NARRATOR: Have you ever wondered how all the chemical elements are made? Then join me as we are lifting all this data secrets to understand the cosmic origin of the chemical elements.

ANNA FREBEL: We just talked about the fusion processes and how elements are made in stars, mostly for energy generation purposes. Now let's look at how that actually manifests in the star as a whole because, as astronomers, we can observe stars but we can't really look inside of stars. We can only see the surface.

[MUSIC PLAYING]

There are a number of ways we can get clues from the surface of the star as to what's going on in the core. And so overall this is really a nice example of how nuclear physics and astrophysics-- nuclear and astrophysics-- come together because the nuclear physics governs what's happening inside the core and then the astrophysics provides what we can actually observe. And both kind of need to come together and work out. So over the last several decades a lot of progress has been made to put these two together and to understand what is now called stellar evolution.

That is actually governed by the nuclear physics processes, specifically fusion, in the core. I wanted to share this with you because it's very insightful. So I'm going to draw what we call a Hertzsprung-Russell diagram. It basically shows how a star evolves during its lifetime. We can use the sun as an example.

And what we're going to have is, we're going to have hot stars here and cool stars here. And then we have more luminous stars up here and less luminous stars down here. And there is a certain track that looks like this, half of a Christmas tree. And the sun actually sits right now about here.

One can put any star in this diagram. And you will see in a moment how we can then learn about the evolutionary phase of the star and hence what's going on inside its core. So the sun is sitting here. And we know on this branch here, which we call the main sequence, that stars burn hydrogen to helium. How does this look?

If we draw a star here, in the core hydrogen is burned into helium just like what we had in the previous section. The star, when it moves on-- oh, and I should say, every star will start somewhere along the main sequence here and it will stay there for about 90% of its lifetime. Which means coming back to the old stars for a second, 90% of 15 billion years is about the age of the universe which means the stars that started here when they were born in the early universe, they are just at the end of this hydrogen to helium process which really means they haven't done anything else but burning hydrogen into helium which really is the key to why these stars don't show their age.

They are just like what they've always done. And we can observe them today and infer things about the early universe from them today because they haven't changed. That's the key. But if we look at a star that has a shorter lifetime and wants to evolve, it will move up here. And it will move up here when the core-- let's see, this was hydrogen here and it has been converted to helium-- when we indeed have just helium in the core and there there's no hydrogen left in the core.

Then the star will get a little bit rumbly. And so it's going to start moving along here. And there are all sorts of things going on in the core because the thermostat is out. There is no energy being produced right now. And so what happens is, the star actually inflates to counteract that and it will move up here and become very luminous.

And up here we have the red giants. They're called red giants because they are much bigger and more luminous but they're also cooler because-- they're bigger and so they turn red. And so they have just a helium core and what's happening is, in an outer shell here they still burn hydrogen to helium burning going on in the shell. And that provides a little bit of substitute energy, a little interim energy to the star as it moves up here.

And then up here, we have something called the helium flash which means the helium here in the core is now being converted to carbon. How can I draw this? I'll make this go away. So we eventually get-- helium gets converted to carbon. So eventually we're going to get to a carbon core.

And then we have helium burning further out and hydrogen burning yet further out. When helium burning starts here, by the time it reaches here it has this carbon core. So here it reaches a helium core, this region. And then helium starts to burn. And then by the time it gets here we have a carbon core, and then it moves up here.

And this last part here, it really depends on the mass of the star. The sun is actually not going to do much. It's going to just stick it out with a carbon oxygen core here and then turn into white dwarf and just cool down. So the sun is actually pretty boring star that has a pretty boring fate.

If we make the sun much more massive, let's say 10 times more massive, it would move up here in this carbon burning phase. And if we have variety of later burning stages that lead to iron. And then it would have an iron core up here. And you already know what's going to happen.

If a star has an iron core it has lost its energy source and it will explode as a supernova. And so before it explodes, what's it going to look like? We have a whole bunch of these so-called shells. Sometimes they're referred to as onion shells. In the center you have iron and then there's silicon and all the other elements folding out here-- oxygen, carbon, helium. Let's draw another one. Hydrogen.

There are a few other elements being produced in minority processes. So some of these shells are not pure in these elements. But that's the basic idea that you go-- this is oxygen and silicon. This is sulfur and others. That you have a star that looks like that.

So what you see here is that whatever is happening in the core has a direct impact of where the object sits on this diagram here. And so by measuring the luminosity of a star as well as its temperature we can place it on this diagram and then learn which evolutionary state the star is in, which tells us what is going on in its core.

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