Astronomy Cast Episode 77:
What is the Centre of the Universe?

Fraser Cain: There are some people – I'm not naming names – who think the universe revolves around them. In fact, for most of humankind, everybody thought that. It's only been in the last few hundred years that scientists finally puzzled out that the Earth isn't the centre of the universe at all. That begs the question: where is the centre?

I don't think we're going to like the answer. Pamela? Before we give the answer, why don't we go back and do the history lesson and talk about when people first went from thinking the Earth was the centre of everything, to a better view of the universe.

I was thinking about it, and it's actually a surprisingly difficult thing to figure out. If you look up into the universe, the Moon goes around the Earth, the Sun goes around the Earth, the planets and stars go around the Earth. Without any really sensitive instruments, it would be really hard to think anything otherwise.

Think about when you're sitting on a train, and looking at a train beside you and it starts to move. Your stomach almost feels like you're the one who's moving. Until you look down at the ground, up at the sky or at some other fixed object, you don't know that you're not the one moving. How did that first insight come into maybe we aren't the centre of everything?

Dr. Pamela Gay: It didn't start scientifically as it started from philosophically looking at the universe and saying, "what if…" The first person to make the "what if the Sun is the centre and the Earth goes around it" was Aristarchus of Samoi. He lived from about 310BC to 230BC. He was a mathematician, and perhaps one of the first people to try and figure out just how far away the Sun is if we take into consideration shadows and angles on the sky and all these different things.

He didn't do such a good job at getting it right because it's hard to accurately measure angles on the sky when you have the Sun (which is a little bit too bright to look at comfortably) as one of the objects you're trying to measure, but he tried. Unfortunately, coming as he did, right on basically the end of Aristotle's life (he was about 10 years old when Aristotle died), he couldn't compete with the influence Aristotle had over the entire way people thought back in Greece.

Aristotle had said (and people decided it must be so), that the Earth is the centre and the sphere is the perfect form and everything goes around the Earth. That's the way everything was for hundreds and hundreds of years.

Fraser: Okay, so then when did the idea come back around, that maybe we're not at the middle?

Pamela: It actually wasn't until Nicolai Copernicus in the middle of the 1500's, of all times. Copernicus came along. He was driven not by science, but by his love of the Sun god Apollo to say, "no – let's go back to considering the Sun as the centre."

By the 1400's and 1500's, we were working to come up with mathematical explanations for why things are the way they are in the sky, why the planets move the way they do. We were trying to make predictions.

Prior to Copernicus, the person who had the corner on that market was Ptolemy. He'd come up with this really complicated model with circles within circles. He had things on perfect circles going around the Earth, and there were secondary circles attached to those circles. The objects were basically going on curly-qs around and around the Earth.

Fraser: Right, and that was to explain the retrograde motion that the planets make in the sky. We now know that the Earth and Mars are both going around the Sun. in the Sky, sometimes it looks like Mars is going one direction, and then for a few nights it turns around and goes back the other direction before it goes forward again.

Pamela: It's all just crazy perspective. Once you realise it's just us going past them so that our line of sight between us, Mars and the background stars zigs sideways, making Mars appear to go backwards. Once you realise that, everything makes sense.

The problem is that, in coming up with Copernicus' model, he also adhered to the "everything must be perfect circles, perfect spheres" – Aristotle's way of thinking. That didn't work mathematically, any better than what Ptolemy had done.

So you had Copernicus with his mathematical model. While it had the Sun in the centre, he still adhered to Aristotle's that the sphere, the three dimensional circle, is the perfect form. So he put the planets on circles, but it didn't match. He put circles on those circles. He couldn't get a model that worked any better than Ptolemy's.

It wasn't until Kepler and Galileo came along that, between Galileo's observations and Kepler's realisation that a circle is part of the family of geometric figures, the ellipse, and planets actually move in an ellipse, that we were able to move towards saying that yes, the Sun is in the centre and having observational justifications, and here's math that makes accurate predictions.

Up until Kepler, we couldn't accurately predict where anything would be. That's troubling.

Fraser: Galileo at this time was starting to use a telescope to look at the heavens, and he saw moons going around Jupiter.

Pamela: He saw moons going around Jupiter, and he also saw craters on the Moon. So the heavenly bodies aren't perfect spheres.

The final piece of evidence was he saw that Venus had phases that you could only get if it was going around the Sun.

Fraser: Right, I've seen that. If you look through a telescope at Venus, it will actually look like a crescent (go back and listen to our Venus episode). It looks like a crescent. You'll see, at its brightest point in the sky, it looks like the slimmest crescent, because the planet is closest to us, and yet most of the Sunlight is hitting the face away from us. So we only see the thin crescent.

Pamela: The crescent you can get if you have an Earth-centred solar system. The crescent Venus is one you can get if you put it in the same solar system as the Sun and have everything going around the Earth.

What you don't get is the gibbous phases. You don't get the phases where Venus is going out beyond the Sun and we're starting to be able to see the full face of Venus as it passes closer and closer to the Sun.

So we were able to see the whole host of crescent, half, gibbous, illuminated face (the half is actually a quarter of a sphere) of Venus. By seeing all the different phases, we knew that Venus had to be going around the Sun.

Fraser: So for all the evidence that scientists have worked out, that the Sun was actually the centre of the solar system, would you say Venus was the slam-dunk?

Pamela: Venus was definitely the slam-dunk.

Fraser: Nobody could look at that and say, "Well… here's another idea that works."

Pamela: Yeah. You need to have Venus going around the Sun in order to get that to happen. It's really quite cool.

Fraser: Okay. But then we still sort of thought the Sun was the centre of the universe. Once again, you look up into the sky and see all the stars going around the Sun and you say, well, we're in the middle. I bet some people are going, "wait a minute – maybe we're not in the middle"

Pamela: This is where it starts to get difficult. The initial evidence said we knew we were in a disk. If you look one way, you see one density of stars. If you look

180 degrees away from that, into the Milky Way, you see the same density of stars.

The problem is, the Milky Way's kind of opaque. It's like being inside a fog that only allows you to see five feet away from you in all directions. You might be six feet from the edge of the fog in one direction and a hundred feet from the edge in the other direction. Because you can only see five feet into the fog, you'll never know how close to the edge or centre you're located.

Fraser: If I took pictures of the Milky Way, and maybe sat in a circular room and put them around me, would I be able to say, "there's the centre of the Milky Way?"

Pamela: You might get a slight hint that over in one direction it's a little bit wider or a little bit thicker. But nothing definitive, nothing you can scientifically point to as evidence right off the top of the bat that we're definitely, 100%, guaranteed, not at the centre.

Fraser: Right, but I would see in all directions a really high concentration of stars in this disk. If you've ever gone out and looked at the Milky Way at night with your own eyes, you really see that. It's a concentration of stars. You can see that, especially if you use a telescope, you can really see the individual stars in the Milky Way. Yet, if I look up and down in this circular (or spherical) room, it would just be stars.

So definitely clear evidence that I'm in a disk, but I wouldn't know where I was in that disk. In fact, I'd probably assume I was in the middle of the disk because in every direction I see, I see the same concentration of stars. How did they know they weren't, then?

Pamela: It took a long time to figure that out. It wasn't actually until the turn of the 1900s – about 1917 that we were able to scientifically say, "aha! We are not the centre" In fact, we're about a third of the way out.

It was a man by the name of Harlow Shapely, who was studying globular clusters – clusters of stars out in the outer halo of the Milky Way.

Fraser: I believe we did a show about that.

Pamela: I believe we just might have. We'll link to it in the show notes.

As Shapely looked out and started counting and measuring the positions on the sky, all the known clusters (which was about 150 at the time), he found that 90% of them were off in the direction of the constellation Sagittarius. Only about 9% of them were in the opposite direction on the sky. This indicated we're not the centre.

If you assume the globular clusters form a spherical distribution around the galaxy. We're kind of thinking that there's a disk and we're embedded inside it. When we look above and below it, we find this distribution of globular clusters. It happens there's more of them when you look towards Sagittarius, because you're seeing the ones that are above the entire other half of the Milky Way, as well as the ones that are above the half of the Milky Way that we live in, that is toward the centre from us.

Fraser: The ones we can't see are the ones that are obscured by the dust in the centre of the Milky Way.

Pamela: Or in the entire disk. We can't see the ones out at the outer edge of the Milky Way either. Everywhere we look in the plane of the galaxy, in that disk of the Milky Way, we can't see any globular clusters (at least not with optical telescopes).

Fraser: I know that in the last few years with all these infrared telescopes, people are starting to find them--

Pamela: Yeah, they're out there.

Fraser: --by being able to see through the dust, they're starting to turn up the globular clusters that were previously completely hidden.

Pamela: But Harlow Shapely back in the 19-teens didn't have liquid helium cooled infrared detectors. He did have his optical cameras that took actual glass plate photographs. He and his team pored through them and figured out roughly, our place in the Milky Way.

We've been working to improve that number for a long time. We now think that (depending on whose paper you read) we're somewhere between 25,000 and 28,000 light years from the centre of the Milky Way. Those numbers come from looking at variable stars that pulsate in specific ways (RR Lyrae stars), from looking at parallax and stellar motions. We're using all sorts of different techniques to figure out how far away the centre of the Milky Way is – which is 25-28,000 light years away.

Fraser: Back then, the view was sure, we're in a disk of stars. We can look up and down and see stars. Then they thought that was the universe – that's all there was. The Milky Way – the galaxy – and that was it.

I know they saw other galaxies, but they didn't realise (I guess the telescopes were that bad) they were other galaxies. They called them nebula, and thought they were the same as the Orion Nebula and other nebula in the galaxy.

Pamela: What's really fun is when you talk to older astronomers, they'll still sometimes refer to Andromeda as the Andromeda Nebula, instead of the Andromeda Galaxy.

Fraser: I had an old astronomy book – no, an old planisphere. On it, it said the Andromeda Nebula.

Pamela: It was all the way up until the middle of the last century that there were still some holdouts arguing that these were nebula, they were islands of stars but not other Milky Ways.

We started to understand that no, these are other galaxies, as early (again) as the 1910s. In this case, it was good old-fashioned Hubble who made the observations that showed the Andromeda Nebula has pulsating variable stars (in this case Cepheids) in it.

While we didn't know the exact distance-scaling relationship, we knew that based on Cepheids, the Large and Small Magellenic clouds were one set of distances away. We had ratios of distances going. Then, when we worked the ratios to find out where Andromeda was, it was so much further away that it had to be its own separate island galaxy, it's own island of stars that was gravitationally bound together and completely separate from the Milky Way.

Fraser: So for a brief moment there, astronomers must have finally said, "Okay, we're not the centre of anything. We're one galaxy – there's one over there and another over there. Clearly there's just some distribution of them across the universe that could go on forever."

Pamela: Ever since then, we've been trying to figure out what our place is relative to everything else that's out there, our place in the universe.

All of a sudden in the 1910s all the way up through the 1930s, there was this complete revolution of thought going on in astronomy. We were realising that we're not the centre of the Milky Way, Andromeda isn't part of the Milky Way – it's its own separate galaxy.

Then we started making observations that most of the galaxies we look at are receding away from us. What does this mean? In 1931, Hubble wrote a letter to cosmologist Willem De Sitter and said, "what if the universe is expanding?" Everything changed.

Fraser: I guess the other way to look at it is what if all the galaxies are speeding away from us, at the centre of the universe? What if we're the middle of the universe and everything is moving away from us?

Pamela: That's one concern we have. Observationally, there's no way to say that's any different. We have what we call different cosmological principles. One of the principles says that we don't live in a special time or place. It goes on where our universe is homogeneous and isotropic. This means if you take a large enough chunk of any part of the universe, it's going to be similar to any other chunk of the universe. No matter where you go, as you look out at what you can see, you should be able to see pretty much the same stuff I can see here.

So, when you start basing your understanding on the notion that any place should be able to see the same thing, you can't say the Milky Way is the centre everything's expanding away from. In fact, as we start to build up a framework in which to mathematically explain our universe, when we started to develop the big bang theory, all of a sudden we had to have an expanding universe. It had to have no centre within that universe.

It's sort of like if you look at the surface of an expanding balloon. If you speckle little bits of glitter all over that balloon, the pieces of glitter stay the same size as the balloon expands, but the distance between the pieces of glitter is constantly increasing. You can't point to any one location on the surface of the balloon that is the centre of that surface.

Fraser: But there is a centre to the volume of it.

Pamela: But it's not a centre any of those specks of glitter can get to.

Fraser: Right. I think the analogy falls apart in people's brains when you say that. I'm sure everyone is imagining a ball expanding in their heads, with galaxies inside that are all spreading apart from one another. If you could grab that ball and cut it in half, you could say, "right there is the centre part of this expanding ball."

Why does that analogy fall apart with our universe?

Pamela: Because we're confined to the surface of that balloon. Except the balloon we're dealing with isn't the three-dimensional balloon like you might give someone for their birthday. Instead, it's a four dimensional object. We're still trying to sort out what that object's specific shape is.

We live on the surface of this four dimensional object, with our three dimensional reality confined to that surface. Once you start thinking in more than three dimensions, you no longer have a balloon you can cut open. Instead you have this hyper shape that is still empty on the inside, and we're still confined to the surface of a shape. That surface has no centre.

Fraser: Okay. Here's where the show turns and the unhappy answer comes. Where is the centre of the universe?

Pamela: Nowhere we can experience.

Fraser: So, you can hold a ball in your hand. If you say to yourself, what is the centre of the surface of the ball, the answer is nowhere because in any direction you go on that ball, you'll come back to your starting point in an equal amount of time or distance.

You say you could cut your ball in half or through the middle. But we're just talking about the surface area. IF we then expand out one dimension and say where is the centre of the universe, the volume of the universe, it's the same thing.

I guess with a ball, I'm saying I can move in one direction and end up where I started. If I'm in the universe, and I move in one direction…

Pamela: We think you'll eventually get where you started. We're not sure. There are hints coming out of studies of WMAP, there are hints out of studies of basically building simulations with specific geometry and see if, over moments that simulate the big bang, to moments that simulate now, you can build what we live in.

From those simulations and observations, it looks like we live in a universe where if you take two laser beams and you fire them off, and they're extremely powerful, coherent and have an impossibly narrow beam (really – impossibly narrow), those two beams will stay parallel to one another and come around and zap you in the back. Given enough time. That amount of time won't exist.

Fraser: Together.

Pamela: It looks like we live in a universe where parallel lines stay parallel, and you can go back to where you started.

Fraser: This is going to be two shows. I think that is a tremendously complicated topic and people are going to want it unpacked for them in a way they can really grok it.

I've got so many questions I don't even know where to start. Why? How is it possible you could shoot a laser beam and it could hit you in the back of the head?

Pamela: Let's talk about the shape of the universe next week, but finish talking about where we are in the observable universe today.

Fraser: Okay, all right. We'll talk about that. That hasn't been fully decided yet – that it is open or closed, that it works or doesn't work. We'll have that conversation next week. We'll finish off then.

Pamela: The rest of our story of our place in space is kind of boring. We're in a run-of-the-mill galaxy. It's kind of interesting. It's not terribly huge, but it is a giant galaxy. It appears to have bars. It appears to be one of these neat spiral systems that has well-formed arms and a little bar across the centre.

We have our own happy little spuds living next to us that make us look pretty in the telescopes of people looking at us from other galaxies. We have the large and small Magellenic clouds. We have all these dwarf spheroidal galaxies and dwarf ellipticals orbiting us.

We are in a fairly small group of galaxies. It's not a compact group or anything interesting like that. It's a small group. The Local Group (for lack of a more inventive name).

Fraser: How many galaxies are in the Local Group?

Pamela: That depends on how you count, because there are all these hundreds and hundreds of baby galaxies. The big ones are pretty much us and Andromeda. There are other galaxies in the local group though that are cool to look at through a telescope.

Fraser: When you see pictures of really nice, grand spirals captured by Hubble, like M81, are those in the Local Group?

Pamela: Those aren't with us.

Fraser: Those aren't with us?

Pamela: No. In our Local Group, the primary members are the Andromeda Galaxy and us. There's also the Triangulum galaxy that looks kind of cool. Those are really the big ones you'll be looking at. There are also the Leo I, and Leo II, smaller galaxies, the Tucana Dwarf, Sexton's A and B, NGC3109… they're all out there waiting to be looked at.

Then we have the Pegasus dwarf, the Aquarius dwarf, and the Ursa Minor dwarf. Bazillions of dwarf galaxies. You can't count all of the dwarf galaxies. We don't have the technology to see all of them in great detail yet.

Fraser: What's the next big structure?

Pamela: We're falling into the Virgo Super cluster. If you go out at night with your telescope and you pan around in the Virgo constellation, there are hundreds and hundreds of galaxies waiting to be looked at. This is one of the larger superstructures around. It's basically a corner in the large-scale structure of the universe. We're falling into this nexus of systems.

This is where you start having things like M81 being nearby. It's all sorts of really cool systems that are gravitationally sucking us into their grasp.

Fraser: There are many of these super clusters?

Pamela: There are all sorts of super clusters out there. We're falling into the Virgo super cluster, but there's also the Coma cluster, which isn't too far away. What's neat is as we make progressively more and more detailed maps of all the galaxies, we're finding they trace out a Swiss cheese formation where you get bubbles of nothing.

Where the bubbles come together you have super clusters. Sometimes inside the bubbles you'll have hairs and little tiny groups of galaxies. You have walls of galaxy clusters and galaxy groups.

Our universe forms a coherent structure that is evolving overtime that is becoming more filamentary. More thin-edged with larger voids. It's a beautiful universe.

Fraser: I guess as the expansion is happening, all of what were clumps are getting stretched out almost like spaghettification. It's all getting stretched out like gum or silly putty.

Pamela: The sad part about this is that as we look out over the volume of space that we're able to see (because light takes a finite amount of time to get to us, so we can only see stuff the light left within a certain amount of time and had time to get itself all the way to planet Earth). There are those who think we can only see 3 or 4% of the total universe. We only see one small bubble, and that bubble is filled with bubbles (which is kinda cool to think about).

Fraser: That bubble we're in is not at the centre of the universe because there is no centre.

Pamela: Exactly.

Fraser: We are equally distant in all directions from ourselves, and so is everybody else. Yeah, we'll need another whole show. We'll do it next week.

Pamela: The key is when someone acts like they're the centre of the universe you can say, "dude, no really – you are not the centre of anything. Get over it."

Fraser: Or we all are.

Pamela: Or we all are.

Fraser: Yeah, you're the centre and so am I.

Pamela: It all works the same.

Fraser: Well, I think you've all been warned to prepare for next week's headache.

Pamela: Send us some questions to help us out.

Fraser: We're going to unleash a mighty headache on your brain.

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