Astronomy Cast Episode 79:
How Big is the Universe

Fraser Cain: We're ready to complete our trilogy of discovery about the universe. We've learned that it has no center; rather everywhere is its center and nowhere.

We discovered that the universe seems to be flat. It not open, it is not closed, it is flat. If that doesn't make any sense, you need to listen to the previous show because there's no way I could give that an explanation.

So now we want to know: "How big is it?" Does it go on forever or is it finite in scale? How much of it can we see? All right, I know you wanted to define some terms before we got rolling so why don't we break this down.

Dr. Pamela Gay: The first thing we have to figure out is what is the visible universe. The part of the universe we can see is probably only a very small fraction of the total universe. But it's not what we think it is.

Fraser: Well, what do I think it is?

Pamela: So, most people ask, "How far away do you think we can see?" They reply, if they've been listening to the show long enough, well the universe is 13.7 billions years old and so that means we can probably see things that are 13.7 billion light years away.

Fraser: In all directions?

Pamela: In all directions. And its sort of valid logic, but the problem is that the Universe is expanding. We can see objects with light that has traveled a path that is 13.7 billion light years long, but the problem is the starting point of that photon that traveled that 13.7 billion years isn't 13.7 billion light years away.

Fraser: You're right. If you had asked me, that would have been my answer. But now that I think about it, it's all red chipped; it's all spread out. So, it's actually been traveling further than that. Okay, someone must have done the math.

Pamela: Someone has done the math. In fact, it's more like 78 billion light years away is where that starting point for that furthest photon that we're able to see started.

Fraser: Seventy billion light years?

Pamela: Seventy-eight billion light years away is the starting point of that photon.

Fraser: So we can see a sphere around us 78 billion light years radius, so 156 billion light years - a bubble, I guess across.

Pamela: And that's all because the universe is expanding. The light travels one distance but the objects are moving away from us so what we're actually able to see represents a larger sphere than the sphere the light traveled on. It's really weird.

Fraser: But, wait a minute. I'm having one of those moments where the questions are bubbling up faster than I can enunciate them. So let me just sort of harness this.

I can just imagine let's say we have the most distant the thing that happened at the Big Bang and it's moving away from us and it's emitting light. We're seeing the light that came to us at the moment of the Big Bang, but how are we still seeing light that is coming from it as it's moving 80 billion light years away? Help.

Pamela: Here is how I think of it: Imagine that you're standing at the very end of a moving walkway that's moving away from you. You start off with the moving walkway turned off. There is someone right in front of you with a bag full of marbles. They're able to roll the marbles a little bit faster than the walkway is moving.

So you turn on the walkway and you tell them to start firing marbles. The marbles that they're throwing at you are having to travel further than the original distance between you and that person, but less than the distance between you and that person when the marble gets to you.

So that person keeps moving away from you and that marble that's moving just a little bit faster than the walkway is moving gets to you eventually but it has to travel this increasing distance with time.

Now if that person keeps rolling marbles, you'll get a steady stream of marbles from that person the same way we get a steady stream of photons from the cosmic microwave background. But each of those marbles has to travel a little bit longer and a little bit longer as the universe expands.

Fraser: And that would be all well and good except we now have the problem of the accelerating expansion of the universe thanks to dark energy. So there could be a time when that poor person rolling marbles is going to roll marbles and they're just never going to reach you.

Pamela: Exactly. One of the problems that we have is that even ignoring the fact that the universe's expansion is accelerating the moving walkway kind of breaks down because the universe isn't causing people to move at a constant or causing galaxies as the case may be to move away at a constant velocity from us.

Rather, objects that are further and further away are moving away faster and faster. So objects that are coming from greater distances actually have to travel even more than you'd expect from our simplistic moving walkway.

What you might imagine is instead you have this expanding floor where you're each standing on a different edge of a tile and the tiles are getting bigger and bigger. The more tiles there are between you and the person rolling marbles, the faster they have to roll the marbles. So, it gets really mathematically complicated very quickly.

Fraser: Or maybe they step on to faster moving walkways every five minutes, right? So the furthest people have the hardest trouble. What implication does this have? I can imagine when cosmologists are even doing their calculation, which we went into last episode, talking just about the shape of the universe.

The math must come in pretty heavy. I've read articles about how astronomers have found a galaxy and we see it, as it was a mere one billion years after the Big Bang. This implication must really come into their calculations.

Pamela: Well one of the things that gets most complicated is trying to state what you mean by distance. When I say a galaxy is some distance away, I could be talking about the distance between where it was and where the Earth was at the moment that the light was given off. That's a really tiny distance.

I could be talking about the distance that the light traveled. That's the middle distance. I could be talking about the distance between where the object was when it gave off the light and where the Earth is now, which is a little bit bigger.

I could be talking about the distance between where the object is now and where the Earth is now which is the largest distance.

Fraser: I get this complaint from a lot of people when they're reading articles and we talk about something like right now this star is giving off puffs of stellar material. It's giving off its outside envelope.

But the star is 12,000 light years away. People will complain, don't say the words right now because it happened 12,000 light years away. This is just sort of a bigger version when as you say, there are four different ways to talk about right now.

It's not fair to pick one arbitrarily and so it's almost like the one we default to when we're doing the writing is right now for the light as we see it today.

Pamela: Yeah. It's like if you look at this moment at this place in the sky this is what you would see.

Fraser: Because that's the only one we can really know for sure. All the others we are projecting and right now we don't know what's going to happen in 12,000 years. On the converse we could say when we look at this object it's not really what is was doing 12,000 years ago. That's just what the light was doing 12,000 years ago.

So you almost need to get into a cosmology conversation with the person when they have that argument with you. We just default to this is what we're seeing right now and that's what it's doing right now. Yes we know that it happened in the past but this is the only way that we can write about it.

Pamela: And it gets particularly confusing when we're looking at objects that its light got to us from two different directions. Imagine that you're looking at a quasar where you're seeing the light that went on the straight-line path in our flat geometry of the universe and came straight toward the planet Earth.

Fraser: We're also looking at a bent image of this quasar where the light perhaps was headed off somewhere else and then was bent by a large galaxy, cluster of galaxies or some sort of a gravitational mass that lensed the object and bent its light to come to us from a different path.

That different path is going to be longer so it took more time for the light to get to us. So we see two different images, neither of which is now but we're seeing them now. And we can see the galaxy do something in the straight line image and then look a little while later and see it do that exact same thing again in the bent line image.

That really mucks up when is now when you're observing and what is the quasar doing now? 'Now' has way too many meanings.

Fraser: Did I mention people should keep some more of that ibuprofin this week for this weeks' headache. Let's go back then. We said that the observable universe is about 156 billion light years across.

That begs the next question: "What percentage of the real universe are we actually able to see?"

Pamela: We don't know.

Fraser: Okay, well then I guess that depends. When I see a percentage I guess that depends on whether a universe is finite or infinite. So why don't we talk about that and then we can come back around.

Pamela: This is where all cosmologists just sort of hang their heads and say, "We're working on it. We have limits. We have ideas and we may never know the exact answer."

Fraser: So let's define then an infinite universe first. That would mean that wherever you go, in whatever direction you look, whatever direction you travel, it's galaxy after galaxy; star after star; dark matter after dark matter. It's turtles all the way down.

Pamela: It's turtles all the way down and you can never get from the top turtle to the bottom turtle.

Fraser: Right. And one of the implications for that is I think we talked about multiple dimensions. When you have an infinite universe, not only is everything possible, but also everything has to exist.

If you travel in one direction far enough you will run into another Fraser and Pamela sitting on a planet that looks like the Earth recording a podcast talking about this situation.

In fact there will be an infinite number of Frasers & Pamelas having this conversation because if it's an infinite universe, everything has to exist an infinite number of times.

Pamela: And it starts to get really screwball.

Fraser: Like it starts; like the things that I just said isn't screwball enough.

Pamela: So here's where you start to go augh! Because like you said, in a truly infinite universe you start getting into infinite numbers of the same thing happening over and over again no matter how small the probability you eventually find it.

Now if you have a small enough finite universe, the light wraps around and we can see us in the past.

Fraser: Right. I believe we talked about that since the universe is flat parallel lines move in the same direction. You look one direction and once you hit the edge of the universe as it were, that's just the back of your head.

There is no edge and so in all directions at the most distant thing, what you will see is where you started. But then I guess you would look past your own shoulder and see further, right?

Pamela: Well, what's so cool about that idea, which doesn't work out it turns out, is we could in principle if the universe were finite and small enough, look and see what the Earth looked like 10 billion years ago. That would be so cool to actually watch the evolution of the planet.

Fraser: But if is was small enough wouldn't we it a billion light years and the just past the Earth there's another Earth and that one we're seeing at 2 billion years ago?

Pamela: That's if you're really tiny. And we really would have noticed that by now. It's not that tiny. But there was some hope, dashed horribly by the Wilkinson Microwave Anisotropy Probe that perhaps we lived in a universe that was either a four-dimensional toroid or some hyper-dodecahedron which is just fun to say.

If the universe was small enough we could look out at the cosmic microwave background and see in different places on the cosmic microwave background identical splotches of light. Identical places where we're basically looking out the front door of the universe and seeing in through the back door.

Fraser: And we don't see that.

Pamela: We don't see that.

Fraser: So then wouldn't that just say well fine then, that's not true? When physicists say you're looking out the front door and you're seeing the back door shouldn't that evidence from WMAP have said no?

Pamela: Well, so we looked out and astronomers stared at WMAP with great dedication and computer software trying to find identical splotches and they couldn't do it. Now the thing is that doesn't tell us that with certainty the universe is not a hyper-toroid It is not a hyper-dodecahedron, not a soccer ball, not a donut.

We can't say that because it could be that it's just such a big donut or soccer ball that the two identical splotches, the front door and the back door that see in through one another lie further apart than the size of our visible universe.

Fraser: So they moved away too far?

Pamela: Yeah. And we just can't see the two identical splotches on the sky.

Fraser: So, seeing identical splotches would give you the confirmation, so it's still unknown. Let's go back to the infinite universe for a second. How would the Big Bang fit into that concept?

Pamela: The idea is that with certain geometries, for instance the saddle shaped geometry, you can't create a geometry that is saddle shaped and closed in. The edges are just reaching out and it has to be infinite to get to that geometry.

With flat you can start to get the things like toroids, which are finite. But in general flat in most of the ways we work the math with you end up with an infinite universe. It's just the geometry of space that you can always take that next step and fall out of the universe but you're still in it because it's infinite. You can just keep going and the universe has no edges in its particular geometry.

Fraser: So the discovery of the flat universe supports the infinite universe.

Pamela: It supports it but it doesn't require it because we could have this hypertoroid. We could have some other really crazy geometries. And there is also the question of if our universe is really big enough it could have all sorts of crazy shapes, crazy geometries where it's just the little tiny part of the universe that we're in appears to be flat.

That's one of the annoying things when you start dealing with really big things. You stretch anything out and it looks flat. You stretch anything out and it looks like it's constant consistency.

Fraser: But I guess with the Big Bang; like imagine an infinite universe, 13.7 billion years ago, the universe was a singularity.

Pamela: Right.

Fraser: And then it started expanding from that. But yet if it's infinite, was it a singularity of infinite size? I guess.

Pamela: It's a singularity with no edges. This is where the finite/infinite thing starts to break the human brain. Because part of the definition of a finite universe is that you have a closed geometry. The definition of finite is that you go in a straight line and you move back to the back of your own head.

And with an infinite universe, the geometry, you just keep going. And so you start to get into the, well it's not finite and infinite in the sense of six dice versus an uncountable infinite number of dice. It's a does the thing have an edge or not type of boundary.

Fraser: Now we talked a bit about it that WMAP helped close off some of the possibilities that would have said that it is absolutely finite. But left open the possibility for both, then where is the research going now to define it?

Pamela: So now we start looking and saying okay, so we've ruled out these possibilities. Smaller dodecahedrons. So with the next generation microwave probe, the Plank mission, we're going to have higher resolution and greater sensitivity.

So, let's start figuring out what are the patterns in the hot spots and cold spots in the microwave background that we'd see if you made the universe a little bit bigger and just starting to get the edges of these doors and windows looking in through one another.

What are the patterns in the light if you have it going one way or another way? What are the geometries we haven't thought of yet?

The ones that get the most attention in the media that people have talked about are basically a soccer ball type shape and a donut type shape that are both highly unsatisfactory. We don't want the universe to be shaped like that. It hurts our little brains.

So, let's start thinking outside of the box. Let's start by figuring out what are the different ways that we can mathematically define something as flat. Which strictly means two parallel lines stay parallel and two lines that start out at right angles to each other stay at right angles to each other.

What are different ways that we can start getting at those geometries and what are the different signals that we would find in the cosmic microwave background if we had these alternative geometries? And let's start thinking in lots of dimensions.

Let's start thinking with a box that's rotated in all sorts of crazy ways that we can't generally visualize but we can program a computer to create. It becomes the world's ugliest geometry problem. Then you start trying to figure out what are the limitations if the universe is this big what does it mean?

Unfortunately, all we can ever do is put a lower limit on the size of the universe. If the universe truly is infinite, we'll never be able to say that with certainty. That's one of the sad things about this.

At most we'll be able to say: "The universe is bigger than," and then state some number.

Fraser: Right, because with this increasing sensitivity of our instruments we will be able to measure the hot and cold spots better and better. Each time that we don't see the mirror images, then we know that the universe has to be bigger than 'X .

Then we'll produce a spacecraft that is even more sensitive and it will have another look at it and say okay, it has to be bigger than 'Y'.

That's the best we can do? We can never know for sure?

Pamela: That's the best we can do.

Fraser: However, when I talk to you, your thinking seems to be that it's finite, right? That seems to be your synthesis of the science so far. Why is that?

Pamela: At a certain point when you look at multiple lines of evidence you just sort of have to pick the one that your stomach is happiest with. This is where I have to admit that there is no consensus and more people are doing the math for an infinite universe – a little bit easier to do the math that way – than are doing it for a finite universe.

I have problems with the idea of an infinite universe that could be parallel to other infinite universes. That sort of breaks my brain.

Then there is just the notion of "How do you create a singularity that contains everything in an infinite universe that currently has a density of around six hydrogen atoms per cubic meter on average?" How do you create an infinite version of that?

It seems to make more sense in my brain, which favors the cosmology of multiple parallel universes, to have a finite starting point that has a critical density that is evolving as the volume changes and everything balances out but you're dealing with finite amounts.

Packing multiple infinities side-by-side, my brain says no to that idea. However, I can't scientifically say that my decision to like that theory is anymore valid than someone else's decision that the universe should be completely infinite and that there is only one of them; and someone else's idea that there are infinite branching universes.

There could be someone else's idea that there are finite branching universes. There are so many different things that could be coming together and we don't observationally have a way of saying who is more right than whom.

Fraser: But you don't need to bring in all of the multiple universe stuff into this, right? That's ways of trying to answer problems in quantum theory. Which is a whole other show. Maybe that will be part four?

Then even so, no matter how insane the possibility is, all you have is the evidence. We're so far beyond where your intuition can help you out. You left your intuition back home in the Savannah in Africa a million years ago. It's not ready for contemplating an infinite versus a finite universe.

So, what lines of evidence could we possibly have to try and determine and narrow this? Is that all we've got is looking at the cosmic microwave background radiation and seeing the edge.

Pamela: Right now, yes. Right now all we can do to define the size of the viewable universe and to place limits on the size of the total universe is to look at the cosmic microwave background. And not place on it some size of the total universe; and to study the rate of recession of the objects that are between us in the cosmic microwave background to measure the evolution of the expansion of the universe.

If we don't actually understand how the rate of expansion has changed with time, we can't accurately say where that point that admitted the photon from the cosmic ray background that we're seeing is currently.

So we need to constantly work to refine our values for the expansion rate in the universe at various points in time. And we need to study the microwave background in as much detail as possible.

Through those two sets of observations we can figure out just how far away is that wall of the cosmic microwave background in terms of where are the points that admitted the light that we see now with our current location compared to where those points were when they admitted the light.

We can place limits on well we know the universe is bigger than what we can see. And that's as good as it gets.

Fraser: All right, so let's assume then that the universe is finite. I'll give you this. How big is the universe?

Pamela: Well, a lot of people working on theories are coming up with numbers on the order of it's about a hundred times bigger than what we can see. So that's the current mainstream cosmology. About a hundred times bigger than what we can see.

Fraser: Okay, so that would then put us at about 1.5 trillion light years across. Not bad for only 13.7 billion years of expansion.

Pamela: It's that period of inflation during the first second or so that really allowed us to get to where we are. Without that, we'd probably be able to see everything, but that period of inflation really stretched things out and allows us to only see a small corner of where we live.

Fraser: How much of that was inflation? How big was the universe by the end of inflation? Or was it just like the big accelerant?

Pamela: It's the big accelerant.

Fraser: Right, so what then finally, percentage of the whole universe is our observable universe? In a finite universe?

Pamela: Oh, so now you're starting to deal with cubes. You have to figure if the radius is 100 times of what we're able to see, you take one over 100 cubed and that's the fraction we see. So 100 cubed is 10 to the 6th so one over 10,000th. We see one over 10,000 the universe.

Fraser: One 10,000th of the universe? At our current minimum size of the universe based on what we see with WMAP.

Pamela: Kinda cool?

Fraser: Kinda sad. I just want to see more of the universe. I like to travel I have to say so….

Pamela: It gets worse though, think of this. In the part of the universe we can see, we only see four percent of the mass. What we can see is visible matter.

Fraser: Right, the rest being dark matter, dark energy and just black matter that we can't see. It's regular matter just not shiny.

Pamela: So we see four percent of one ten thousandth of the universe.

Fraser: And we only see what's happening now or recently in a tiny little sphere around the earth. The further back we look, it's old news. It would be like the only newspaper that shows up is news from the 14th century. Not really helping.

News from Japan is what happened in the 18th century. That would suck. Could you make it any sadder?

Pamela: No, I'm happy.

Fraser: All right, so just to reiterate, we can see just a teeny tiny fraction of the universe and an even teeny tinier fraction of what actually is and a teeny tiny fraction of what's happening right now.

Well, I think we are done with this trilogy of the center, the shape and the size of the universe. I know we'll get some questions. So send them in and maybe we'll queue up our next question show to try and run through all of the headaches we've caused people and try and give you some relief.

This transcript is not an exact match to the audio file. It has been edited for clarity.
Transcription and editing by Cindy Leonard.