Exploring the Universe: Crash Course Big History #2

Crash Course: Big History
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Hi, I'm John Green and this is Crash Course Big History. Today we're gonna 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.

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

John: 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 gonna 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 gonna need some chemistry.

(Intro)

(0:52) 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!

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, mmm. Ugh!

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!

(2:29) Hank: Indeed! A liberal dose of hot sauce was yet to come! Hydrogen and helium though, are light gasses. 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 cosmos back together... Provided it has some wrinkles in the universe to work with.

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 am 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.

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 the Kepler space telescope has revealed, a mind-numbing number of planets.

(3:50) John: 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 10 billion years ago. Our galaxy's 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 gonna stay, just peeping out on the rest of the universe.

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, has closer to a trillion stars, is actually said to collide with us in 3.75 billion years. But don't worry, this isn't gonna 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 gonna 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.

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 thousand light years across. And the giant elliptical galaxy, excitingly named M87 - because astronomers are so good at naming things - is 980 thousand 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 Supercluster 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, Superclusters in the universe. Wait, literally infinite? Wow!

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 and galaxies.

Mind you, the light we observe billions of years after it's 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 thousand light year galaxy!

(Just for a little bit of context, the circumference of the earth is less than one fifth of one light second.) 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!

John from the past: What?!

John: 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 an anti-climax 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. 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!

(8:22) Hank: 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.

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 60-100 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 5 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. But elements heavier than iron can't be created in 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, 8-60 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 combined with proton and neutron capture, supernovae 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.

(10:21) John: 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 jewellery store - a nice person sold it to me, a jeweller 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 slither 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 Sarah and I spent $450 on this which we could have spent on an Xbox!

(11:58) Emily: Tiny wrinkles in the early universe had a major impact on one of the unifying themes of 13.8 billion years - rising 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 in 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 can arise - none whatsoever. 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 sized 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 than spans cosmology, geology, biology and human history would have a unifying theme, but rising complexity is something that stretches across all 13.8 billion years... And it began with those tiny wrinkles in the early cosmos.

(13:13) John: So now, moving past, 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-great-great-great-great-great-great-great-great-great etc grandparents! And you wouldn't ignore your grandparents, would you?!

John from the past: Mr Green, Mr Green! No- no way! I mean, they're a big part of my plan to get a car for my sixteenth birthday!

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

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 rise. But more on that next time!