

**ANNA FREBEL:** Have you ever wondered how all the chemical elements are made? Then join me as we are lifting all the [INAUDIBLE] secrets to understand the cosmic origin of the chemical elements.

What is the universe actually made of?

[MUSIC PLAYING]

Let's look at three different times in the universe and consider what it was made of then-- first, after the Big Bang. So if we draw a little pie chart here, the universe was made from just hydrogen and helium and tiny little bits of lithium. We can just cut it up like this. And so this is hydrogen, 75%, and helium, 25%.

And that pretty much adds up to 100 already. But we'll just write it up here, so lithium is of the order  $10^{-10}$ , which is really just a tiny, tiny, tiny amount. And we don't really need to worry much more about lithium. Now at a time later, namely 4.6 billion years after the Big Bang, an important event happened-- at least for us humans. The sun was born!

And from studying the chemical composition of the sun, as I will explain later, we can deduce what the universe was made of at that time. And as it turns out the universe looked a little bit different in its composition. It looked something like this. Here we have hydrogen, 71.6%, 27% helium, and then this one here. That's 1.4% of heavy elements.

So what we can see-- and again, we're going to go into more detail later-- some of the hydrogen got converted into helium. So we have less hydrogen about 5 billion years after the Big Bang, a little bit more helium. And helium, through various steps, has been converted into heavier elements-- a whole 1.4%.

Now if we then look at what things look like today-- that's 13.8 billion years after the Big Bang-- We see that the heavy elements make up a whole 2% elements. And there's a little bit more helium and a little bit less hydrogen. So we have a whole 2% of all the matter is in elements heavier than hydrogen and helium.

So as you can see, the two most important elements in the universe clearly are hydrogen and helium. And really who cares about all of these other heavy elements? They make today 2% and in the early universe it was zero and then a little bit. And accordingly, astronomers already

quite a while ago came up with the Astronomer's Periodic Table that is pretty simple-- actually so simple that I can draw it for you here. And it contains of three things-- X, Y, and Z.

And you can guess what X is, it's hydrogen. Hydrogen is pretty important in the universe and it sits up there in the periodic table. Helium is also pretty important, second most common element. It's in the top right corner there. And then all the heavy elements combined, they were called metals. And they together make up Z.

So we can simplify the universe pretty well to just hydrogen, helium, and metals. But of course we know that the devil is in the detail and we are really interested in these metals here because that is the subject of this lecture-- the cosmic origin of these heavy elements. And I should say here, of course, that metals is not-- in terms of the chemistry, it's not the correct description of all these elements that are found in the periodic table.

But in all we are astronomers so we get away with calling all the elements metals even if in a chemical sense they are nothing but metal. So that's a little historical piece. And people still use the term metal. And we're going to use it for our stars as well.

Before we move on to the next topic, I just want to say that you can see the universe changes its overall composition with time, which means that stars formed at different times will naturally have a slightly different composition as well because stars form from gas that is available at a given place at a given time in the universe. And the star's surface layers, they do reflect the composition of the birth gas cloud. So we are in a very lucky position that if we find stars born at different times and we study their chemical composition, we can reconstruct how the composition, the makeup of the universe, changed. And that's exactly what we're going to do.