light travelling toward the Earth – how you interpret that observation is still highly controversial. Most people have said this was not a measurement of the speed of gravity, it was a measurement of something else.

I hang my hat on the binary pulsar results. They're well-accepted, there's no other explanation out there. I look at what was done with Jupiter as a neat proof that gravity bends light, and I don't interpret the results any further than that.

**Fraser:** Now won't the detection of gravity waves really give the answer one way or the other?

**Pamela:** All we need is to get LIGO or its future satellite version LISA up and running effectively and get a couple really good detections and we'll be able to say with certainty that the speed of light and the speed of gravity are the exact same thing.

**Fraser:** Right because gravity waves are where maybe you've got black holes colliding and the ripples in space-time expand out at the speed of light and so we should be able to detect those ripples as they pass through us, as they make us grow and shrink.

Okay, and I think we will do an episode on gravity waves at some point. But let's not go into too much more detail this show because we've still got three or four more questions.

On to the email questions: John Darnell wants to know: "Shouldn't most of the light generated from the early years of the Universe have already passed us by? Our velocity is much less than the speed of light and even radiation reflecting backwards from an object on the other side of the Universe should have passed us by."

He finds it hard to believe that anything occurred more than 6 billion years would have already moved on past us. He finds it amazing that you can still see the Cosmic Microwave Background Radiation when you look out 13 billion light years away.

How is that possible? Shouldn't all the light generated in the Big Bang have passed us by so now all we can see is the light that is within a certain range of us?

**Pamela:** Well, that would be true if the Cosmic Microwave Background had all emerged from one point or from a shell a given distance away from us. But the truth is the Cosmic Microwave Background Radiation came from every point in the Universe. Everywhere that is part of the Universe at some point in time was the centre of the Big Bang. Every point that is everywhere in the Universe at one time was part of that crazy moment when the photons and the matter separated and the Cosmic Microwave Background was formed.

So yeah, some of the photons have already passed right past us and are off heading toward a different part of the Universe. But there's still photons from other parts of the Universe, from other places that let off the Cosmic Microwave Background that are sending their light toward us. So every moment, we're getting Cosmic Microwave Background Radiation from a different point in space. We're seeing a continuous reflective shell but that shell is coming from everywhere all at once.

**Fraser:** Can you imagine a time when we won't see the Cosmic Microwave Background Radiation? Will there be a point where John's question comes into play? 25 million years down the road will there be a point where the speed of the expansion of the parts of the Universe that were once Cosmic Microwave Background Radiation are not within that range of us?

**Pamela:** Well, there's a couple of different ways to think about this. The first problem is, is there a point in time where the Universe has expanded itself at what is perceived as faster than the speed of light, such that there's photons off in the distance that just can't get here. That is possible if you look long enough down the line, where we're going to have the horizon so far away and enough time is going to have passed that everything that could get here has gotten here.

The other problem is, what about some point in the far distant future (and I'm talking in the unimaginably far distant future) where all the photons have had time to interact, where all the photons from the Cosmic Microwave Background have been absorbed, have been re-emitted in a different form, have somehow had their existence altered so that we no longer recognize them as the Cosmic Microwave Background. It's possible, but we're talking unimaginably far in the future.

**Fraser:** I think part of the misunderstanding is when people imagine the expanding Universe, they think of a sphere that's 13.7 billion years in all directions.

**Pamela:** And in reality we're only seeing a few percent of the total Universe.

**Fraser:** Right, the Universe itself is probably actually much, much bigger – maybe infinitely bigger. So if you imagine the Big Bang, and you had the Cosmic Microwave Background Radiation, which was essentially all that energy and then now it's expanding, our sphere of what we can see is growing and yet because the Universe is only 13.7 billion years old, as that sphere grows what we're seeing of the very outside edges of it is always the Cosmic Microwave Background Radiation. We can't see something as it looks today, we have to see it 13.7 billion years ago and what was there was the background radiation.

**Pamela:** You know, 2 billion years from now we're going to be looking at what the Universe looked like at the moment when the Cosmic Microwave Background formed at some place that was 15.7 billion light years away.

**Fraser:** So all we get to see is at the very outer edges is just baby pictures.

[laughter]

**Pamela:** Exactly.

**Fraser:** Wherever we look. That's funny. I don't know if we gave people headaches there, but I think we'll move on.

[laughter]

We are planning a show where we'll talk in more detail about that. We get that question literally every couple of days. Lots of email asking what the Universe is expanding into.

All right. The next question is from Rick. He wants to know – he says, "Fraser asked a question about if the Earth would go into a black hole in a trillion years. Pamela responded saying by that time the Milky Way will have collided with Andromeda. My question is how is it that two galaxies will collide when every galaxy is moving away? Obviously to collide with Andromeda, that means it's coming toward us."

Andromeda is coming toward us, isn't it?

**Pamela:** Oh yeah. We are on a head-on collision course. The catch here is the entire Universe is expanding, but if I hold on to my desk hard enough (and really, I don't need to) the expansion of the Universe isn't going to carry me and my desk apart because we're holding on to one another.

The truth is, the Earth is holding on to us, and the Sun is holding onto the Earth and the galaxy is holding onto the Sun and all the rest of the stars, so we are a gravitationally bound together set of masses that aren't expanding. The space around us is expanding, but we're held together and we're going to maintain our size and shape.

Now, we're also holding on, gravitationally, to our local group; to the Large and Small Magellenic Clouds, to Andromeda. Our local group is all gravitationally bound together, and interacting gravitationally as this island of material that is stuck together in this expanding sea of Universe.

As long as things are gravitationally held together, they can still squish together with gravity, and still interact. They maintain their distances (or in some cases, lose their distances as they collide) because they're held together by a different force.

When we look at galaxies that we're not gravitationally bound to, those are pretty much all moving away from us. Some of them seem to be moving away faster, some moving away slower and that has to do with both the Universe tearing them apart and then there's also individual velocities.

There's this really neat diagram of galaxies as a function of where they are in the sky (left, right, up and down) and how fast we see them moving away from us. In this diagram, there's what's called the "Finger of God". It's this cluster of galaxies that seem to be forming this straight line through this map.

It's not that all these galaxies are clumped together in this weird ellipse shape that we've named the Finger of God, rather that all these galaxies are in a tight little spheroidal bundle, but within this bundle they're all moving. Some are moving toward us and some away from us, and these velocities within this swarm of galaxies are superimposed on top of the velocity they have because the Universe is expanding. So it's velocity on top of velocity.

When things are gravitationally bound together, it adds a new layer of complexity to this idea that the Universe is expanding and everything's moving away.

**Fraser:** But the expansion of the Universe is affecting the distance between us and Andromeda, isn't it? If it wasn't for the expansion of the Universe, Andromeda would probably get here a lot quicker.

**Pamela:** I think the reality is that we're gravitationally bound together, and because of that we don't see the expansion within our small little system.

**Fraser:** So the expansion isn't acting as a counter-force to the gravitational attraction between us and Andromeda.

**Pamela:** Not at the small scale of our local group. Now, when you start looking at how our local group is moving toward nearby superclusters, there you start to get this superpositioning of expansion pulling us apart while our gravitationally falling in is causing an overall motion toward the supercluster, but its slowed.

**Fraser:** Could you get a situation where two objects are gravitationally moving toward each other at the rate at which the Universe is expanding so they appear to be not moving away? Like if you're swimming up a river at the same speed as the river's pushing you down, so you just stay stable.

**Pamela:** The Universe is a vast enough place that I can see that happening, where you end up with this exact balance between gravity trying to pull two objects together and expansion trying to pull them apart.

**Fraser:** Okay, I hope that answers the question, Rick. We're too close, we've got gravity, so we're going to hit Andromeda.

Moving on, this is our last question. It's from Stephen Williams who wants to know about redshift. He says, "How do we know that the redshift we observe in more distant galaxies isn't simply due to the speed of the galaxies at the time they're seen? So, to explain, when any explosion goes off, it starts off fast and slows with time. The further back in time, the faster galaxies will be moving at that time. Isn't the increase in redshift in distant galaxies in fact prove that the Universe is slowing down?

I guess that’s the question, you can imagine that if the Big Bang were an explosion, then in that first few moments everything would be moving much more quickly apart and so we would see that redshift. Here we are now, why do we see it?

**Pamela:** This is a very complicated question to try and answer. With your standard explosion model, you'd expect that if you're standing in any one point relative to where the explosion took place, you'd see different things going in different directions, different velocities. At the moment of the explosion, everything would be moving fastest away from that point of the explosion.

Over time (because explosions take place in air), drag forces slow them down. Because explosions that we're used to take place with gravity, gravity slows down the objects.

If instead, you imagine a Big Bang out in space, then everything is going to shoot away from that point that was the Big Bang – but every point was the Big Bang. Okay, so, every point starts off moving faster at a given moment, but then why would everything slow down?

There's gravity. We look at gravity and say "gravity should be slowing things down" and that's what we thought we would find. You start with the presupposition that the entire Universe is expanding because every point was part of the Big Bang. In the past, everything should've been moving faster away than it was now.

So you build a model, taking into account that the entire Universe is expanding which means every megaparsec of space is moving at roughly 70km/s apart. So something that's two megaparsecs away is going to appear to be moving at 140km/s. Something three megaparsecs away is going to be appearing to go about at 210km/s.

So that's where you get your initial things further away appear to be moving faster. But then you assume it took time for that light to get to us and we assume that right after the Big Bang things were moving faster and we talk about the galaxies that we could first see. It's really a few billion years after the Big Bang.

That's what astronomers thought, so we made our models and started measuring the velocities of objects and looking for the changes in the expansion rate as a function of time and got confused. It appears that today, the Universe is accelerating apart, that the velocities of two things moving apart today are higher than the velocity of two things moving apart in the early Universe.

We see things further away moving faster because there's more megaparsecs of space to be expanding, but because we expected gravity to slow down the rate at which the Universe is expanding, we expect to see certain velocities at certain times. If we measure those velocities we don't find them. Instead we find we're speeding up. It's – we're going to have a bunch of –

Exactly. To help you try and understand this better. Because it is this very complicated layer of math upon layer of math, but this explosion sped up.

**Fraser:** Right, the expansion of the Universe has accelerated. It's not that it went quickly and then slowed down, it's actually going quickly then accelerating. The stuff that's the furthest away would be moving the slowest while the stuff that's closer would actually be moving more quickly. But what we get is the opposite of that.

**Pamela:** Exactly.

**Fraser:** The stuff that's the furthest away still does appear to be moving the most quickly and the answer for that is because of this redshift.

**Pamela:** Exactly.

**Fraser:** Great, thanks for answering people's questions. It's great to get people's audio questions – we're always looking for more questions.

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