Astronomy Cast Episode 60:
Questions on Inflation

Fraser: I know we promised to continue with the planetary tour, but we need one last interruption to deal with the questions that arose from our inflation show. It's about time for a question show anyway, so this show is going to mainly be on that, but we've got a few others that are kind of related thrown in.

So if you still don't understand inflation, no problem – keep the questions coming. We'll just keep referring to it from now until forever.

So let's go on to the first question. This one is an audio question from Aaron Slack. Let's take a listen.

Aaron Slack: Hi Fraser and Pamela, we've heard a lot on the episodes about the Big Bang and inflation about how two points in space are allowed to exceed the speed of light limit as long as it is just the space between them that is expanding. I thought all velocity was relative. Doesn't this imply there is a preferred frame of reference in the universe, thus violating relativity? How could we go about measuring velocity in this reference frame? Thank you.

Fraser: That's a good question. If space is expanding apart, then you can almost imagine there's an underlying grid of reality to which objects are expanding apart within. So, it almost moves away from that concept that no part of the universe is special, that everything's relative. In fact, from an objective third point of view, two galaxies are expanding away from each other but there's some kind of underlying grid of space that everything's relative to. Is that wrong?

Pamela: It's a really hard question to try and figure out. Einstein said with his theory of relativity, that you can't say there is a specific frame. You always have to measure velocities, positions and accelerations relative to something.

So I can measure my position relative to my desk, relative to the centre of the Earth, relative to the centre of the galaxy, relative to the cosmic microwave background. I'm always measuring my position relative to stuff.

When we're talking about individual motions, we can't specifically say that everything is just superficially relative. There is an underlying grid to space, we just can't point to a specific point and say, "that is sector A-7 on the grid of space-time". Instead we have to look at bulk motions.

As we go out and look at larger and larger sections of the universe, we start to see motions evening out. Eventually, you end up averaging out to the motions that you observe being dominated by the expansion of the universe. When you reach that point where you can say the bulk motion is dominated by the expansion of the universe, that expanding grid-frame is the not-quite-rest frame, but that underlying frame of reference that is what's doing the expanding and which things move relative to.

Fraser: You say the underlying frame of reference. Does that mean then, that it's the primary frame of reference that everything is relative to?

Pamela: It means there are two different effects going on. Like I said, there's no individual point A7 on the grid of space-time, but what we can say is there are two different sets of motions going on.

One is gravity-dominated – our galaxy and Andromeda are falling toward one another. Our local group is falling toward a galaxy cluster. These are bulk motions driven by gravity. These are motions that can't exceed the speed of light.

But there's also the universe itself is not staying the same size. As space expands, that's a different set of motions that actually has different rules. That motion can be greater than the speed of light, and so when we look at the grid of space-time, it is there. It is underlying everything.

I'm going to destroy an everyday analogy to try and explain this. We often talk about the expanding universe using rising raisin bread dough as an example. If you're on any one raisin, if you're a little microbe happily nibbling away at the raisin, and you look at all the other raisins in this growing blob of dough on the counter, you see all the raisins moving away from you. You see ones that are further across the dough from you expanding away faster.

Fraser: So it's invisible bread.

Pamela: Assuming it's invisible bread, or you have x-ray abilities … yeah.

Fraser: Right. So you see the other raisins moving away.

Pamela: Right. So here the expansion is caused by the expanding dough. That's your grid of space-time. Now, imagine that some hungry raisin-eating beetles come burrowing through the dough to chow on raisins. Those beetles are moving relative to the grid of the dough. Their motions are dominated by the maximum speed a beetle is capable of moving – not the speed of light, something much, much slower.

Now, if you have two beetles embedded in the dough, happily chowing on raisins, and that dough is expanding faster than a beetle on its own can move, they'll see each other moving faster than a beetle's speed. But as the beetles chew their way through the dough to get to the new raisin, relative to the dough, their velocities are confined.

I don't know if that helped any, but that's the best way I have of thinking of it, of de-coupling the two sets of motions. The expanding universe is caused by one set of physics, where the grid of space-time actually is expanding and if you look at a large enough chunk of the universe, the motions are dominated by that expansion. Our motions relative to that grid are motions that are dominated by gravity. Those are limited where we can't move faster than the speed of light.

Fraser: It just sounds like there is an underlying reference frame of the universe, or a grid. I guess where it becomes complex (if it wasn't already complex enough) is that there's no end to the grid, no top, no bottom, no right, no left.

Pamela: No zero point

Fraser: No zero, no middle, no side. Just grid.

Pamela: We have no real way of putting stationary markers on that grid with little buoys that mark the intersecting points of x, y and z planes or lines. Because of that, we can't just say, "Here we are relative to the grid of space-time". The closest we can get is saying, "Here we are relative to the cosmic microwave background radiation." Relative to that, the Milky Way is moving at 600km/s. That's as close as we can get to defining a rest frame.

Fraser: That's kind of interesting though. You say the Milky Way is moving relative to the microwave background radiation – in what direction? Are we moving toward one side of it and away from a different side? Or ---

Pamela: Yeah, that's exactly it. We're moving and can actually look around the universe and find the high-mass objects that are sucking us toward them with their gravity and the areas of space that don't have enough gravity to hold us in place.

So yeah, if we look out at the cosmic microwave background, we can actually (once we remove redshifts and blue shifts that are associated with the Earth's motion, with the Sun's motion around the Milky Way), see that we're still left with this 600km/s relative to the cosmic microwave background that's the Milky Way's motion. We can look and see how we're moving relative to the galaxies in our Local Group and correct for that and figure out the Local Group's motion relative to the cosmic microwave background.

Fraser: So our motion relative to the background is purely based on us accelerating toward galaxies in our local group.

Pamela: And based on our local group's own acceleration toward galaxy clusters.

Fraser: Right, right. But if you took away all of that, then the background would be accelerating away from us at the same rate in all directions.

Pamela: Yes.

Fraser: Okay. I was wondering if there was some imbalance, but it sounds like there's not.

Pamela: No.

Fraser: I think that's the best we can do, so let's move on to the next question.

This comes from James Stovall:

"If you took a grid of space, and then divided it by two, and divided the result by two, and so on, would you eventually reach a limit where you couldn't get any smaller?"

Now, I guess with this question, that assumes there's something that allows you to take a grid of space in your hands (which I don't think you can do), and then some kind of knife that allows you to divide it by two (which I don't think exists), and so on and so forth. So the question is there some fundamentally small place where for example there's no such thing as radiation or mass or where things stop behaving in analogue and start behaving in digital, if that makes any sense.

Pamela: I think a better way of putting it is things stop being discrete. I can look at my desk and say, "there's a box, it's sitting still. There's my trackball, it's sitting still." These are discrete objects. I can bump them and they move in ways I can describe their position over time as a function of their velocity. There are no probabilistic behaviours in here.

If you take a chunk of say, a neutron material – a neutron star – and you start cutting it up, you eventually reach the point where you have a neutron. You can keep cutting that up, and in theory you're down to the quarks.

Now things are starting to behave where you start having to worry about the Heisenberg Uncertainty Principle, where you can only sort-of-kind-of describe where things are, but you still have discrete particles.

If you keep cutting things up, you eventually reach a point where everything just becomes foam. This is called the Planck length, and it's where quantum mechanics starts to dominate everything and you can only discus things in terms of pure probabilities.

The Planck length, we're not entirely sure of its physical meaning because we can't get there from here. It's such a small quantity that we don't have the ability to study things that behave in that regime.

Fraser: But what does it describe? What is the Planck length, it has some meaning, right?

Pamela: It's meaning is actually somewhat silly.

In physics, we often get sick of carrying around all our constants, so when you're studying relativity you often say the speed of light is one, and we'll change all the units on everything. You end up working with a different set of numbers, but you're not longer carrying around the constant c all the time. When you're dealing with gravity, you always have this G, the gravitational constant that you're carrying around. You can set that to one, and now you're working in a different set of units. These are natural units.

You have, also, this little ħ that you carry around with you in quantum mechanics. By setting all of these constants equal to one, you end up with what's called a Planck length: the correction term you use to get the universe to work on this natural scale. It was Planck who originally came up with this idea. The Planck length is equal to $\sqrt{\frac{\hbar G}{c^3}}$ when you throw these numbers together it's kind of small. You end up with 1.6x10^-35m. It's really tiny.

That is where we think physics sort of breaks, and everything becomes dominated by quantum mechanics and gravity we will only be able to understand within that short, tiny length scale, once we develop a theory for quantum gravity. We're not there yet, but it's one of those things where when we understand physics at that scale, we think we'll have a much better understanding of how the earliest parts of the big bang took place.

Fraser: So, probably not? I'm trying to think what your answer is here.

Pamela: So is there a point at which you can no longer divide things in half? No. You can always divide things in half.

Fraser: Right – mathematically, of course. You just put an additional decimal place and boom – you've divided it.

Pamela: Exactly. Now, is there a point at which when you try and divide things in half, you end up following Alice through the rabbit hole and physics breaks down in strange ways? Yes.

When you get smaller than the Planck length – smaller than 1.6*10^-35m, physics gets really crazy and at that point, you no longer are dealing with anything recognizable. You're dealing with a foamy-quantum-dominated regime. Maybe we'll be able to get beyond that length, once we have a quantum gravity theory

Fraser: I have a feeling that just scratched the surface of the answer, but I think that's about as far as we can go today.

Pamela: Probably.

Fraser: So, mathematically of course – piece of cake, just add another decimal. Actual physics-wise, our understanding of physics breaks down below that point and we don't really understand how things might behave if you're trying to measure them on a position-to-position basis.

Pamela: Physics and philosophy aren't always in agreement, but it leads to neat and scary discussions.

Fraser: I don't see how it's philosophical… just math.

[laughter]

It's not like there's a purpose to it, or a meaning to it… I don't see how that question gets raised.

Let's move on. So Will (and I don't have your last name, Will, I'm sorry about that) asks "Our galaxy and Andromeda are moving towards each other because of their gravity, so as they move closer they move faster because the gravity's stronger. Do they also accelerate because there is less space expanding between them?"

He's calling in dark energy on this one, which is to say we know our galaxy and Andromeda are accelerating toward each other because they are gravitationally bound. As objects get closer, their gravity gets stronger so they accelerate faster. But, at the same time because Andromeda and the Milky Way are getting closer, there's less dark energy in between them popping into space and pushing them apart. Would there be even more acceleration happening?

Pamela: Sort-of kind-of?

Fraser: Sort-of kind-of?! Yes or no?

Pamela: It's going to be a day of wussy answers, I guess.

So, dark energy is accelerating the universe apart. The current expansion rate today, right now, as near as WMAP can tell, is about 73.5 kilometres per second per megaparsec of space.

This means if you have a megaparsec, that megaparsec, every second, is getting 73.5 km bigger. Now, Andromeda is about 0.8 megaparsecs away. This says that dark energy is trying to push the universe apart, and that push is causing

Andromeda (ignoring everything else), to potentially have a movement away from us of 58.8km/s.

The thing is, dark energy… there's a lot of it, so it's able to do a lot of pushing, but gravity's much, much stronger. When we go out and measure how quickly Andromeda is moving toward us, Andromeda's coming toward us at 301km/s, and that's a gravity-dominated number that is overcoming anything dark energy is trying to do.

Fraser: That sounds like a lot though – I mean, 301km/s toward us, and dark energy is pushing it back at 58km/s

Pamela: That 301km/s is after dark energy has done its pushing.

Fraser: Well sure, so it would've been 358km/s, and now it's only 300. So I mean, before I was assuming it was miniscule, but that sounds like it's about 20% of the rate is being overcome by dark energy.

Pamela: The forces themselves are very different. So we are locked together with Andromeda gravitationally. While dark energy is moving the grid of space and time, it doesn't have the ability to pull us apart from Andromeda. Space itself is expanding, but it's not exerting a huge force.

You're held together with chemical bonds. Those chemical bonds are way stronger than gravity. There is a difference in the gravitational pull between your feet and your head. It's measurable, it's noticeable, and there are probably people in your town who have devices that will allow you to measure this difference.

Even if you got a lot closer to the centre of the planet, those chemical bonds would continue to hold your body together in the exact shape it's in right now. Those bonds are much, much stronger than gravity.

So yeah, there's this change in the gravitational force between your feet and your head, but we can ignore it when we try and figure out the shape of Fraser's body. The shape of your body is defined by the biology of the chemical bonds that make you grow into the shape you have.

Yes, there is dark energy that is trying to push Andromeda and us apart, but it's pushing on space and doesn't need a lot of force to cause space itself to expand. We're locked together with Andromeda, and that locking is a strong force holding us together.

The accelerations, the velocities that we see, they have meaningful numbers. Yes, dark energy is repelling the space that we exist in apart at 58.8km/s, but we're happily holding onto Andromeda using gravity, and it's gravity that's dominating that 301km/s motion toward us that Andromeda has.

Fraser: Fine, so what if the two were balanced out, then? What if dark energy was expanding us away at, let's say, 300km/s, and Andromeda was pulling us at 300km/s, what would happen?

Pamela: The thing is, these velocities aren't actual pushes or pulls. A better way to think about it is if there is wind going at 30km/h toward your car, and you're driving into the wind, and your speedometer says relative to the ground you're going 30km/h those two velocities don't cancel each other out.

Gravity is a very strong force that is locking Andromeda together the same way your car engine is a strong engine. Yeah, the wind's blowing on your car at 30km/h but your car's like, "yeah, I don't care – I'm going to keep going forward, relative to the ground, at 30km/h." The wind has a negligible effect on how much work your car's engine has to do.

So looking at just the velocities doesn't give us the full picture. We're still trying to figure out exactly how to calculate the force dark energy's exerting as it's expanding the universe, but in first order calculations, it doesn't even come up. It's there, but all basic models I use gravity and ignore dark energy.

Fraser: So you couldn't have a situation where two galaxies are, although they're gravitationally pulling toward each other, the amount of space is increasing in between them, so they stay roughly the same distance apart?

Pamela: You can, but they have to be much further apart, so that gravity is much, much weaker. As you get closer, gravity gets stronger and stronger and stronger. It does it rather quickly, because it depends on the distance squared. There is a point that if you go far enough away, the acceleration of the universe, the expansion of the universe, is balanced out with the attempt of gravity to pull things in. Andromeda's way closer than that, and that's where it starts to matter.

It's sort of like even with drag, the faster you go in your car, the more the air in your car starts to matter, the more drag starts to matter. In my happy little Jeep going at normal road speeds the police won't arrest me for, drag only starts to matter when I'm on the highway. My husband's Subaru doesn't even notice it at highway speeds. When you look at race cars zooming across the salt planes out in the Southwest, those cars have to be built extraordinarily aerodynamically to be able to get through the air that is creating a drag force on them as they're trying to go 300 or 400 miles/hour to break the sound barrier with a car. As you go faster, air matters. As you get further away, with gravity, then dark energy starts to matter.

Fraser: There must be some balancing.

Pamela: There is a balancing point, but it’s extremely far away.

Fraser: That’s all I wanted you to say!

Pamela: There is a balancing point, but Andromeda is way inside of it.

Fraser: I understand – of course, of course.

Ken Mogul asks, “when we see galaxies that we estimate at 14 billion light years away, why does that make it close to the beginning of the universe?”

That’s a good question, and it’s a very bizarre thing to think about – to look out and the galaxies that you see, how come no matter where I look, I’m only able to see 14 billion light years away, and how do I know that was the beginning of the universe?

Pamela: Here’s the weird thing. There are galaxies out there that are 14 billion light years away or even, (we think) 114 billion light years away. We’re never going to be able to see them.

Light takes time to travel. The universe, we think, is about 13.7±0.2 billion years old. Light travels at 3*10^8m/s. It travels at a finite speed. So an object that was 2 billion light years away from us, 2 billion years ago, (and there’s second order effects I’m broadly ignoring, so those of you with PhDs out there – I know I’m ignoring things – so ignoring expansion and how it effects the amount of time it takes for something to get to us). When we look at this object that was 2 billion light years from us 2 billion years ago, that light was released and started coming toward us and we couldn’t see it. It kept coming toward us and we still couldn’t see it. Finally, one day after that light had been travelling for roughly 2 billion years, that light finally got to us and we could see it.

The universe we’re able to see every day gets a little bit bigger, because light from further, more distant corners of the universe has been able to reach us. Anytime we see something, we’re not seeing it as it appears right now, we’re seeing it as it appeared the distance it was away times the speed of light, ago.

Think of it this way. It used to be that when we (not we, but when our grandparents, great-grandparents, and most likely great-great-great-grandparents) heard news from another part of the country that news was always delayed by however much time it took the pony express or the railroad or whomever was carrying the news, to get to the point where the news was being received.

So it might be that we only heard in Boston about events in California, three weeks after they occurred. So whenever we learned information about

California, we were learning about what happened 3 weeks ago – we were always looking back in time when we read our news.

When we look out in the universe – when I look at the Sun, I'm seeing what it looked like 8 minutes ago. 8 minutes from now, I'll see the sun as it looks right now. But I can never see the Sun as it appears right now, in the moment now.

Fraser: How did we get that 14 billion light year number then?

Pamela: We don't actually see 14 billion light years. What we can see is about 10 billion light years away. We get that number by first of all we luckily (thank God), have these things called standard candles that allow us to measure the actual distance to where the light was given off. So we look at something and say, "Okay, I know how much light the object actually gave off, and I know how bright it appears" we can calculate the distance to the object. We use type Ia supernovas to do this.

By knowing the distance to something, and the rate at which the universe is expanding, and chewing through a really scary-long equation, we can calculate how far away that object was in time as well as in space. We can say, "I know it's distance, the rate of the universe's expansion, I can put all of that together and get the moment in time when all that light was emitted." It allows us to see back in time, essentially, the same way I see the sun as it was 8 minutes ago, I see the universe as it was 10 billion years ago, when I look at an object that's roughly 10 billion light years away when it gave off the light – it's somewhere totally different now.

Fraser: Right, so I guess you can, using the redshifts, you can take the motion of all the galaxies and galaxy clusters that we see, and calculate them back to a point where they were all in the same spot. That happens to be about 13.5 billion years ago.

Pamela: Yes, and this is where we start getting back to that standard grid we were talking about before where on average everything is moving away from us. That allows us to get at the rate of expansion in the universe, and then you work it backwards. We call that a Hubble time, the amount of time it takes to get back down to a single point.

Fraser: When we see around us, especially when the more powerful telescopes come online, everywhere we look we're seeing into the dark, dark past. And yet, as you said, there may be galaxies 110 billion light years away from us and we just can't see them – but they're there. I wonder what the universe would look like if we could see it in all directions as it looked right now, today.

Pamela: We can only make estimations, we can only make guesses based on looking at the very small area of the universe right around us, assuming it's representative of the entire universe.

There are theories that say perhaps inflation didn't take place exactly the same way in the entire universe. What if our volume of space is slightly different, and it expanded slightly more or less? We can't get there from here, that's one of the frustrating parts. We can never get to that light that is more than a certain distance away, no matter how long we wait, because the universe is expanding and that light can never quite catch up to us. Some questions we can never know the answers to.

Fraser: I'm just going to go with your assumption that the universe everywhere looks kind of like how it does around here.

Pamela: That's all we can do.

Fraser: So if we look out there we would see spiral galaxies and old galaxies – we wouldn't see the young galaxies we see with Hubble, that's the funny thing.

Pamela: At least, not in large numbers. There's probably some still forming. As we look out, we do find the occasional small, baby galaxy still forming, but they're still there.

Fraser: Right, so with the deep field surveys from Hubble, what you see are a lot of young galaxies, but that's just not what we would see. We would see middle-aged and aging galaxies everywhere we looked. That's all we'd see.

Let's move on.

Pamela: Yes, that was very depressing.

Fraser: Okay, this is cool.

[laughter]

Jake Perdue asks, "In optimal conditions, would it ever be possible for light to be caught into orbit around a source of gravity? If not light, could any other ray be caught in orbit? If there's a particularly weak black hole, would it go into orbit instead of being sucked in?"

So you have light, moving past a black hole and the light moves on just the perfect trajectory, that it doesn't get sucked into the black hole, it doesn't get distorted but still come toward us, it moves perfectly into orbit around the black hole and just goes around and around forever. Is that possible?

Pamela: Sort of kind of?

That's the answer for the day!

Fraser: Mathematically.

Pamela: Mathematically, yes. You can get light orbiting a black hole, but it's doing it inside of the Schwarzschild limit. So we can't get there from here. With physics, we're not entirely sure of what happens inside the Schwarzschild radius. Presumably the actual surface of the black hole is way down beneath the Schwarzschild radius, but we don't know that – it's a guess. So if you do all the math, what you find is the radius of the orbit where your orbital velocity is the speed of light is at one half the radius of the Schwarzschild radius.

Fraser: That's the event horizon, right? The point at which nothing can escape.

Pamela: Right, that's the point at which you have to go faster than the speed of light to get back out. You can have a light ray come in and make a glancing blow on the gravitational field of the black hole and get bent slightly. The closer and closer it comes in, the more it's going to get bent. You can end up with light rays that come in and get bent all the way around the black hole before they start going off in some other direction and probably with some completely different colour because their energy has been changed in the interaction.

Fraser: Okay, you're kind of leading into what my next question is going to be, but let's finish this up. The problem here is for you to be able to encounter that light orbiting the black hole, you'd have to fall into the even horizon on your own and die a terrible death.

Pamela: But you'd get to see orbiting light in the process.

Fraser: For a brief moment, what would you see – as your eyes are being torn apart, what would you see?

[laughter]

Pamela: If you make it down to the point where the light is in orbit, and here's the problem with it: if the light is in an orbit, you have to be intersecting that light's orbit in order to be able to see it.

Fraser: So you're falling in, you're passing through orbiting light.

Pamela: As you look into it, you're getting blasted like you're being hit with a giant spotlight. You're absorbing it and it's really no different than being hit by a spotlight, except you're moving so fast that you're dead – because really, you're in the event horizon of a black hole. You're dead.

[laughter]

Fraser: Okay fine. Let's say somehow, you cannot die.

Pamela: In that case, it's really like you're being hit by a spotlight. The light that's going in orbit, it's just light. It's just photons. It's travelling at the speed of light (which is what it always does), it just happens to be doing it such that its orbital velocity is keeping it going around at half the Schwarzschild radius in a nice, circular orbit around the black hole.

Fraser: So it's like a spotlight, but you can't see where it's coming from. It's just like boom, there's light in your eyes.

Pamela: Yeah.

Fraser: Or radiation. X-Rays in your eyes, or what have you.

Pamela: It's all light. If there's an accretion disk, if there's anything there that can absorb the light and then re-emit it into a slightly different direction, the light's going straight in.

Fraser: It's cool though.

Pamela: It's very cool.

Fraser: Theoretically, mathematically – you were able to calculate it – there is a point where light will orbit a black hole.

Pamela: It's a nice, friendly, freshman physics problem.

Fraser: Is that what you did? Did you unleash it on a student?

Pamela: No, but I can!

Fraser: Good. So there you go, Jake, you've given Pamela a test question.

Pamela: My students do, after all, have a test next week.

Fraser: Perfect. Let's move on to our last question of the day. This is from Bill Mannery, and it's related to the question we just answered.

"When we send a satellite somewhere, we'll often have it pass close to a planet and pick up speed from the gravity of the planet and the ellipse of the orbit. What would happen to light as it passes near the event horizon of a black hole?

Assume it would be in the perfect trajectory to increase the speed, but light can't increase in speed. What would happen?"

I guess that's the same thing. We can imagine how the Voyager spacecraft or New Horizons received a speed boost as they flew past Jupiter – you know, a gravitational slingshot. Light can't get that speed boost, so what happens to it?

Pamela: It's all about conservation of energy. With light, energy and colour are directly related. So a photon of blue light has a higher energy than a photon of red light. That boost that we're giving to satellites, that's a change in kinetic energy – the energy of motion. Instead of boosting the velocity of light, we end up boosting the colour from a redder colour to a bluer colour.

We're still changing the energy – and we're changing the energy the exact same way with the gravitational pull that's going in, but instead of translating gravitational potential energy into kinetic energy like we do with a satellite, we're translating the gravitational potential energy into a change in colour.

We actually see this. It's hard to measure, but it's out there. The cosmic microwave background, as it works its way across the universe toward us, is in very small amounts getting blueshifted, heated up, as it comes through matter between us and where it's located.

We can also see light that's getting redshifted as it comes out of extremely high gravitational situations. There are people who, for a long time, tried really hard to measure this using Sirius A and B, the white dwarf that is orbiting the brightest star in the northern hemisphere. They didn't quite get there, but we have, since the original 1924 attempts, been able to measure very slight changes in light coming out of the high mass situations.

What's cool is if you are in a lower gravity situation than where the light is coming from, you always see the light redshifted. If you're in the higher gravity situation – say you're standing on top of the white dwarf star – you see light coming in toward you getting blueshifted. You can both raise and lower the energy, and you can compare where you are on the gravitational hill, in relation to the light, by seeing how its colour has been changed.

Fraser: So, not just theoretically, but actually out there, light that moves past gravitational bodies is changing in colour, getting either more red or more blue, and we actually can detect that in some of our instruments.

I guess as instruments get better, I can imagine that being another technique for probing out into the universe.

Pamela: It's really a neat way for probing into high gravity situations. What's happening down in cataclysmic variables. It allows us to map out the gravity: how are things getting redshifted and blueshifted as they're coming through galaxy clusters; how is light getting changed.

Kind of cool.

Fraser: Sounds like the kind of thing that would be good for a spacecraft. It'd be a good, new telescope, that's only job is to do that.

Pamela: What's cool is we can actually see differences – very, very, very slight ones – between how things are detected up in orbit and how they're detected here on the surface of the Earth.

Fraser: Because we're in a different gravity position than the satellites up in space.

Pamela: So things will get slightly blueshifted as they come into our planet.

Fraser: There you go, Bill. That's a really cool use of relativity.

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