Astronomy Cast Episode 28:
What is the Universe Expanding Into?

Fraser Cain: We get this question all the time, and we were going to include it as part of our question shows, but it's such a cool topic with so much background that goes into explaining the answer that you get a lot of meat on it.

Astronomers generally accept that our Universe got its start 13.7 Billion years ago from a compressed state and then expanded rapidly and continues today, and that's what we all call the Big Bang. But when you think about that expanding Universe, what is it expanding into? What's outside the Universe?

All right, Pamela. I've seen this question posed to other astronomers: what's the answer you get?

Dr. Pamela Gay: The standard answer is: it's a nonsense question.

Fraser: That's what I thought you were going to say.

[laughter]

So normally, I guess we'd walk away going "what does that *mean?*" with the astronomer looking down their nose at you with their "that's a nonsense question". This time, I'm not going to let you go – we're going to get to the bottom of this.

So, what does that mean? When you imagine in your mind, you can imagine this expanding ball like a balloon and inside the balloon, Universe, outside the balloon, something else. As the Universe is expanding, there's something outside the Universe, but, as you said, that's a nonsense question. Let's get to the bottom of it – why is it a nonsense question?

Pamela: To say that there's something outside of the Universe, that means that outside of the Universe has to exist. We say that all that there is of space, all that there is of time, everything that is everything is inside of our Universe. So, if you go outside the Universe, there ceases to be dimensions, there ceases to be any time and that nothing can't be labelled as a something – it can't even really be labelled as a nothing because our concept of nothing is space that still has dimensions and still exists in time.

So, you end up with this philosophical breaking point when you leave the Universe of "but… but… it doesn't exist!"

Fraser: But doesn't that question rely on whether the Universe is finite or infinite? If it's infinity, if the Universe is all there is and that's all there is in all directions, then I buy it. What's infinity plus one? Infinity. What's infinity times infinity? Still infinity. If you go to infinity in all directions, still infinity. But if the Universe is finite, if there's an outside edge to what's expanding, then there must be something that it's expanding into.

Pamela: But why can't you just say that everything that is everything is expanding? Our idea for the shape of the Universe is that its flat. If the Universe is finite, the way you get a flat and finite Universe at once is the entire Universe is basically a donut.

Fraser: You're going to have to explain flat for a second there.

Pamela: Okay.

Fraser: Because I think of it as three dimensions, right?

Pamela: The way we define the geometry of the Universe is by considering what would happen if you send off two photons that started off (we thought) parallel to one another. On a normal sheet of paper, if you draw two lines parallel to one another, they always stay the exact same distance apart. In a flat Universe, two photons that are shot off always stay the exact same distance apart. If we had a closed geometry, then those two photons would be more like two airplanes launched on parallel lines on the Earth; as they travel around the sphere, they're eventually going to come together at the same point.

Fraser: Right, I see. So if you take two airplanes and launch them from some place, as they follow the longitude lines of the Earth, when they reach the pole they'll crash into each other, right?

Pamela: Exactly. That's a closed geometry.

We also have what's called an open geometry, which is more like a saddle. IN this case, as things travel away from the seat of the saddle down the opening up curve towards where you hopefully don't fall off, the two light rays are going to diverge and move apart as they move away from this seat. The question is how do you then transform these into a three dimensional Universe that also has time.

We have this complicated thing going on and for our flat geometry, the way you translate it if we have an infinite Universe, then it's sort of like a sheet of paper that extends in all directions but it's a sheet of paper that has more than just the two dimensions – it also has the three dimensions

Fraser: Right, a sheet of paper that extends like a cube of paper.

Pamela: Yeeeaah.

Fraser: … that's… big.

[laughter]

Pamela: Exactly. So that works for an infinite Universe. But if you have a finite Universe, somehow things have to be able to circle back to themselves. In this case, the way we can get a flat geometry is if we have a donut.

If you imagine yourself sitting on the top of the donut as a sprinkle, if you and your neighbouring sprinkle both head off in a straight line in any direction, you'll always come back to where you started and you'll always stay the same distance. You might decide to spiral around the top surface of the donut. You might decide that you're going to arc around the outside of the donut. So you have two different paths that both allow you to get back to the same point, one is a short path and one is a long path, but you and your neighbouring sprinkle, as long as you decide to head off in the same direction, you always stay the same distance apart.

Fraser: So in our Universe, if we fire off two photons in opposite directions? Or in the same direction?

Pamela: In the same direction.

Fraser: In the same direction, they will stay the same distance apart, but they can come back to their starting position again?

Pamela: If our Universe is finite. Now, most people believe the Universe is finite, but we can't actually prove it right now. It's hoped that with the upcoming European Space Agency's Planck spacecraft, they might be able to prove with certainty that the Universe is finite, but we don't quite have the observational evidence yet.

Fraser: So, if the Universe is finite, as opposed to infinite, Planck will be able to see … what will it be able to see?

Pamela: It will be able to see certain patterns in the Cosmic Microwave Background that weren't quite visible for the WMAP satellite. It's hoped that with the Planck satellite, a further level of getting at patterns within the anisotropies and the temperature distribution will allow us to figure out just what the geometry is.

Fraser: It's amazing. It always comes back to the Cosmic Microwave Background Radiation. It's like the most useful piece of data we've got out there.

Pamela: It's the furthest back we can possibly look, and you can learn a lot from looking at baby pictures. In this particular case, looking at the CMB we get to get at the density profile of the early Universe and we get to see how the photons were travelling and communicating with one another. We get to get a sense of what paths they were taking and its hoped that with Planck we'll be able to understand "is it possible that photons leaving the same place could travel to where they are now along two different paths?"

Fraser: I see, so it's almost like if I had a globe in my hand (a small globe) and I had some little toy airplanes and I was moving them on parallel lines on the Earth, I'd very clearly be able to see them crashing together. But with the actual Earth, if I saw two airplanes go past I wouldn't be able to make that understanding because now the Universe at the size that we have, it's really hard to see it. If we can look back to when the Universe was a baby, then those kinds of things are more clear.

Pamela: Exactly.

Fraser: Right. So is the Universe actually a donut, or is it just that a donut is a good model to think of a shape where you can go in those different directions and get back where you started?

Pamela: In this case, I think it's a good way to look at it. It's one of these things where there are a lot of things in astronomy that the mathematical models and the reality you're never quite sure if one is a way of modeling the other, or if the one is a reflection of the other. One of these examples is how we view gravity.

Einstein said that gravity actually warps space. But is space truly warped? If we were able to get outside of our Universe and look in on it, would we see deformations around stars? Or is that simply the best way to mathematically model how things move through space to see gravity as a deformation?

Mathematically, the best way to view a flat Universe is as a donut, a Taurus mathematically. But I don't know if I can say with certainty "the Universe is actually shaped like a Taurus if it's finite". I just know that's a mathematical model that works.

Fraser: Okay. So let's go back then and say that hopefully we've got this part so far: the Universe is finite, there's a set amount – you could measure it with a measuring stick big enough? Is that right?

Pamela: Yes.

Fraser: And the Universe is flat.

Pamela: Yes.

Fraser: Probably. In other words ---

Pamela: We know it's flat with certainty. Whether or not it's finite or infinite we're not quite so sure on.

Fraser: Okay, we know it's flat and suspect it's finite, but then I think you're falling into this trap of what's outside of it. I'll let you have the infinite, but the finite – I'm going to fight you.

[laughter]

So let's go back to that then. How can the Universe be expanding without expanding into something?

Pamela: Okay. This starts to get philosophically ugly. The problem is –

Fraser: Stick to the evidence!

[laughter]

Pamela: The understanding that we have is all time and all of the special dimensions exist inside our Universe. Were you to somehow teleport via some magic technology that will probably never exist, outside of our Universe, you'd be some place where the spatial dimensions don't exist, and time doesn't exist.

This is something that crops up in places like Stephen King's *Dark Tower* series, where you can actually fall out of the parallel Universes in his science fiction. It's not something that outside of the sci-fi genre we exactly have a way to discuss. You might say that this is some sort of purgatory, where when you get there time stops. How do you perceive anything when time is no longer ticking?

Fraser: All right, I think I have an analogy (it's going be an analogy filled episode), but I think it's that we describe the Universe using the concept of dimensions and time. It's almost like (I'm trying to think…) let's say you're playing a game of Scrabble or something. Then, for you to get outside the Universe, you're getting outside the concepts of time and spatial dimensions. It's the same kind of thing. If you're not playing the game of Scrabble, you can't apply the rules of scrabble to the outside world, outside the scrabble game itself.

Pamela: Exactly.

Fraser: But I still think that's not good enough because then, could there be something else with other rules, not time but something else; not dimensions but something else ?

Pamela: There are a variety of different cosmologists that work on different multi-verse theories. They say our Universe is one of perhaps a finite, perhaps an infinite (most likely infinite if this theory is true) set of parallel Universes that are all bubbling together. If you were to jump from our Universe to a different Universe, not into the space between them but from our Universe to a different Universe, you'd find a place where the physical parameters were different, where gravity worked differently, where the electrostatic forces worked differently, where the forces that hold atoms together are controlled by different constants than the ones we experience.

The problem with these theories, is we have no way of testing them. While they're brilliant, they have lots of complicated mathematics in them and they're put forward by some of the most brilliant theorists out there, they aren't testable science. So, they're philosophically satisfying. They tell us 'this could be what's outside of our universe,' but we've also stepped outside of our ability to have a testable model that makes predictions that are observable.

Fraser: And that's the whole point.

Pamela: Exactly.

Fraser: All right. Okay, so what does the shape of the Universe mean for it's expansion?

Pamela: There's this weird thing about how we think and how it actually works that when I say the Universe is shaped like a donut, you sort of imagine you're on the surface and can zip around. What about someone who's 30 miles away from you in any direction? They're still on the surface. What about someone who's 300 thousand light years in any direction? They're still on the surface. How do you get off of the surface if you're trapped on the surface and every dimension you can perceive is still on the surface? Does that make sense?

Fraser: [long pause] Yeah, I mean… Nooo, but yes?

[laughter]

Pamela: So when we start thinking 'what are we expanding into?' We're expanding into something beyond our ability to perceive because everything we perceive is trapped on this surface.

Fraser: Is it possible that we are expanding into something just like our Universe, but there's (and once again, and analogy fails me) a bubble popping inside something else, where it is the exact same rules. It is time and space. I think when people ask that question, that's what they're asking, intuitively, maybe there's an outside, there's a bigger Universe and our Universe is just something that's expanding inside that Universe. Maybe other Universes are going to expand inside of our Universe and pop off.

Pamela: There are a lot of untestable theories out there. One of the theories out there, put forward by Andre Linde is that during the epic of inflation, the period before the formation of the cosmic microwave background, in the smallest fractions of a second after the Big Bang started (300 thousand plus years before the cosmic microwave background formed, actually), our Universe went through this period of amazing expansion. It's because of this expansion, actually, that we perceive things as flat. Just like if you put a pattern on silly putty and stretch it out, it goes from having a nice pretty pattern on it to appearing a constant shade of grey, when our Universe inflated, it eventually stopped inflating. This allowed us to come into existence.

What if there were pockets in that early Universe that didn't stop expanding? What if there were places where the inflation just kept going? Those pockets of continued inflation might've formed branching Universes that are attached to our own, that might’ve mostly stopped inflating but still had another pocket that kept on expanding.

From these branching Universes, [Linde] builds a picture of multiple, parallel universes. They don't all have to have the same parameters, in fact it's much more likely that they all have slightly different parameters.

We can't find any underlying physics that says we have to have the gravity we have, that we have to have the fine structure constant controlling quantum mechanics that we have, that so many of the different parameters – just the matter to anti-matter ratio that we have. There's no reason that we know of for this stuff to be the way it is, so if you're going to come up with another second, third, bazillionth Universe, probability says they most likely are going to be different.

Fraser: And each one of those Universes is expanding into something else.

Pamela: One of the troubling (again, non-testable) theories, is it's possible for one of those Universes to engulf our own.

Fraser: You just blew my mind.

[laughter]

Pamela: Think of it as soap bubbles. Each soap bubble has slightly different parameters inside of it. One soap bubble can engulf another soap bubble, in the process wiping out the contents of both.

Fraser: People have been puzzling over this question for hundreds of years – or, I guess, since the discovery of the Big Bang… has dark energy had any effect on thinking?

Pamela: It's actually totally changed our view of a lot of things. In preparing for this, I was pulling out a bunch of my cosmology books and I ended up s—

Fraser: This is wrong, that is wrong..

Pamela: I set them aside in disgust, because all of my favourite books talk about lambda = 0, no dark energy – we didn't know what dark energy was. They said the fate of the Universe is going to be defined by the geometry of the Universe, where if we have a closed geometry (the geometry where two light beams or two airplanes come together and crash) then the Universe will eventually expand out, slow, reverse directions and crash back together. They said, perhaps we've a flat Universe, in which case the Universe expands and expands and given infinite time will stop expanding.

Perhaps we have an open Universe, in which case it just keeps expanding forever.

Thus, the fate was defined by the geometry.

It now appears that we have this flat geometry which, (if geometry defined our fate), if given enough time (infinite time), expansion would pretty much stop. We're never going to get to infinite time. The thing is, with dark energy, dark energy is accelerating everything apart, so we have a completely open future with a flat geometry.

Fraser: Open future with a flat geometry. Before, I think the cosmologists were always walking on this balancing act – they weren't sure, it was one or the other, all the information wasn't in. Now, both the answer they're looking for is in and it's over-ridden by dark energy.

Pamela: Yeah, 1998 when the two red shift teams came out with their results saying we have dark energy, I think a lot of cosmologists just decided that math was evil.

[laughter]

We had all been assuming for a long time that we're going to have lambda = 0, geometry is flat, and that made the math a whole lot easier.

This whole lambda not being equal to 0 makes the mathematics a lot harder, the modelling a lot harder and the Universe more exciting.

Fraser: I think this question is one of those questions that's at one of the very extreme ends of science and (as you said) walks into and out of philosophical land quite a bit. There is some great new observatories and we talked about Planck briefly. What discoveries, what evidence should people be keeping an ear out for in the next decade or so to help really fundamentally drive all this home for us?

Pamela: What we're always trying to do is look for ways to measure how the Universe has changed over time, how it's acceleration, how the rate at which it's expanding has changed with time. We're always trying to check that different parameters are staying constant with time.

One of the things that people try to measure is the fine structure constant, which governs a lot of quantum mechanics and electrostatic things. It's the little alpha that keeps cropping up in mathematical equations.

By making sure that the Universe is pretty much staying constant or changing in known ways, we can check our theories and periodically the Universe rears its ugly head and shows us it's changing with time. This whole 'it was originally slowing down due to mass slowing the expansion and then dark energy took over and now its accelerating apart the expansion – that was a surprise.

We've only been able to go so far back in our understanding. Supernova, are really bright, but they're not bright enough to study the earliest moments of the Universe. We need to find new ways to probe further and further back. There are people working to do this, looking at gamma ray bursts, for instance. We also need to find other ways to measure the Universe. We look at how light is shifted by gravity, we look at how the cosmic microwave background is changed as it passes through the large mass of galaxy clusters. We can use this to probe the Universe.

The key is figuring out how to look further and further back. Part of that is looking in new wavelengths, looking in new ways and by looking deeper and deeper with larger and larger telescopes. We're lucky, because light takes time to travel and this allows telescopes to be time machines. At the end of the day, collecting photons is hard work.

Fraser: Mhmm. Okay. I don't think I was able to corner you this time around.

[laughter]

I think so far, we're walking away with the 'question doesn't make sense' part. Hopefully we've been able to give people some context to the question. When your friends ask you that, you can ask them if they think the Universe is infinite or finite and if it's finite is it flat or curved and if it's flat and so on.

I think, hopefully you can give people a pretty good explanation on why the question doesn't make any sense. That's the best we can do for now, until more evidence comes in. If it does, we'll definitely cover it.