Astronomy Cast Episode 14:
We’re All Made of Supernovae

Fraser Cain: Okay, so let’s move on to the big, awaited show. Two weeks ago we talked about where stars come from, and last week we discussed how stars die. This week we complete the stellar trilogy to answer the question, What happens to the really, really, really big stars when they die?

All right, we won’t keep you holding your breath any longer. Pamela, let’s talk about the really big stars.

Dr. Pamela Gay: How big do you want to start with?

Fraser: Bigger than the biggest stars we talked about last week, I guess, with a stellar mass a little bit bigger.

Pamela: Well, why don’t we start with the really big guys first? So, there are stars out there that are a hundred and fifty times the mass of the sun, a hundred times the mass of the sun; these are giant stars. And in fact, they’re so big that the light pressure, the radiation pressure from the centres of the stars outward, is so strong that gravity’s really struggling to hold these starts together. And at a certain point, gravity begins to lose. The outer layers of the star fly out and the hydrogen gets stripped away, and if it goes on long enough, even some of the helium starts to get stripped away.

These stars are called Wolf-Rayet stars. They are, in their early stages, bright, luminous, variable. There’s one of them that our southern hemisphere companions can see called Eta Carinae. It hasn’t quite reached the Wolf-Rayet stage yet, but it’s going to get there. And when it does, it’s going to start blowing off huge amounts of mass, stripping away its atmosphere. And in its core, it is going to eventually start building helium into carbon and eventually that carbon is going to flash, and when it does, it’s going to put so much energy into the system that the star is just going to stop being a star. It’s going to self-destruct the kinetic energy of the particles in the star, it’s going to be so great that it just flies apart and leaves nothing behind. How’s that for dramatic death?

Fraser: So, it’s the light pressure of the fuel it’s burning that’s so strong that it’s just blowing away excess fuel.

Pamela: It’s just blowing away the outer atmosphere of the star. The hydrogen goes, and if a little bit of hydrogen’s left behind, you get one type of supernova. If you only have a little bit of helium left behind from the atmosphere, you get a different type. These are the type 1B and 1C supernovae.

Fraser: And how big do they have to be? When does that start happening?

Pamela: Well, the star starts off as a hundred or a hundred and fifty solar masses, but as it's blowing the outer parts of that, it's atmosphere, further and further away, it's getting smaller and smaller, and by the time it blows, it's only between 3 and 15 solar masses. So it gets rid of a lot of mass while it's getting rid of its atmosphere

Fraser: But why do the heavier elements, the carbon and so on, why does that explode?

Pamela: So, you have a core that's compressed down, and it compresses itself down into its smallest possible configuration. Packs itself up so the atoms are all perfect aligned, so they really can't get any closer.

Now, normally, when you add heat to a star, it expands a bit and it adjusts itself so the temperature never does anything too dramatically bad to the star. Well, because the atoms are all packed in so tightly, they can't move. And when the temperature increases, it increases at runaway speeds. And the sudden huge increase in temperature causes the star to just blow itself apart.

So by packing the core so tightly together, it makes it sort of like a packed theater where someone yells "fire!" and people just can't get out in an orderly fashion. In this case, the fire ignites and the atoms can't expand out in a normal fashion to cut off the temperature building.

Fraser: And is there anything left?

Pamela: Nope.

Fraser: It just...

Pamela: No, no more star.

Fraser: Just kaboom.

Pamela: Just kaboom.

Fraser: Wow.

Pamela: You get a really pretty nebula.

Fraser: That's a big explosion. Okay, so...

Pamela: It's really cool.

Fraser: Now, there are a bunch of types of supernovae, so, let's get a little smaller I guess. Something a little more, you know, a little less dangerous.

Pamela: Well, so, there's all different types of ways to become a supernova. You can start off really huge and reduce yourself down to being a little bit smaller. Or you can start off not so huge, not shed as much matter, but when you're getting ready to explode, be a lot bigger. So, if a star ends up, after going through it's different phases of life, with more than 15 solar masses, it's able to actually build heavier and heavier elements in its centre, getting to the point where it has things like silicon in the centre.

Fraser: That's right, like last week we talked about how our star, you know, will only get to the point where it's packing carbon together into a nice, pretty diamond. But it doesn't go any further than that.

Pamela: Exactly.

Fraser: But if there's enough gravitational force that it can just keep mashing carbon together, and heavier and heavier elements...

Pamela: And as it builds up with elements, eventually the star will get to the point where they have a solid iron core. The problem with iron is everything up to iron, everything that weighs less up until that point, when you fuse it together, you release energy. So, you can merge carbon and oxygen into silicon and you get energy released in the process. Iron's not so good.

Fraser: And so light pressure, that's the point you release the energy, you get more light pressure.

Pamela: And this radiation pressure, this light pressure, that's holding the star from not collapsing, is supporting the outer layer of the atmosphere that wants to collapse down. So, you end up building heavier and heavier elements, you get this iron in there and it's like, "I refuse to fuse. You can't make me." And it sits there and energy generation shuts down. And all of a sudden, gravity gets to win.

And the outer layers of the star come smashing down on the core, the core collapses and depending on just how big the core is, you can either end up with a black hole left in the centre, you can end up with a neutron store in the centre, and as the outer layers come crashing down, they smash together and thermonuclear reactions explode. You get a gazillion nuclear bombs basically going off.

As the layers collapse down, nuclear actions take off. And then the outer layers of the star explode out with all sorts of neat reactions going on, and this is how we get all the elements that are heavier than iron. Gold, silver, all this cool radioactive stuff that we use to build nuclear power plants. All of it comes out of supernovae.

Fraser: Okay, I've got a million questions. So, let's dismantle this piece by piece. So, all of the heavier elements are kind of coming down together, and then you hit the iron stage. So is there like, a big gap in between the core and the outer layers of the star?

Pamela: It’s not so much a big gap as you have these onion layers where you have each layer doing different types of nuclear fusion. So, you have iron being formed in the core. You have silicon being formed in a shell outside of that, oxygen in a shell outside of that, carbon and helium and then hydrogen as you work your way out from the centre towards the surface of the star.

And so that iron core’s embedded in the very centre of this onion level. But when it collapses down into black hole or neutron star, some of these outer layers, they begin to collapse down and as they do, they reignite and all sorts of wild nuclear reactions start happening. You also get all of these neutrons being given off by what’s happening in the core. So the protons, electrons, all sorts of things, are being smashed together, you have neutrons flying in all directions, and when you bombard atoms with neutrons, they’ll accept them up to a point. And at that point, those neutrons will start converting into other things. So you can actually start building iron into heavier elements if you bombard it with neutrons long enough. So you bombard it with neutrons, bombard it with neutrons, and eventually it becomes something that’s unstable. And it undergoes radioactive decay. And when it does that, we get the heavier elements.

Fraser: Right, and so in the previous case with the Wolf-Rayet stars, they just disappear in a puff of particles. With these, what kind of shape does the explosion take, and what’s left behind?

Pamela: Well, the outer layers of the star explode out, just like in the other case. But whereas before, the centre of the star also exploded outwards, here the centre of the star collapses down into a dead thing. It’s either a black hole, which is not generating energy as far as we know, or a neutron star, which is just radiating away heat but isn’t producing any new energy through nuclear reactions.

Fraser: So would the neutron star be largely made of iron? Or what, what’s left, what’s formerly known as iron?

Pamela: So, with a neutron star, the matter gets smashed together so closely that when the electrons and the protons get squished together, there’s not enough room for them to stay separate particles. So they smush together into their smallest form, which is actually a neutron and some energy. So we’re converting our protons and electrons into just a neutron and then little tiny particles are flying off to conserve charge and things like that. So neutron stars are just neutrons.

Fraser: All right. It’s no longer recognizable as what it once was.

Pamela: Exactly. All the previous atoms’ memories get erased.

Fraser: And more so for black holes, but we’ll cover that for another show

[laughter]

Pamela: Exactly.

Fraser: Okay, all right, so we've got the really, really big stars exploding, and we've got the, you know, fairly big stars exploding, is there anything smaller, or is that just the smallest you're going to get?

Pamela: Well, for smaller things to explode, they need to have a partner in crime. So we do have smaller stars that explode. In fact, if our sun was partnered with someone else, it, too, could go supernova.

One of the end stages of smaller stars' life cycles is to become a white dwarf. This is where the outer layers of the star just drift away and become a planetary nebula, and the core of the star, which is generally carbon, oxygen, or helium, gets left behind. And that left-behind remnant that is just thermally radiating away, it still has gravity, and if it's too close to another star, that gravity can start stripping material off of its neighboring star.

As the material spirals in and stars to gather on the surface of the white dwarf, it undergoes lots of different reactions. As it streams from the nearby star onto the white dwarf, it forms an accretion disk. The matter can't go straight from the neighbor star to the surface of the white dwarf, because there's all sorts of things having to do with conservation of angular momentum that spirals.

Fraser: So this is like water going down the drain.

Pamela: Exactly. This disk will occasionally undergo its own thermonuclear reactions, its own fusion processes, because the disk will get so dense that it's like the conditions in the centre of the star. And all of these different outbursts, all of these different times that that disk flares up, it can end up depositing ash on the surface of the white dwarf, gradually making it bigger and bigger and bigger. And as the white dwarf grows, the pressure in the centre gets higher and higher and the temperature in the centre gets higher and higher. And this can eventually cause the same sort of thing that happens in the core of that Wolf-Rayet star: basically the temperatures go up and the star can't react to that increase in temperature, it can't expand, and instead it ends up detonating. The entire star ends up exploding. Just like with the Wolf-Rayet, except this time it's cause by dumping matter onto a white dwarf.

Fraser: Now, I know that astronomers can look at the different kinds of supernova explosions and say, that was a Wolf-Rayet star, that was a type 1B star. How can they tell the difference?

Pamela: Well, the different stars have different characteristic explosions. It's sort of like, you can look at fireworks and identify what sort of firework you're looking at based on the colors of the light given off in the explosions and the shape of the dispersion of the light.

With supernovae, we can look at how much light is given off over how much time, we can look at what elements are present in the supernova explosion. And by looking at all these different characteristics, we're able to dump them into bins. We actually created the bins before we understood the meaning of the bins, because it's sometimes easier to see characteristics than to understand why the characteristics we see exist. So, the type 1 and type 2 are based on the shape of the light curve. And then the different subcategories are based on what elements we see in the explosions. So we go out and we look, is there silicon there? We go out and we look, how long was it? How bright was it? And all these characteristics allow us to reverse engineer what star must have been there before.

Fraser: And how can we know how bright they are? Because I mean, it can vary in distance, right?

Pamela: Luckily, supernovae in many cases work sort of like standard explosions. If you have a certain amount of dynamite, and you set it to explode, it will create a certain size explosion. And so there's a direct correlation between amount of dynamite and size blast.

Well, with supernovae, there's a correlation between what type of supernova there was and the amount of energy that it gives off, and we've been able to measure the brightness of supernovae to get at the actual luminosity of the supernova by looking at them in nearby systems. Occasionally we get lucky and supernovae go off in galaxies that we have other means of measuring the distances to either using Cepheid variable stars or some other technique. And by calibrating the amount of light given off by a supernova with the distance, and using some other method defined by that distance, we're able to then say, this supernova that's way far away, I know how bright it appears, I know how much light it gave off, now I can use it to determine the distance to that far away galaxy.

Fraser: A few shows back we talked about how to measure distance in the Universe, and one of the standard candles that we mentioned was this, these type 1A supernovas. Can you give a little more information now about how that connects together?

Pamela: Well, in general, white dwarfs are all about the exact same size. So we have our standardized size of dynamite. And these white dwarfs slowly accrete ash from nuclear explosions in their accretion disk. And the accretion disk comes from them gravitationally stripping matter off of a nearby star.

Pretty much all of the stars explode once they hit the exact same point. So the mass acts as a natural triggering mechanism. Dump enough mass on it, it explodes. Dump enough mass on it, it explodes. Works the exact same way all the time. And it doesn't matter what size the white dwarf started, if it started off really tiny, it just accretes mass for a lot longer time, or depending on mass rate it just accretes enough mass to get to that same threshold level. One that starts bigger doesn't need to get as much mass off of it's companion star before it explodes.

Fraser: Now, do we see any stars that are like, doing this?

Pamela: Yes. We see stars all the time that are stripping matter off of their companions. It's one of those really cool things about variable star astronomy, we can look across the sky and occasionally see stars flare up in brightness. And if we look at them with large telescopes, we can then start to see the accretion disk next to some sort of a normal star. The white dwarfs are too small to generally get to see, but we can see the accretion discs, and we know what's going on inside. So we see what's going on, we haven't actually gotten to see any good supernovae yet, but we see the early stages and we see the results. And we can build theories to bring the two points together.

Fraser: Right, I've covered a few stories in Universe Today about stars that appear to be right on the edge, that they're having little novas, little flashes of light off of them that are detectable, and they can measure the mass of the star and detect it right at just that limit, where the stars are about to blow. Whether about to blow means tomorrow or another hundred thousand years.

Pamela: And that's one of the scary things about these things, is the really big stars that are doing the supernovae, they're easy to find, they're sitting out there, they're huge, they're bloated, we know what they're going to do. White dwarfs are these little tiny things that can often go completely unnoticed, so there could be some out there that are going to blow and we don't know they're going to blow until it actually happens.

Fraser: Okay, so, now you're going to freak people out.

[laughter]

Fraser: How close does a supernova have to be for it to be dangerous to us?

Pamela: A star needs to be about 25 light years away before we start running into problems. But luckily, as far as we know, there aren't any giant stars - and we would have found them -within 25 light years, that pose us any danger.

Fraser: So just those nice safe red dwarfs that will be around for a trillion years.

Pamela: And some other more mediocre stars that will be around for a few trillion, but nothing dangerous. The two most dangerous nearby stars are probably Eta Carinae, which is about 7,000 light years away, and Betelgeuse, which is about 800 light years away. These two stars don't pose us any danger in terms of actually causing harm to the planet Earth. They're going to cause some really pretty explosions, they're going to shine much brighter than the moon, but other than a really cool light show, no harm is going to come to anyone on Earth.

Although, there's actually a lot of scientists that think some of the past mass extinctions on the planet Earth may have been caused by supernovae in the past. But we haven't been able to identify any exactly. The most powerful nearby supernova, the one that created the Cygnus Loop, which is easily visible in amateur telescopes, was about 80 light years away and it occurred about 20 thousand years ago when Cro-Magnon man walked the Earth. It gave off a thousand times more UV light than the sun does, but our atmosphere took care of us, so while it was out there looking blazingly, sterilely bright during the day and probably traumatizing our early genetic relatives, no harm came to the planet.

Fraser: And so with Betelgeuse and Eta Carinae, are they due to blow at any time in the near future?

Pamela: Depends on who you talk to. There are the hopeful few who are like, "they're going to go, they're going to go, they're going to go." But with Eta Carinae, we really have no clue what's going on. Eta Carinae is a giant mystery. It is a star that occasionally does funky stuff; it flared up about a hundred and fifty plus years ago, and became this amazingly bright star after previously really just living a life of security. It goes through all sorts of weird x-ray things and, yeah, we don't understand it. So it could blow. More popular theories, the ones that most people trust, say that it actually has to go through a Wolf-Rayet stage first, and it's not there yet, so, give it a million years.

Fraser: But those stars don't last long.

Pamela: They don't last long. So our planet will still be here when they explode. But it could go on a thousand years, it could go on a million years, and more likely a million years from now, because it does have to go through this Wolf-Rayet stage.

Fraser: And Betelgeuse

Pamela: Betelgeuse is just starting to do neat flaring, poofing things with its atmosphere. And so it, too, probably has another few hundred thousand to a million years to go. But it could go any moment, if you listen to the right papers.

Fraser: Right. Okay, well, I think that covers all my questions this week. That's great. Kaboom.

Pamela: Kaboom! It's very exciting.

Fraser: Awesome. All right, well, we'll talk to you next week. Thanks, Pamela.

Pamela: Sounds great. Talk to you later, Fraser.

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