[MUSIC PLAYING]

ANNA FREBEL: 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.

Let's look at the early chemical evolution. Some 14 billion years ago, everything started with a big bang. A big bang. And it left behind a universe that was made from just hydrogen and helium gas. I mentioned before, there's a tiny, tiny little trace of lithium, but we're not going to worry about that.

So we had a universe, but there were no stars yet. So it was actually dark. And some people call that the cosmic dark ages. But structure began to form, and gas began to clump. And so eventually, in a gas cloud, the very first stars formed. Here are two of the first stars. And they were made just from hydrogen and helium, because the gas was just hydrogen and helium.

But for energy generation purposes, these stars needed to have nuclear fusion go on in their cores to produce energy. And so the first elements heavier than hydrogen and helium were created inside of these stars. And later, when they exploded in supernovae, they were expelled into this gas cloud. So we had the first elements here.

And of course, they also gave the first light. So they lit up the universe for the first time and changed it in a number of ways, not just by bringing in light, but also by producing the first heavier elements. And that set in motion the chemical evolution of the elements that's an ongoing process until today.

Now, these stars here, because they're formed from just hydrogen and helium gas, they're very massive. Rather large. Maybe something like 100 solar masses. So we use the unity of solar mass-- this is the symbol for the sun here-- as a unit. So 100 times more-- a ton of times as heavy as the sun. And the reason for that is that hydrogen and helium gas has trouble getting really cold, making small stars.

The important thing with massive stars is that they have really short lifetime. So they have a short lifetime of maybe a few million years only. A few million years is not much on a cosmic timescale.

Which means they exploded pretty quickly as gigantic supernovae. And as already indicated, what happened at a later time, these stars were gone, but they left behind all the heavy elements that that created. And I should be specific here. These heavier elements were all the elements made in fusion processes up to iron. So we have fusion elements in the gas.

And with the onset of these little other elements being in the gas, now the gas could form a clump much better and actually make small stars. So the next generation of stars-- so this was the first generation. First generation. And here now, we have the formation of second-generation stars. Here's a second-generation star. Here's a second-generation star. So small stars similar to the sun, and perhaps a little bit less massive than the sun, actually.

But of course, you're not going to make just small stars. You're also going to make big stars. So we have a few big stars here again, and a few intermediate ones.

And the big ones, the massive ones, will again explode on a pretty fast time scale and make more elements. But these little guys-- and that's the interesting part for us here now. So the low-mass second-generation stars, they have very long lifetimes. Long lifetimes of something like 15 to 20 billion years, because they have-- and I can just write that here. So low mass, they had maybe masses-- or at least some of them had masses between 0.6 to 0.8 solar masses. So less massive than our sun.

And as a good rule of thumb-- I can write this here-- the sun has, by definition, one solar mass. And that has a lifetime, or the sun has a lifetime of 10 billion years. And so everything that has less mass will have a longer lifetime. And everything that is more massive than one solar mass will have a much shorter lifetime.

Now, what does this imply, having a long lifetime? It means that these stars are still around. They're around today. We can observe them today. We can see them today.

And that means that we can use them to study the composition of this early gas here, because that's when they're formed. They have incorporated in all their layers throughout the composition of this gas cloud, that was enriched by these very first stars. So we have means to study the first stars, and what came out of the supernovae explosions, and what happened at this very early phase here of star formation, galaxy formation, and the formation of all the chemical elements.

If you then wind the clock forward, many things happened after. Well, of course, more stars formed. Many, many more stars. More supernovae. And with every generation of supernovae, more of all the elements was provided. More of all the elements.

Because, as we will see later, in some of these very early processes-- nuclear physics processes, all the elements from the periodic table could have been or were created already at the earliest times. Then with time, more and more of all of them were created.

It's not like that the universe, because it was just hydrogen and helium in the beginning, then it took time to build up all the elements and march through the periodic table with time. That is not the case. Everything was produced from early on, and then just more and more often.

And so, well, we have more stars and more chemical enrichment. But also, the formation of the first bigger structures-- formation of larger structures, including the Milky Way. Just going to abbreviate it like this.

Because this all happened in small gravitationally-bound systems. And they were then gobbled up later by slightly bigger neighbors. And then those were maybe gobbled up by the proto Milky Way, and eventually, the Milky Way formed, and formed from the remnants of all these little systems. And so all of this here happened as time went on until today.

Today, we have a universe that's full of structure, and full of all the elements. Well, a whole 2%, but I think we can consider this full, at least if you're an astronomer. And chemical evolution is an ongoing process.

So in the following, we're going to look in more detail at chemical enrichment and chemical evolution. And also, stellar archeology, which is the way how we use old stars to trace these different early stages of chemical evolution.

[MUSIC PLAYING]