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WHAT DID THE STARS GIVE US?

David Christian explains how the chemical elements heavier than hydrogen and helium are created by stars. This two-part lecture focuses on types of stars and their life cycles. **Low-mass stars** and **high-mass stars** follow very different paths, and only high-mass stars are capable of producing elements heavier than iron. When very large stars age, and when they die in massive explosions called **supernovae**, many of the chemical elements of the periodic table are dispersed into space. After reading the text below and watching this video, you should be able to explain how the chemical elements are created by dying and exploding stars.

Key questions

1 What are the main differences between high-mass and low-mass stars? How are elements produced in aging and dying stars?

2 Why is the creation of chemical elements an important threshold in our big history story?

Transcript: Part 1

0:12-1:19

THE PERIODIC TABLE OF THE ELEMENTS

Here we are at Lakeside School in beautiful Seattle. Now look around you at this beautiful campus, okay? I'm going to make you a bet that this contains a lot more than hydrogen and helium; in fact, we can be pretty sure it contains a fair bit of carbon, oxygen, nitrogen, probably a fair bit of phosphorus, sulfur, and trace elements of all the other things in the **periodic table**.

This is the periodic table; you can see all the elements we were just talking about. So here's the problem: There's hydrogen and there's helium. In a Universe that had only hydrogen and helium, what could you make? Well, you certainly couldn't make all the stuff out there, you couldn't make a planet, you couldn't make a laptop, and you couldn't make my friend Raul, nor could you make my living friends over here. So this is a real problem. Where did all those other elements come from? And the answer is, they came from stars.

1:19-1:52

THE "COOL" EARLY UNIVERSE RESULTS IN SIMPLE ELEMENTS

So far our story has been about a Universe that's cooling down. And that cooling down was really important because it allowed matter and energy to separate from each other, and it created the forms of matter that we've seen so far. But now we need to talk about ways in which the Universe began to heat up. And that is something that happened inside stars. It was that heating-up process that allowed stars to cook all the other elements that we've seen around us. And that's why stars are, sort of, the stars of this part of the story.

1:52-3:03

OUR HOT SUN

The nearest star to us is our Sun. At the surface the Sun is **5,800 degrees Celsius**, but at its center it's 15 million degrees. Think about that. Water boils at about **100 degrees Celsius**; that's about 373 degrees above absolute zero, the coldest temperature there is. So the center of the Sun is about 40,000 times hotter than boiling water.

HIGH TEMPERATURES ARE NEEDED TO CREATE MORE COMPLEX THINGS

At these enormous temperatures protons have a huge amount of energy, and as we saw in the last unit, they smash together really violently and eventually they fuse to form helium nuclei. Now that's pretty hard, but here's the problem: There's **carbon** up there; it's got six protons in the center. You can see the six above the carbon. So to get carbon, we need to smash six protons together, and for that you need much higher temperatures, like **200 million degrees**. And now let's go on to iron. Where's iron? There's iron, with 26 protons. So now you need to smash 26 protons together to get iron, and to do that you need temperatures as high as **3 billion degrees**!

3:03-3:54

So, where in our young Universe are you going to find temperatures of 3 billion degrees? The answer is: inside dying stars. That's right, dying stars.

THE LIFE AND DEATH OF TYPICAL STARS

And here's why: Remember that most stars spend most of their life, about 90 percent of their life over billions of years, fusing protons, hydrogen nuclei into helium nuclei. But think, what happens when they run out of fuel? Well, what happens is that the furnace at the center of the star stops supporting the star; gravity takes over and collapses the whole thing. Now that collapse is really violent, and it creates high temperatures at the center, but how high depends on how large the star is, how much stuff there is, how powerful gravity is.

3:54-4:48

THE LIFE AND DEATH OF A SMALL STAR

Now think of **small stars**. A small star doesn't have much pressure at the center, it burns hydrogen slowly over billions of years at low temperatures, and it lives a very long, slow life. And when it dies, eventually it runs out of fuel, and it will just slowly fade away, like a dying campfire. Nothing very interesting happens.

THE LIFE AND DEATH OF A LARGE STAR

Larger stars are much more interesting. They create higher temperatures at their cores; they burn hydrogen much more violently; and when they run out of hydrogen and collapse, they generate much higher temperatures, up to 200 million degrees. Now you may remember that's the temperature at which you can fuse six protons to form carbon. So they start burning helium to form carbon. Now when stars run out of helium, things start moving faster and faster.

Transcript: Part 2

4:52-6:11

NEW ELEMENTS EMERGE

If a star runs out of helium, it will start fusing **carbon into neon** at close to 1 billion degrees. And then, in a whole series of collapses and new fusion processes that keep getting faster and faster and faster, it starts fusing **neon into oxygen**, then **oxygen into silicon**. And then finally, at 3 billion degrees, it fuses **silicon into iron**, and that's as far as the process can go.

I'd like to read to you Cesare Emiliani's wonderful description of the final few million years in the life of a dying, huge star: "A star 25 times more massive than the Sun will exhaust the hydrogen in its core in a few million years, will burn helium for half a million years, and — as the core continues to contract and the temperature continues to rise — will burn carbon for 600 years, oxygen for six months, and silicon for one day."

By this time, the center of the star is like a sort of layer cake, with all these different elements. And eventually, when it fills up with iron, it can't go any further. It will collapse; it will scatter its outer layers into space, and so they'll spread around the star into nearby space all the elements it's just created.

6:11-7:10

AGING AND EXPLODING HIGH-MASS STARS PRODUCE ALL ELEMENTS HEAVIER THAN IRON

Well that's great. Now we've seen how to generate all the elements on the periodic table up to iron, but what about all of these? Where do they come from? Well, the answer is that the rest of these elements are not produced in dying stars but in exploding stars. That's right, exploding stars.

Now when a really large star fills up with iron at its center, it eventually collapses, and it explodes, generating staggering temperatures. These explosions are called **supernovae**, and they are amongst the most spectacular things you can see in the whole of astronomy. In just a few seconds all the elements of the periodic table are manufactured in that supernova explosion. It shines so brightly, it generates such high temperatures, that for a few weeks a supernova can outshine an entire galaxy. In fact, many of the "new stars" we hear about in history, such the Star over Bethlehem, may well have been supernovae.

7:10-8:14

HELIUM AND HYDROGEN MAKE UP 98% OF THE ATOMS IN THE UNIVERSE

So, where the dead star is, where the supernova was, we have a huge cloud of dust and particles containing every single element in the periodic table, and it's drifting out in space.

THE THIRD THRESHOLD OF COMPLEXITY

But let's put all of this in perspective. We began this unit, remember, in a Universe that had just helium and hydrogen, nothing else. Now, at the end of this unit, we've got all of the elements on the periodic table. But the truth is that, even after billions of supernovae and billions of years, helium and hydrogen make up **98 percent** of the atoms in the Universe. All the rest make up just **2 percent**. So you may be thinking, What's the big deal about that? Well that 2 percent is actually a huge deal. Without it, you couldn't make my friend Raul over here, you couldn't make me, you couldn't make you. So it really makes a difference. And that's why in this course we call the creation of new chemical elements the **third great threshold of complexity**.

8:14-9:00

EVIDENCE

So, now we've got to the time when we need to ask some questions: What are the main features of this threshold? And is it really important? And also, you should be asking, what were the Goldilocks Conditions for this threshold?

And here's another group of questions: Would it matter if we hadn't crossed that threshold. If the Universe had never contained such large stars?

And finally, you should be thinking about evidence. I don't think I've given a single piece of evidence during this talk. Why should you believe me? I'm a historian not a scientist. Think about it.

So we've covered a lot of territory in this unit. Now it's your job to dig deeper.