Astronomy Cast Episode 68:
Globular Clusters

Fraser Cain: This week, we're going to study some of the most ancient objects in the entire universe: globular clusters. These relics of the early universe contain hundreds of thousands of stars held together by their mutual gravity. In fact, when I get a telescope out to show my friends and family, the great globular cluster in Hercules is one of the first things I'll point out. It just looks like a fuzzy ball through a telescope, but in my mind I can see all the stars.

Let's just talk a bit about globular clusters. What are they?

Dr. Pamela Gay: They are, at the most simplistic level, they're collections of 10 thousand to hundreds of thousands of stars gravitationally bound together that formed in some cases 12 billion years ago. They're out, orbiting on the edges of our galaxy, and on the edges of most of the galaxies we observe out there.

Fraser: How many are we going to find in a typical galaxy like the Milky Way?

Pamela: It's all a function of how big the galaxy they're attached to is. Our own galaxy seems to have well over a hundred different globular clusters. We're finding new ones every day as satellites like the Spitzer Infrared Observatory peer through the dust and gas and are able to find new globular clusters in places we hadn't been able to look before.

They basically form a spherical distribution all the way around our galaxy, orbiting in some cases in two different directions. There's two different populations. They're old, metal-poor, and everywhere we look. They're the ancient stewards of our galaxy.

Fraser: Okay. When we talk about ancient, how ancient are they?

Pamela: One of the great mysteries for a long time was, we looked at them and they seemed to be older than the universe. It turned out we had miscalculated how old the universe was and we had miscalculated how old the stars were. Around the year 2000, once we got everything put together, it began to show up that our universe is 13.7 billion years old and these clusters of stars are 12 billion years old.

Fraser: I love that. I love that up until the year 2000, astronomers knew there were stars that were older than the estimates of the age of the universe, and that bugged them, but they were able to just kind of deal with it – "yeah, we have our estimate for the age of the universe wrong, and we probably have our estimate for the age of the stars wrong, but for now this is the best we can do."

[laughter]

I think that's great.

Pamela: I've had this moment at the chalkboard before. You start off at the upper-left-hand corner of three chalkboards and you start deriving equations, and you keep going and going and get to the very end and look at the number on the board and it doesn't match the number you calculated in the quiet of the privacy of your own office. You know somewhere on those three chalkboards, there was a mistake. And you don't know where.

Now, at the chalkboard, I can usually go through and my students are more than willing to help me find where I dropped the one-half or squared something that should've been cubed. But when making calculations of the age of globular clusters, you're not talking about three chalkboards of calculations. You're talking about thousands of lines of computer code going through and trying to calculate stellar evolution models, saying, "a star spends this long on the main sequence doing these things"

In all those thousands of lines of code, in all of the mathematics that go into the simulations to write those thousands of lines of code, there are so may places where our approximations might not be right, or where we might be missing a term in our calculations. It took us a long time to figure out what was going on and to get computers powerful enough that we didn't have to make as many approximations.

Then, when it came to measuring the age of the universe, it was an observational challenge that was pretty much unsettled until the WMAP results came in. There, we just had to build the bigger, better microwave telescope.

Fraser: Okay, fine. So they're not older than the universe. That's still plenty old. What kind of forces came together to build these globular clusters in the first place?

Pamela: A large, dense, glob of stuff all by its lonesome settled into forming dense, rich stars. Over time, the stars segregated themselves by mass.

Fraser: Why did they form all these different stars and not just one big, supermassive black hole?

Pamela: As the cloud of material collapses, it ends up fragmenting. It turns out that you don't generally have one nice, completely smooth cloud of gas. Rather, you have a cloud of gas with a few knots in it. Those individual knots, those individual places that are a little bit more dense than other locations, as the entire cloud collapses those little knots end up collecting gas to themselves, hogging it and forming individual stars out of this large clump of gas and dust.

It’s through the fragmentation that you end up with these populations of tens or hundreds of thousands of stars all clumped together.

Fraser: Do they form as separate clumps as the galaxy is forming, almost like planets inside a solar system might form around a star? Or did they form as kind of mini-galaxies and get absorbed into galaxies through collisions later on?

Pamela: One of the large mysteries we’re trying to sort out is why we have globular clusters with very specific geometries and star distributions that are roughly the same size as dwarf galaxies. What is it that made one clump of dust and gas form a globular cluster, and another clump of dust and gas form a dwarf galaxy? We’re still working to figure that out.

We think part of it might be globular clusters form in the halos of pre-existing giant galaxies. Dwarf spheroidal galaxies tend to form in isolation all by themselves. Some how, the kinematics involved ends up with two different things forming. Part of this might be the dark matter involved. Globular clusters don’t have the same dark matter halos associated with them that you get with little tiny dwarf galaxies. If you take a dark matter halo and throw a globular cluster’s worth of mass inside of it, you can get a dwarf galaxy.

If instead you just take a clump of dust and gas and embed it inside the much larger dark matter halo of a giant galaxy like the milky way, then you seem to get globular clusters.

Fraser: I didn’t realise that the amount of matter in a globular cluster could be the same amount as in a dwarf galaxy. That’s quite interesting.

Pamela: It’s one of those weird things. This is only true for the smallest of the dwarf galaxies and the largest of the globular clusters.

Fraser: What about composition? What kinds of stars are they? You called them metal-poor – why’s that?

Pamela: Stars come in a lot of different compositions. Our Sun tends to have, for a star, a lot of things like iron – a lot of heavier elements (like silicon). We can look at it’s spectrum and say, “look at all those rich titanium lines, those rich strontium lines in the spectrum of the star.”

Instead, if I start looking at the elements found in the stars of a globular cluster, I’ll see a lot of those elements just aren’t present. These stars can have a hundred or even a thousand less metal than our Sun has in it. We call these stars metal-poor because compared to the Sun, they have only a percent or a fraction of a percent of the same number of heavy atoms in their atmosphere.

Fraser: I know that stars get their heavier elements through successive generations of stars living, exploding as supernova, releasing their material which gets sucked into a new star-forming cloud so you get recycling going on and on. Do they just not get a chance to go through very many generations before they formed?

Pamela: 12 billion years ago, there just wasn't that much heavy metal hanging out waiting to be eaten into the newly forming stars. One the really cool things about globular clusters is pretty much all of the stars in the globular cluster formed in one violent period of star formation.

When I look at a sample of a hundred different stars in say, M13 (the Hercules cluster you mentioned), all those stars are going to be basically the exact same age. They're going to have formed out of the same cloud of material (so they have the same composition). The only thing that varies from star to star in these systems is their mass.

Fraser: That was going to be my next question. We learned early on that the heaviest stars burn their fuel quickly and then detonate at supernova, while the smaller – the Sun-sized stars and smaller can live on for billions and billions of years as main sequence or white dwarf stars. Is there some kind of mass limit where you just doesn't see a certain size of star in those clusters anymore?

Pamela: That's right. You look at these things and none of the large stars are left any longer. You're down to stars smaller than the Sun hanging out on the main sequence. Then, you have remnants of the stars. You have whit dwarfs, neutron stars, all hanging out going, "hey! We used to be big!" these are stars that shed their mass, exploded as supernova and went through planetary nebula formation. Those planetary nebula have, in many cases, been largely destroyed just by the passing of time. Globular clusters are systems rich in ancient stars and stellar remnants – nothing young or big.

Fraser: Are there any forces that will take a globular cluster apart? They've been around for 12 billion years – there must be some really serious forces keeping them together.

Pamela: They're one of the most tightly bound objects we know of (in terms of large populations of stars). Open clusters, in the disk of our own galaxy are much smaller – hundreds of stars in some cases. They get shredded by gravity over time. Globular clusters are tightly bound systems that are able to, in general, sustain orbiting our galaxy.

As we look around we do see instances of globular clusters that are elongated or a little bit mis-formed, that have gone through gravitational interactions with our galaxy or with other galaxies. That's the cool thing: we can observe globular clusters around our galaxy, around some of the dwarf galaxies (the Fornax dwarf has its own globular clusters, we see them in the Large

Magellenic Cloud). We can see them in all different environments, and in some cases the environments are rather hostile and destructive.

Fraser: Why do astronomers find globular clusters so interesting? Do they use them as a tool for some of the science they're working on?

Pamela: They're laboratories. Because you can look at M3 and get several thousand stars made out of the same stuff, you can see "if I change this variable involving mass, I get this difference in outcome. If I create a binary system, I get this difference in outcome" We can use them to say "I've now controlled for age and composition, all I'm going to vary is whether a star is in a binary or not, and what the mass of that star is." I can then see the outcome in the star's evolution.

These things, while they're all more metal-poor than our Sun (at least the ones around our own galaxy), they're all slightly different ages. They're ancient – but they're slightly different versions of ancient. It's sort of like going from a 70 year old to a 90 year old. They're all grandparent-age, but there are differences between a 70 year old and a 90 year old biologically. With these systems, they're all ancient, but there are differences in stellar evolution that we're able to observe.

They're one of the most fascinating tools for studying stellar evolution that we have, because you can see so many stars and control what you're looking at so carefully.

Fraser: I guess with a hundred thousand (or more) stars in a cluster, you can see every single mass of star from the smallest white dwarf, or the smallest red dwarf, all the way up to the largest star that hasn't died yet. I guess you can see, in some clusters that line falling off. In some cases, the bigger stars have died, and in other clusters they're younger and the biggest stars haven't died yet.

Pamela: Yeah, no. All the big stars are dead. That's the funky thing about them: there are no big stars. You're left looking at strictly solar-sized type stars and smaller in most cases.

Fraser: Do we see any clusters that are younger than this 12 billion years old? Do we see any that are just forming anywhere?

Pamela: Not locally, but as we look out at other galaxies, we do start to be able to see them around other galaxies, particularly in star-forming regions and in areas where galaxies still have chunks of basically, virgin gas waiting to get used. We did, starting in 2000, start to discover newly-forming globular clusters. That was kind of cool. Up until then, we had no clue where these buggers came from, we just knew they were out there. We didn't know which came first: the galaxy or the globular cluster. Now we know that they form together.

Fraser: They form together. I know there's a relationship between supermassive black holes and galaxies themselves. Is there a relationship between globular clusters and the galaxies they live in?

Pamela: This is something we're still trying to work and figure out. One of the problems is we can steal globular clusters from other galaxies when we eat them. It's hard to sort out the naturally born, biological globular clusters (to use a bad analogy) and the adopted children.

Fraser: How would we tell the difference?

Pamela: That's the problem. With the Milky Way Galaxy, we have these two populations of globular clusters. One is orbiting around the galaxy in the same direction the galaxy is rotating. The other population seems to either not be rotating relative to the Milky Way or it's going in the wrong direction.

With these two different kinematic populations, we also find differences in the composition of the stars. One population has even fewer metals than the other population. Astronomers are left thinking this is probably because we ate another galaxy and stole its globular clusters, but there's also the possibility that maybe one group of these systems just formed a little later on, a little further out. We're not really sure.

We need to keep studying, and keep looking at other galaxies with high-resolution images. If I watch a galaxy that's just starting to form (and we're just starting to find occasional examples of galaxies still forming today), how is it the globular clusters form with them?

Fraser: There was actually a really interesting piece of research that came out in just the last couple of weeks, where scientists were using a globular cluster as a laboratory. In this case they wanted to look at the distribution of regular stars and white dwarfs. Their assumption was the stars will sink down to a certain point in the cluster, depending on their mass – the heavier stars will sink to the middle and the lighter stars would be pushed up. They found a lot of white dwarfs were higher up than they were expected to be. Did you read that?

Pamela: Yeah – that was a really neat case. With globular clusters, the stars do stratify themselves, where the really bloated bigger stars, even the really ancient red stars (the really giant ones that aren't too much bigger than the Sun necessarily, and they aren't main sequence stars, but they're still bigger than little tiny baby red dwarfs). These bigger stars sink to the centre of the globular cluster, but the lighter stars end up floating to the surface. They actually pick up kicks from gravitational interactions – the bigger stars get less of a kick and the littler stars get more of a kick and are able to move outward in the system.

They looked at white dwarfs. White dwarfs come in a small variety of masses. They expected to find the heavier weight white dwarfs in the centre and the lighter weight white dwarfs further out. When they looked at really old white dwarfs (ones that had started to cool and weren't quite as blue in colour), that was true: the bigger ones were further in and the lighter ones were further out. When they looked at really young white dwarfs, from stars that just finished going to the white dwarf phase, all of the young white dwarfs were on the outer edges (that they found) of these globular clusters.

They think what's happening is these stars, during their last stages of life as they puff off their atmosphere, somehow this puffing off isn't completely symmetric. Just like someone going out into space with a little air can, when you spray your air can you might end up rocketing yourself slightly in one direction. These stars, by throwing off more mass in one direction than another, are able to rocket themselves to the outer edges of the globular cluster.

Fraser: Oh I see, so when they turn into a white dwarf, it's almost like a natural rocket. They push themselves outside the cluster and then over time, when they no longer have that kick, gravity asserts itself again and they get sorted back into where they belong in the cluster.

Pamela: In open clusters of stars in the plane of the Milky Way, this kick is enough that white dwarfs leave the open cluster behind. In the higher gravity environment of globular clusters, these stars are kind of stuck hanging out on the outskirts and don't actually get to escape. Overtime, through various interactions with other stars, they do end up sinking to where they belong due to their mass.

Fraser: I know there's been a revolution over the last decade or so: with a lot of the new infrared observatories they're finding a lot of brand new star clusters, some of them are even quite close.

Pamela: As I said, globular clusters form a sphere around our galaxy. This is actually how we were originally able to figure out where in our galaxy our solar system is located. We looked out and could say, "I see this number of globular clusters in this direction, this number in this direction and I know they form a sphere." We were able to pinpoint how far from the centre of the sphere we were located.

There were certain areas of the sky where we weren't able to look through the density of stars, gas and dust in the plane of our galaxy. We weren't able to see that population of globular clusters in that outer sphere, just because they were blocked from our view completely – just like if you threw a hula-hoop around your head, there would be sections of the area around you that you'd never be able to see.

With the Spitzer Space Telescope, we're able to start peering through the gas and dust. Really long wavelengths of light (really red infrared wavelengths) are able to skirt through gas and dust like no big deal. By using this other colour that's invisible to the eye, Spitzer is able to see through the crowded disk of the galaxy to see objects that had previously been hidden from us.

Fraser: Including clusters.

Pamela: Including clusters.

Fraser: Did that change our understanding at all about the distribution of them, or was it always suspected that they would be there and look, they found them?

Pamela: It was always suspected they would be there. This was one of those times we were able to say "Aha!" we knew what the distribution should look like. We couldn't prove it, because there were these areas we couldn't see in. Now, as we peer into these new areas we can say, "yep – we had it all right all along." It's always good to be proven right.

Fraser: What do you think the future holds for globular clusters? Will they just hang on forever, or will they just get chipped away and eventually dissipate into a galaxy?

Pamela: I think they're going to hang on for a long time.

Fraser: Define long – we're talking astronomical terms here, so you can use some big numbers.

Pamela: Ohhh… they're going to be around for billions and billions of years to come. They're going to survive the collision of Andromeda and the Milky Way and end up orbiting whatever new system we end up forming. I'm sure a few will be lost along the line, but there will be survivors out there.

What's kind of cool is someday far in the future, someday these clusters of stars are going to be clusters of white dwarfs, neutron stars and the occasional peppering of black holes. We're looking at future compact mass object clusters instead of star clusters.

Fraser: They've got to be the perfect place to look for black holes and neutron stars. Are many found there?

Pamela: Finding neutron stars is always hard. You end up having to look for them by looking for binary companion systems. Globular clusters are extremely dense, so it becomes hard to do the detailed observations necessary to find neutron stars.

We are finding black holes in these systems. They're able to make themselves apparent by eating things now and then. As gas and dust pours into a happily feeding black hole, it gets heated up and excited into giving off x-ray light.

By pointing telescopes like the XMN Newton at globular clusters, we're able to go "Ooo! X-ray emission – there must be a black hole there." We're finding the theorized population of intermediate-mass black holes can in some cases be found lurking in the centres of globular clusters. This is brand new information (fresh from last January).

We started to get hints about 10-15 years ago that there was observational, certain evidence that there are super-massive black holes in the centres of certain galaxies. We've looked for them in the centres of dwarf galaxies thinking we'd find smaller ones and that's been a really hard journey.

It was theorized that since globular clusters have similar numbers of stars, perhaps they had intermediate-mass black holes in their centres. In the very second globular cluster they looked in (unfortunately not the first), there was that x-ray emission that said, "yes, there's an intermediate black hole here and it's eating something right now!"

Fraser: Good chances – that's amazing.

Pamela: It's always nice when the needle decides to sit on the top of the haystack.

Fraser: Yeah, exactly. There's a classic science fiction story by Isaac Asimov, called Nightfall, where the planet happens to exist in a binary system or in a star cluster. It's always light – it's never dark. The astronomer predicts a bunch of the suns are going to be down and there's going to be an eclipse and things are going to be dark… and predicts everyone's going to go crazy.

I can just imagine… what would it look like to be on a planet in a cluster like that, and to see the sky? What would it look like?

Pamela: Here's one of the random factoids that helps eliminate it (to use a bad pun).

Our nearest star of noticeable brightness is a little more than three light years away. There are 100 thousand or more stars crammed into 100 light years' diameter sphere in a globular cluster.

From within the globular cluster, you have hundreds of stars that are amazingly bright every where you look in the sky, many of which are visible during the day as you orbit whatever star you're able to orbit. It would be amazingly bright.

The only way I can imagine getting sufficient eclipses is if you're surrounded by an asteroid cloud – and that wouldn't be a good way to be a planet.

Fraser: Maybe it wasn't a star cluster, maybe it was just a system with a bunch of stars, but a globular star cluster would take that to the next level.

Pamela: Yeah.

So there are some space artists out there who have done amazing artwork where they've sat down and worked with the scientists to work out what it would look like to orbit a brown dwarf, to orbit in a star cluster. There's some amazing work out there if you just Google hard enough and look around. Lots of different folks are working on this.

Life in a globular cluster: it's like if you imagine having a spaghetti colander above you with a floodlight. A hundred thousand stars near by shining down on your little world.

Fraser: I would love to see that.

Pamela: For now, these are objects that you can go out and see what they look like with a pair of binoculars and in some cases just your eyes. Omega Centauri (if you're lucky enough to live in the right part of the planet) is bright enough to see with your naked eye. M13 is out there waiting to be discovered. All of these systems make excellent small telescope opportunities.

Fraser: I highly recommend it – if you have a small telescope or a friend with a small telescope and you can say, "show me a globular cluster!" They'll know where to point it. It's quite surprising – you'll see a nice, little…. Well, it's a fuzzy ball. But in your imagination, think about that distant world with a spaghetti strainer series of holes with floodlights above you. It's amazing.

[laughter]

But yeah, I really like looking at the clusters. That's one of the first ones I'll point to, after Saturn.

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