Astronomy Cast Episode 46:
Stellar Nurseries

Fraser: So now, we've discussed star formation in the past, but now we wanted to talk specifically about the different kinds of stellar nurseries we can see across the universe. We know where our Sun came from because we can look out and see different stellar neighbourhoods at every stage of development, so let's find out what kind of place it takes to build a star.

So, can we talk a bit about – or at least summarise briefly, how the star formation happens, and the environment.

Pamela: Our universe is filled with these things called giant molecular clouds. Basically all they are is huge globs of hydrogen, carbon and oxygen and other atoms that have gotten together. They're dense enough and cold enough that these atoms are able to form molecules. H bonds H. Two hydrogen molecules come together to form H_2, so these are also often called H_2 regions. They also have carbon monoxide.

Eventually, if they get hit with something, if they get gravitationally bumped by something, if a spiral density wave in a galaxy goes through one, they'll get compressed and this cold, dense gas is capable of fragmenting and turning into packets that form stars.

Fraser: Can I stop you for one second though. You talked about how the hydrogen can get cold enough to form the H_2, so are there regions where the gas is too hot to even take that step?

Pamela: Well, that's actually the neat thing about these. You start off with the cold gas that's cold enough to form molecules and dense enough to form molecules. Here it's more a matter of it becoming dense enough. It started out cold, but enough of it had to get together that it was dense enough that the atoms were close enough together that they could glom onto each other and form molecules.

Once stars start forming, the stars give off light and the light heats up the clouds, and this causes the molecules to break apart. Not just the molecules – but actually the electrons often get knocked off the atoms. So we go from a cold cloud of gas, that forms hydrogen molecules, to a hot star forming region where stars are causing the hydrogen molecules to break apart and the electrons that leave the hydrogen. So now we end up with an H II region. So we have an H_2 molecular clouds, and then we have ionized hydrogen, H II regions which are a different form of cloud.

Fraser: …but will both form stars?

Pamela: They're two different states of the same thing. The cold one is about to form stars and the hot one has started to form stars.

Fraser: All right. What kind of cloud did the Sun form in?

Pamela: It's hard to reverse engineer the exact type of system that the Sun came from.

If you'd asked me this question 15 years ago, I would've looked out, pointed at the Orion Nebula and said, "that looks about right." It's a reasonable-sized system. The total mass of it is about 1000ish solar masses – less than 1000 solar masses, probably closer to 900 solar masses. It's kind of small, but extremely dense: it has 10,000 stars per cubic parsec. This means if you take an area that is roughly 3 light years by 3 light years by 3 light years, you'll find 10,000 stars in that small region.

We figured if a region was much denser than that, then planets wouldn't be able to form, but we're now learning that even in the largest and most violent star-forming regions, it's still possible to form planets. So it's hard to specifically say, "the Sun came from X," because the system we grew up in has dispersed itself all around the galaxy.

We know we grew up in one of these larger molecular clouds that was forming stars of all different sizes.

Fraser: How long would that period take? How long after we went from the cold cloud to the Sun getting dispersed from its cloud, what kind of time period are we looking at?

Pamela: It takes a little bit less than a million years for a molecular cloud to start visibly having its giant stars popping out, showing up well, and for the smaller systems to start being identifiable as what we called proplid. They look like cocoons. These cocoons of gas, we can say, "this is where a star potentially the size of the Sun is forming."

By about an age of 500 million years, we have a system that has started to disperse itself out such that it's hard to identify what stars belong to the system, and what don't. there's a system called the Hyades cluster in the constellation Taurus. Aldeberan, the really bright, red star, the eye of the bull (actually I think it looks kind of burnt orange, but I went to the University of Texas where we have longhorns, and that makes no sense to international listeners), but burnt orange, University of Texas, Taurus the Bull… they all go together if you think about it.

That eye of the bull marks the location of the Hyades cluster which has about 200 visible members that are spread out through the constellation of Taurus. This is a 500 million year old system. Stars like the Sun have formed, they've started to spread apart, this is a system that's only 150 light years away, and the core of this system has already spread itself out to 13 light years in diameter.

Fraser: So are there still stars forming in that region?

Pamela: All the stars in that system have formed, the gas has been used up, and now the system is starting to completely fall apart.

So you can go from about a million year old system that looks like the Orion Nebula to a 500 million year old system like the Hyades cluster, and you can see the cloud completely get used up, the stars begin to move apart, and these are not recognizable as the exact same type of system, but we are looking at the same system, just two systems that are radically different in age.

Fraser: Can you give us some other examples then, of these star-forming regions that we can see out in space? Give us some perspective compared to us.

Pamela: So the Orion Nebula is a nice place to start, it's fairly average. If you want to start finding the crazy systems, the systems that at some point are going to have lots of explosions taking place, unfortunately you really need to go to the southern hemisphere. There are two really good systems to look at if you're in the southern part of the world.

One of these is the Carina star forming region. It's also called the Eta Carina nebula, although that really just refers to the little tiny nebula around the star Eta Carina. There's an entire region around Eta Carina that's forming stars.

This system is tens of times larger than Orion. Orion has one giant star. Carina has over a dozen stars that are tens of masses in size.

Fraser: Isn't Eta Carina one of the biggest, most violent, ready to explode stars we've ever seen?

Pamela: Exactly. If anything is likely to go supernova, Eta Carina is probably it. There are 60 really massive stars with the potential to go boom in that system. It's about 220 light years in diameter, compared to Orion's dozen-ish, 14 light years in diameter.

It's a huge system. It's three times Orion's age (3 million years) but we can still watch stars actively forming, stars the size of the sun are still starting to emerge and look like normal stars out of these proplides, these cocoons of gas and dust.

Fraser: Does the amount of material, and the large stars that are forming, does that have any impact on some of the smaller stars, and even brown dwarfs and stuff?

Pamela: There's this neat thing called the initial mass function that says if you have a given amount of mass, you expect to see this many stars of this size, this many stars of this size, this many stars of this size. It's a function that is exponential. The number of stars of a given mass increases as a power of about 2.3. So as you get smaller, the number of stars gets higher and higher and higher.

Big stars are extremely rare. Little stars, they're all over the place. There are people who actually think once you start getting to systems that are smaller than our own Sun and its surrounding planets, this initial mass function flattens off. So for the smaller stars, there's going to be the same number of half the Sun, the same number as a third the Sun, but above that they constantly get lower and lower numbers, where if you have

100 stars the mass of the Sun you're going to have fewer than ten stars that are twice the mass of the Sun.

Fraser: It takes really special star forming regions to create these monsters.

Pamela: Exactly, and so Orion… it only has enough mass to form one of these giant stars, using this initial mass function. Carina is a much, much bigger star-forming region, so it has 60 of these giant stars.

Fraser: You said there were two places we could look, so where's the other place?

Pamela: The other is called 30 Doradus, or the Tarantula Nebula. It's not actually in the Milky Way Galaxy, it's in a little irregular galaxy in the halo of the Milky Way called the Large Magellenic Cloud.

Now, as this small irregular galaxy orbits the Milky Way galaxy, it's getting gravitationally harassed, it's getting harassed by material that's in the halo, and all of these different harassments add up to triggering star formation.

So the tarantula nebula, it's even bigger than the Carina nebula. It's about 500 light years in radius. It's about the same age as the Carina star-forming region, it's two to three million years old, and the most active star-forming place we know to look at.

It's actually where supernova 1987a took place, so it's in the process of having its giant stars periodically explode.

Fraser: So if we wanted to see future supernova, these would be the places to look. Just focus your telescopes at the big stars in the active star-forming regions, and those are the ones that are going to detonate.

Pamela: Supernova, the type that come from a single star exploding rather than the type that comes from a white dwarf grabbing mass of something else.

Fraser: the type IIa's, right? Or, rather, the type Ia's

Pamela: The type Ia's are the white dwarfs, everything else is a single star exploding.

Fraser: Right.

Pamela: So these different types of single star explosions are going to be associated with star-forming regions, with dense, young systems of stars. Places to find these: 30 Doradus, Carina (we're waiting for Eta Carina to go). When we look at galaxies, spiral galaxies in particular, the types of places we're seeing supernova are in these clouds that have active star formation in the arms of the galaxy.

Fraser: So a place like 30 Doradus wouldn't normally exist in the Large Magellenic Cloud. It's taking its interaction with the Milky Way to create this environment.

Pamela: Exactly. If you just took an irregular galaxy, plopped it down in the middle of a small group of galaxies where nothing's particularly harassing it, it would have star-forming regions, but they probably wouldn't be as large, and they probably wouldn't be as active as this one.

This huge of a system is driven by galaxy-galaxy interactions. We find massive star-forming regions almost everywhere that you have a galaxy with gas and dust interacting with another galaxy.

Fraser: So can we see some environments as big or even bigger out in the universe?

Pamela: One of the most spectacular places to look at massive star formation, and massive star-forming regions is the Antenna Galaxies.

These are two galaxies in the process of merging and to me it looks like a bug head that got squished antennas. That's the only way I can get antennas out of it.

Two systems in the process of merging. Lots of gas and dust knotting up, forming massive amounts of star formation. What's cool with that particular system is some of these clouds of gas and dust that are in the process of forming stars aren't going to form open clusters like the Hyades or the Orion system is going to eventually turn into when it gets torn apart by galactic rotation. These are actually going to form globular clusters. They're going to form small, gravitationally bound, permanent systems of stars.

Fraser: That was going to be one of my questions. We see the open clusters like some of the ones you describe, but we have these globular clusters in the Milky Way even. I know that many of them have been around for billions of years and they're still hanging together. So would it be bigger than 30 Doradus?

Pamela: It's not always the size of the system, it's the location of the system. An open cluster is in the disk of the galaxy, so the stars that are in the inner part of it and the outer part of it have noticeably different rotation rates around the galaxy. The amount of time it takes them to orbit the centre of the galaxy is quite different. This difference causes the open cluster to get torn apart as it goes. Because the system is embedded in the disk, which is filled with mass, pulling on everything from all directions, the open clusters aren't gravitationally bound together.

Now a globular cluster of stars, these exist out in the halo of the Milky Way. So here we had a cloud of gas and dust (that perhaps maybe even didn't start out in the Milky Way Galaxy), formed stars, these stars are gravitationally bound together. While yeah, they do have different distances from the centre of the Milky Way, if the stars in a globular cluster are 20 light years apart, that's going to be a much smaller fraction of their total distance from the centre of the Milky Way, because these things can be thousands of light years from the centre of the galaxy. That 10, 15 light year difference, that's a very small difference compared to in an open cluster that's right plunked down in the middle of the galaxy.

Fraser: Now what's a starburst galaxy? I've seen those described as well.

Pamela: A starburst galaxy is any system that has gas and dust that is massively forming stars as though all the gas and dust in the entire galaxy spontaneously decided, "I'm going to become a star right now."

In our own Milky Way, we have pockets of star formation: we have the Eagle Nebula, Orion, Carina, we have the Omega nebula. We have lots of little nebulas all over the place: they make binocular-viewing of the sky really exciting.

But we also have small clouds of gas, and even large clouds of gas that aren't doing anything. In a star-forming system, it's all forming stars. These systems generally occur when there's an interaction taking place.

So you take a galaxy and thwonk it somehow: either throw it into a cluster of galaxies where there's gas between the galaxies, and as the galaxy you threw in hits that inner cluster of gas, that gas is going to send a shockwave through the galaxy, and that shockwave is going to cause all the gas and dust to either get knocked out of the system, or get knocked into forming stars.

You can also take two galaxies and throw them at each other. This is what Andromeda and the Milky Way are in the process of (very slowly) doing to one another. When we hit Andromeda, the shockwaves of our two systems colliding are going to trigger massive star formation.

So whenever you shock something, whenever you knock something about or hit it… basically whenever you're violent to a galaxy, you trigger star formation.

Fraser: You already stole my next question, then. What does the future hold for the Milky Way? How much material do we have left that's ready to form these star forming regions?

Pamela: We currently have lots and lots of gas and dust still available. I don't know the exact numbers, but when you look out across the sky, gas and dust gets in the way of looking at just about everything.

There are these dark pockets of material called bok-globulous. They're little packets of gas and dust that appear as completely black blobs on the sky if you look at them in visual wavelengths. They're really amazing. It's like a teardrop of nothing on the sky.

If you do all-sky images, you see the dark bands through the disk of the Milky Way. These dark bands in the disk of the Milky Way are bands of dust and gas.

You have things like the North American nebula, that is huge on the sky – several degrees across – that's gas and dust.

Everywhere we look, even if we don't see a nebula, even if we don't see a dark blob of gas blocking our view of other things, as we look at distant galaxies, as we look at stars in the halo, a lot of this stuff appears slightly redder than we know it should be. This slight reddening is due to just the fog of gas and dust causing what's called reddening.

As light comes through gas and dust, the blue light gets scattered out, and what's left is the red light. This is why the Sun appears extremely red when it's on the horizon. All the blue light from the Sun is getting scattered away.

Fraser: Is that kind of like the opposite of why the sky is blue?

Pamela: The reason the sky is blue is because of all that scattered blue light. The light from the Sun is trying to go straight from the Sun to your eye, but some of that light is getting scattered in the atmosphere. The light that's predominately getting scattered is the blue light. So that scattered blue light will then shoot off to the right, but it will eventually hit another particle. When it hits that other particle, then it might get scattered to your eye.

Fraser: When we look out into space, we can see these regions of gas and dust that isn't even going to form a nebula, it isn't even going to form a star-forming region, it's just out there, hanging out.

Pamela: Exactly. What's kind of cool to think about is when we do get hit by Andromeda (or we hit Andromeda, depending on your perspective), that gas and dust is suddenly going to get moved. Some of it is going to plunge into the centre of the Milky Way, and some of it will join star-forming regions.

Fraser: So the gas is just perfectly in balance? It has no reason to gravitationally collapse?

Pamela: It's just a thin, diffuse fog, hanging out in the Milky Way. Now, as spiral density waves (which we talked about in an earlier episode) go through the galaxy, they do gather up the gas and dust and pile it up in the arms, but there is this diffuse gas and dust that's just, mostly everywhere annoying astronomers because everything looks a little too red.

Fraser: So it would be nice if that could all get cleared up and turned into stars so we could see through it.

Pamela: Exactly. What's cool is when we look at elliptical galaxies, they have almost no gas and dust because all the gas and dust has either got swept into stars or gotten knocked out of the system.

Fraser: What are some things we can look at in the night sky that are the end result of some of these stellar nurseries? We talked about the Hyades cluster…

Pamela: The Hyades cluster is a open cluster of stars that pretty much is on its way out. We also have things like the Pleiades. These are, again, in the constellation Taurus. This is a system that has about 500 members that are fairly easy to see. The core part you notice with your eyes is about 30 light years across.

This is a system that's just 50-60 million years old, so when we go from looking at Orion to the Pleiades, that's a difference of 50 million years, and then when we go from the Pleiades to the Hyades, here we're going from 50 million years old to 500 million years old. Those are three systems that are all just a couple hand's-breadths apart on the sky.

Fraser: So 50 million years from now, if we looked at the Orion cluster, it would look kind of like the Pleiades.

Pamela: Exactly. Then there's intermediate systems: there's the Eagle Nebula, which is one of the coolest systems to look at because you have all of these neat structures: the eagle itself, the pillars of creation, and this one little section that kind of looks like a fist doing things you can't show on public television..

Fraser: It's giving you the finger, isn't it?

Pamela: It's giving you the finger.

Fraser: Yeah.

Pamela: There's a section of the cloud doing naughty things.

That's a system that's 5.5 million years old. So the hottest stars in the system, their light has had a chance to burn away parts of the cloud, ionize the gas and dust, and leave behind pillars.

So here we're looking at something that's a little bit older, a little bit more cleared out, and it has all these really neat structures in it. We see pillars in other places (there's also pillars in Carina) but the ones in the Eagle are particularly well-defined, and really cool to look at.

Fraser: The great thing about the objects we're talking about today is with dark skies, many of those are visible just with the unaided eye. You can look up in the sky, in really dark skies, and say, "there's a blurry bit there, I can't quite make out what it is." If you pull out a sky map, chances are you found one of the nebula or clusters we're talking about today. If you get out the binoculars, you'll see a shape, a blurry shape with better definition – especially some of the clusters (the Pleiades look just amazing in a pair of binoculars). If you can get your hands on a small telescope (or even a bigger telescope) you can really start to see some of the stuff we're talking bout.

You're never going to see what they see in Hubble, but you can still make out almost every one of these objects we talked about, with almost any class of telescope. They're totally visible in the night sky.

Pamela: In our own Milky Way galaxy, the majority of star-forming is going on in the disk of the galaxy and toward the centre of the galaxy, if you want to find a nice dense area of lots of neat things going on.

If you're listening to this in the summer (when we're recording) a lot of those objects are easy to see right now. The constellation Sagittarius, which is easiest seen from the southern United States and areas south of that, and then basically from northern Australia and north –

Fraser: We get it here in Canada where I live, but it's pretty close to the horizon, it sort of makes a slow sweep around and then it's gone.

Pamela: Right. So the further south you go (until you hit the equator) the better it's going to be to see. You can just pull out binoculars and scan through Sagittarius and stumble across nebulae and open clusters constantly.

There are dozens of really neat objects to look at in and around Sagittarius.

Fraser: You can make out Sagittarius in a moment. Once you know how to find it – it's a teapot.

Pamela: Yeah, exactly.

Fraser: It's so easy to spot once you know what you're looking for. "There's Sagittarius" You can tell your friends and they'll be like, "where?" and you can say, "see that teapot over there? That's it."

Pamela: It's really fun to just sit back, not even know what you're looking at, scan through it and try and figure out, "okay, I found this on the sky," and then backwards find it on your map.

There's almost no other part of the sky you can look at and find an object by accident all the time.

Fraser: Even with your eyes, without even binoculars sometimes. "There's a blurry bit," then pull out your sky map and, "Oh I found the Orion Nebula"

Pamela: …but that's not in Sagittarius

Fraser: Nononono, I know

Pamela: But yeah, these are extremely bright, extremely beautiful, fun to look at objects.

Fraser: Awesome, all right. So now we know what our neighbourhood started out as, and we can look and see examples of the different stages that they went through and some of the more extreme versions of that out in the universe.

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