3.1

STARS & GALAXIES

0:00–0:26

AFTER THE BIG BANG

Hi, I'm John Green, and this is Crash Course Big History. Today, we're going to be exploring what happened to the Universe after the Big Bang, particularly, how you and I and everyone you know emerged from stars. And we'll also be investigating the burning question of why anyone who studies history has to care about chemistry.

Mr. Green, Mr. Green! I'm sorry, but I hate chemistry. Why can't we just learn about like English kings stabbing each other?

0:26–0:52

IN THE BEGINNING THERE WERE STARS

Sorry, me from the past, the thing is if you look far back enough in your family tree, you're going to find not just like farmers, and foragers, and fish, and microbes, you're going to find stars.

And I don't mean stars like Kim Kardashian, who is actually not a star, she is a person. I mean actual stars, me from the past. And to understand how we got from stars to people, you're going to need some chemistry.

0:52–2:00

COSMIC BACKGROUND RADIATION

So last episode we went from the very beginning of everything to the release of cosmic background radiation. And CBR is a major piece of evidence that the Big Bang happened. Studying it closely also tells us the age of the Universe and it allows us to see the minute variations in temperature and density of the early Universe. And it turns out that those tiny differences are a really big deal.

So when the Universe inflated from much, much smaller than an atom to the size of a grapefruit in a split second, there were quantum fluctuations, tiny little blips on the unpredictable quantum scale. And they created those little variations that we see in cosmic background radiation.

And as the Universe continued to expand — I mean it is currently larger than a grapefruit — those variations in density were inflated to such a scale that gravity was able to take hold and start clumping together clouds of hydrogen and helium gas. So 380,000 years after the Big Bang, the Universe was becoming an increasingly cold and increasingly boring place. Like temperatures were no longer high enough to forge new elements, and if hydrogen and helium hadn't clumped together, nothing would have ever happened ever again.

2:00–2:54

THE UNIVERSE COOLS

Our Universe would just be a dull, homogeneous place with some clouds of hydrogen and helium gas floating around. Dull and gassy, just like North Dakota. I'm just kidding, North Dakota. You do have a lot of natural gas, but you're very interesting. I mean you have Mount Rushmore. What's that? Oh, oh I see. Sorry, yeah, then...

But what happened is that while the Universe on the whole continued to cool, thanks to those tiny variations that emerged during inflation, certain pockets of the Universe were about to get very hot.

Indeed, a liberal dose of hot sauce was yet to come. Hydrogen and helium though are light gases; they are the lightest two elements. So light that they require very little encouragement to escape the Earth's atmosphere. But while the explosive force of the Big Bang flings matter and energy apart, gravity has the ability to pull tiny pockets of the cosmos back together, provided it has some wrinkles in the Universe to work with.

2:55–3:34

HYDROGEN AND HELIUM

As gravity sucked hydrogen and helium atoms together, enormous, thick clouds began to form. While the expansion of the Universe continued to increase the gaps between these clouds, the density of these pockets also increased. The vastness of empty space began to be filled with tiny islands where atoms of hydrogen and helium were increasingly squished together.

Despite being the lightest of all the elements, the immense amount of all that gas built pressure up in the center. Increasing pressure meant increasing temperatures, just like after your 2:00 a.m. taco run, suddenly these gassy pockets were burning inside. It was in this rather uncomfortable state of heartburn that the first stars flared into life, roughly 100 million years after the Big Bang.

3:35–3:50

THE UNIVERSE APPEARS

By a billion years after the Big Bang, the Universe was starting to look like what we think of as a Universe. An immense vastness littered with hundreds of billions of galactic islands containing hundreds of billions of stars. And as recent work with Kepler space telescope has revealed, a mind-numbing number of planets.

3:51–4:26

SIZE OF THE UNIVERSE

So the Universe is big, it's really big. But it's not so big that it's impossible for the average person to get a mental picture of like our neighborhood. Our galaxy, the Milky Way, formed from these galactic mergers with other galaxies that stopped like around ten billion years ago. Our galaxy is about 100,000 light years across, which means that it takes, you know, 100,000 years for light to get across it.

And even if humans become like technologically capable of colonizing the galaxy in the next millions of years, our little galactic island is probably where we're going to stay just peeping out on the rest of the Universe.

4:27–5:14

GALAXIES MERGE

So there are between 200 and 400 billion stars in the Milky Way with huge distances between them. There hasn't been a merger between our galaxy and another for a long time, but our neighbor Andromeda, which has closer to a trillion stars, is actually set to collide with us in 3.75 billion years.

But don't worry, this isn't going to be like a car crash because the vast distances between stars make it very unlikely that stars will actually hit each other in such an event. Although many new stars will form.

Instead of a car crash, think of like a three-billion-year-long tango of two graceful galactic dancers. This is going to totally mess up the constellations that we're familiar with now, but the good news is that by that time, the sun will have wiped out life on Earth regardless, so we won't have to worry about it.And the even better news is that let's face it, there's no way our species is making it until the sun wipes us out.

5:15–5:57

GALACTIC ISLANDS

As far as these galactic islands go, ours is a modest size. Like Malin 1 is a spiral galaxy like ours, but it's a whopping 680,000 light years across. And the giant elliptical galaxy excitingly named M87 — because astronomers are so good at naming things — is 980,000 light years across. And with its radio jets, the elliptical galaxy Hercules A — that's a slightly better name — is a whopping 1.5 million light years across from end to end.

Galactic islands are separated by millions and millions of light years. And the Virgo super cluster of galaxies to which the Milky Way belongs is roughly 110 million light years in diameter, and that's only one of many likely infinite super clusters in the Universe. Wait, literally infinite? Wow.

5:58–6:40

THE COSMIC HORIZON

Unfortunately, we can't know whether the Universe truly is infinite or not because of a little thing called the cosmic horizon. We can only see the light that has reached us from the start of the Universe 13.8 billion years ago. Simply looking into the sky is an act of investigating history, and the farther we look back we begin to see more primitive things. The first stars in galaxies.

Mind you, the light we observe billions of years after it first shown and the continued expansion of the Universe means that the cosmic horizon is approximately 46 billion light years away by now. Roughly double that and you know that our little cosmic bubble is about 92 billion light years across. I mean compare that to our already huge 100,000 light year galaxy.

6:41–7:58

THE COSMIC BUBBLE

Just for a little bit of context…But beyond our little cosmic bubble there is more Universe, eternally inflating. And where our Universe is sort of one hole in a block of Swiss cheese, other holes might exist in that block of cheese, multiple universes with laws of physics completely different from ours. I know, right, it's nuts! It's actually more like cheese, but it's nuts!

But our cosmic bubble, while it's very large, is not such an intimidating place. Like it's pretty easy just to get a mental picture of it. A vast bubble with a lot of empty space and a light dusting of galaxies.

To further this point, and don't take this too seriously, but in 2002, Karl Glazebrook and Ivan Baldry added up the light from 200,000 galaxies and determined that if you were able to stand outside our cosmic bubble and look at it with human eyes, the color of our Universe would be — wait for it: beige. That's a bit of a anticlimax, so they tried to dress it up by calling it cosmic latte. But I don't mind beige. I mean look, this stuff is gigantic and somewhat scary, but you can't be scared of beige.

And a lot of cosmologists infuse their lessons with a sense of awe at this vast expanse. And that awe is certainly justified. I mean the Universe is literally awesome.

7:59–8:22

WHERE THE ACTION IS

Though let me ask you this, if you lived in New York City would you feel bashful or depressed about the size of your city compared to, say, the miles and miles of the plains of Saskatchewan? So yeah, there are millions and millions of light years of empty space, but it's empty space. One thing we find out about the rising complexity in Big History is just how unique some of these tiny areas of the Universe can be. This is where the action is.

8:23–8:57

STARS ARE BORN

Enough of the pontification, let's get back to those gassy, heartburn-suffering stars. As core regions of the gas clouds heat up, the atoms get jumpy, move faster and faster and collide with ever-increasing ferocity. Eventually it's ferocious enough to overcome the electric repulsion between the atoms, they fuse and the cloud officially becomes a star.

Hydrogen atoms fuse into helium atoms at about ten million degrees, releasing yet more energy. The sun is a massive hydrogen bomb in the sky. And the release of energy in just the right amounts is very good for us, provided we don't mess up the ozone layer too bad or spend too much time tanning on the beach.

8:58–9:42

SIZE MATTERS

When it comes to stars, size matters. If an initial cloud is smaller than 8% of the size of our sun, it'll never form a star. Maybe only a brown dwarf. If the initial cloud is 60 to 100 times our sun it will probably split into two or more regions of stellar formation. If the cloud is between 8% and eight times the size of our sun it has a longer lifespan. Our sun is middle-aged and will last for about another five billion years. Much smaller stars may have lifespans of hundreds of billions of years. Large stars sometimes only live for a few hundred million years.

As all stars run out of hydrogen and helium as fuel, the outer edges of the star swells up. Fusion of heavier elements occurs, requiring higher and higher temperatures, creating heavier and heavier elements, all the way up to iron.

9:43–10:24

THE PERIODIC TABLE

But elements heavier than iron can't be created in the stars. There simply isn't enough energy to fuse those heavier nuclei together. So how is the rest of the periodic table formed? When giant stars, eight to 60 times the size of our sun exhaust their fuel, they collapse. This may last no longer than a second, but it will be followed by a huge explosion.

These explosions shine with the energy of billions of stars and combine with proton and neutron capture, supernova are responsible for creating the heavier elements of the periodic table. Flinging out these elements, the rest of the cosmos is fertilized and nourished by the ashes of dead stars.

10:25–11:59

WE ARE MADE OF STARS

Carl Sagan said it best, "We are made of star-stuff," and he really meant that. I mean you see this globe? It was made in the belly of a star. You see your computer? Made in the belly of a star. Your dog, made in the belly of a star. Your right hand, made in the belly of a star. Your left hand, potentially made in the belly of a different star.

Stellar evolution bridges the gap between the mind-boggling origin of our Universe and the tangible material stuff that you see around you, and, in fact, the tangible material stuff that you are.

Humans haven't just appeared out of nowhere. We've changed form. We used to be much hotter, of course — I mean temperature-wise. This is why chemistry is important to understanding the grand narrative of 13.8 billion years. And it's also why we look at the big history of individual objects, something we call little big histories.

Like see this ring on my finger? I bought it in a jewelry store. A nice person sold it to me. A jeweler crafted it and miners dug it out of the ground. But it got there by being flung out of a huge star in a massive explosion billions of years ago. It wound up in our Solar System, was part of the tiny .1% of matter that didn't get sucked into the sun, accreted from the dusty debris in the one sliver of the Solar System where the Earth was. And because gold is an iron-loving element, it was more prone to sink to the center of the Earth, making it even more unlikely that it should be found on the Earth's crust.

Rare and shiny things are valued by a lot of human social orders, and during the agrarian era, gold became a sign of social standing and wealth. And in marriage tradition, giving someone an expensive gift can be a sign of esteem. Hence Sara and I spent $450 on this, which we could have spent on an Xbox.

12:00–12:39

WRINKLES IN THE UNIVERSE

Tiny wrinkles in the early Universe had a major impact on one of the unifying themes of 13.8 billion years: rise in complexity. Wrinkles created stars, stars created elements, and some of those elements came together to form life, and, of course, us.

Gradually, we see an increase in the number of connections and building blocks present in the Universe. For instance, a star's comprised primarily of two elements: hydrogen and helium.

But here's the thing, if there had been no wrinkles in the early Universe, energy would have been evenly distributed across the cosmos. Without flow of energy, like say that through a star, no complexity could arise. None whatsoever.

12:40–13:15

THERMODYNAMIC DISEQUILIBRIUM

This state of existence is called thermodynamic disequilibrium, which means that energy is not evenly distributed.

A simple structure like a star is big, but it's just a large pile of the lightest elements and doesn't score very high in energy flow density. Your brain is 75,000 times more complex than a similar size chunk of the sun. Its building blocks and nodes are way more intricate. Your brain has way more connections than there are stars in the galaxy.

You wouldn't think a story that spans cosmology, geology, biology, and human history would have a unifying theme, but rise in complexity is something that stretches across all 13.8 billion years. And it began with those tiny wrinkles in the early cosmos.

13:16–13:37

CHEMISTRY IS IMPORTANT

So now moving fast, I hope you see why a basic understanding of chemistry is important to understanding our ancestry. I mean stars are pretty much your great-great-great-et cetera grandparents. And you wouldn't ignore your grandparents, would you?

Mr. Green, Mr. Green, no, no way, I mean they're a big part of my plan to get a car for my 16th birthday.

That's really touching, me from the past. Also I've got bad news for you.

13:38–14:07

WE EXIST BECAUSE OF STARS

So in today's episode, we've learned that everything around us, everything that we can touch, and feel, and see, even us, is debris floating around enormous stars in the vacuum of space. We clump into specks, we change form, but we owe our entire existence to these burning, gassy balls that we see in the night sky.

We may just be the ashes of dead stars, but those ashes hold the potential to arrange themselves in increasingly complex ways from which the Earth and all it contains can arise, but more on that next time.