[MUSIC PLAYING]

ANNA FREBEL: Have you ever wondered how all the chemical elements are made? Then join me as we are lifting all these data secrets to understand the cosmic origin of the chemical elements. Let's talk about spectroscopy. This is the technique we use to observe stars in order to figure out their chemical composition.

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Now you've probably all seen a rainbow. I really hope you have. And what happens in a rainbow? Well, white light comes through a little water droplet and it gets split up into the rainbow colors. And we do the same thing with a spectrograph mounted at a telescope. We take the starlight and we split it up into its rainbow colors.

Now what we see when we do this is not just the rainbow. Actually, we see less than the rainbow, because there are certain colors of the rainbow missing. So if I draw this schematically here, I have a rainbow. And let's say I have blue here and then green and yellow, what I will see also is that there is a big line, something like this, missing here and it's black. And then there will be a few things here and a couple there and many really, really thin ones in between that are hard to see.

And that missing part, or those missing parts here, they contain all the information that we want. It's actually not the colors and such, it's what's missing from there. Now how can we understand that?

If we come back to our stars and look at stellar surface, let's draw a surface layer here, and the core is here. We know that nuclear fusion is going on in the core, so it's really hot there, and energy comes out of the core in the form of hot photons. So we have these photons escaping from the core. And they come, they pass through this outer layer.

Of course, we are sitting here with our telescope observing the stellar surface. All right, as I mentioned in a previous section, that we can't look into the core, we can only observe the surface here. And specifically what we're observing is we're observing all the photons that come off the surface.

So in this outer layer we have hydrogen and helium atoms, because that's what the stars are mostly made of, hydrogen, helium. But, of course, there are-- unless we're talking about the very first stars, but that's a separate story-- there will be other atoms in here, iron, magnesium, carbon, oxygen. And so what happens is that all elements, hydrogen and helium as well, plus iron, magnesium, and so forth, they absorb. So let's draw this here. They absorb photons with their very specific energy or wavelength that's equivalent.

And so what comes out of here, here is one that gets absorbed, all these get absorbed, and then there are some that pass through. So what we see here is all the ones that came through and, of course, not the ones that were absorbed by these atoms. And so that's exactly what we see here. The colors is everything that came through, and then the black lines here are the ones that are missing. So we can see what's missing.

All the iron atoms here, they have absorbed all the photons at a specific color, at a specific wavelength. And so that's missing. However, this is actually not entirely black black. It has only a certain amount being absorbed, perhaps not completely. And so what we can measure is when we take a cross cut through this, we are going to get something that looks like this.

And so there is a strong absorption here, less absorption here. Let's say that this is our calcium. That's a calcium line here. And these are three magnesium lines. These are two sodium lines. Then we can see from these line strength here what the abundance of the magnesium atoms here-- here is another one-- is. So line strength here corresponds to abundance of magnesium atoms in the outer atmosphere.

And the nice thing, of course, is that when we want to find the most metal poor stars, or the oldest stars, then we want to look for stars whose spectra have very weak lines. Let's say like this. Because that means that only a little calcium, magnesium, and sodium actually are present in the star, which means that the star must have formed at a really early time when the cycle of chemical enrichment had only gone around a few times.

So this is the secret of spectroscopy, absorption line spectroscopy. We take these kinds of data here and we measure the line strength. We measure how much is present here. And with the help of computer programs, and a whole bunch of physics, we can turn these lines strengths here into an abundance in the stellar surface, and that tells us about the formation time of these stars.

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