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WHAT EMERGED FROM THE BIG BANG?

David Christian explains how the Big Bang theory developed during the 20th century. This three-part lecture focuses on how the evidence for the expansion of the Universe discovered by **Hubble**, and the discovery of the **cosmic microwave background** by **Penzias and Wilson**, helped convince astronomers that the Big Bang was a good, logical, evidence-based explanation for the beginnings of the Universe. The lecture also looks at what scientists currently believe happened during the Universe's infancy. After reading the text below and watching the video, you should be able to explain these turning points and the evidence that supports the story of the Big Bang.

Key questions

1 As you read and view this lecture, pay attention to the key turning points in the early stages of the Big Bang: the moment of the Big Bang, the first few seconds after the Big Bang, and 380,000 years after the Big Bang. What can be said about each of these points in the story? Why are they important to the story of the Big Bang?

2 What evidence supports the descriptions scientists give of the key turning points in the story?

Transcript: Part 1

0:12-1:09

HUBBLE'S DISCOVERIES FORM THE FOUNDATION OF THE BIG BANG THEORY

Think about this: Edwin Hubble, building upon generations of work in astronomy and lots of new evidence, came up with a very simple idea about the Universe, and the idea was the Universe is expanding. But when you start thinking about that idea, it's really mind-boggling.

For example, what it means is that everything in the Universe — every galaxy, every star, every planet, every atom in your body — was squashed into a tiny space probably smaller than an atom, certainly smaller than the smallest dot you could make on a piece of paper.

Now that was an idea so strange that even many scientists in Hubble's time struggled with it. But some scientists thought the evidence was so compelling that they started looking at this very carefully, and slowly, using logic and the evidence available, and sometimes new evidence, they began to figure out what might have happened in such a Universe.

1:09-2:06

BEGINNINGS OF A THEORY

Hubble had already figured out that if you could calculate the speed at which the Universe was expanding, you could calculate when it was formed. Now think about it: that's actually quite amazing. It means he was saying you could calculate the Universe's birthday. That's fairly amazing.

Some scientists then began to think we can figure out what things might have been like at the Big Bang. And they figured out pretty soon if you have all the energy and all the mass of the Universe in one tiny space, it had to be incredibly hot, billions of degrees hot. It also had to be very dense, and it had to be expanding so fast that it would have been a bit like an explosion. Now it was this image that encouraged an English astronomer, Fred Hoyle, who was always a skeptic about this theory, to describe this, jokingly, as the "Big Bang" theory. Well, he was being satirical, but the name has actually stuck.

2:06-3:12

NUCLEAR WEAPONS AND THE BIG BANG

Then some scientists began to try to figure out what matter and energy would be doing under these extreme conditions. They got a lot of help because during World War II a lot of people worked on atomic weapons, and atomic weapons are all about extreme conditions. Einstein had already shown that under extreme heat and temperature, matter and energy are interchangeable. They change into each other. So this was the first thing they found out. At the very beginning the Universe must have been a sort of blur of energy and matter.

They also realized that as the Universe expanded, it would have cooled. And they knew that matter and energy behave in different ways at different temperatures and pressures. Slowly they began to figure out the precise temperatures and pressures in the first few moments of the Big Bang. And in this way they managed to construct a good, logical, evidence-based story of what happened during the Big Bang. So let's look at that story.

3:12-3:42

BEFORE THE BIG BANG

About the exact instant of the Big Bang, there's nothing they could say, and we still don't know how to explain it today. We can't explain the exact moment of the Big Bang, what happened before, or why the Big Bang happened. Cosmologists have lots of ideas about this but, frankly, no real evidence. So Big Bang cosmology can't do any better than any traditional origin story in explaining why the Big Bang happened or what happened at the instant of the Universe's creation. But from a split second after that they can tell a very good, evidence-based, logical story.

Transcript: Part 2

3:46-4:59

THE FOUR FUNDAMENTAL FORCES

We believe that everything appeared in the Big Bang, including even time and space. And at first things are happening incredibly quickly. We begin our story, in fact, at a billionth of a billionth of a billionth of a billionth of a second after the Universe first appears. Everything is off the charts. The Universe is gazillions of degrees hot, it's incredibly dense, and it's expanding as fast as you can imagine. But as it expands it cools, and as it cools distinct forms of energy begin to appear.

Four main forms of energy, we call these the **four fundamental forces**. The first is **gravity**; that's the force, remember, that Newton identified. It appears a billionth of a billionth of a billionth of a second after the Universe is created. Then **electromagnetism** appears; that comes with positive and negative charges. And of course it's the force we are all familiar with: it's basically electricity. Then we get the third and fourth forces, the **strong** and **weak nuclear forces**; these operate over tiny distances, but they bind the center of "nuclei" together in atoms.

4:59-6:14

ENERGY AND MATTER

THE INGREDIENTS OF AN ATOM

Now some of this **energy** congealed to form the first **matter**. Remember, energy is what makes things happen. Matter is the "stuff" of the Universe, its basic constructional material. The first forms of matter were probably **quarks**. But quarks instantly combined in triplets to form **protons** — which have positive charges, electrical charges — and **neutrons**, which have no charges at all. Protons and neutrons will make up the **nuclei** of all atoms. Very quickly **electrons** also appeared; these are much lighter than protons and neutrons, and they have negative charges. But, despite the fact that protons and electrons have opposite charges, they can't yet combine because there is just too much going on, there is too much energy.

So we enter what scientists call a **plasma universe**. All of this happened in just a second or two. The Universe is now a mere 10 billion degrees hot. It's still very dense. It's probably about a hundred thousand times as dense as a piece of rock. So if I were to grab a piece of the Universe the size of this rock, it would probably weigh about as much as 25 elephants.

6:14-7:17

THE PLASMA ENDS ATOMS FORM

The Universe we've seen is also a plasma. All the matter is in the form of a plasma, that is to say, it is dominated by charged particles — protons and electrons. And because they're charged, it's as if the Universe is full of velcro, and they sort of cling onto **photons** of light, photons of electromagnetic energy, as they try to pass through. So the Universe is very different from today's Universe. Light cannot move freely through it, and you cannot form atoms, which are the basic building blocks of our Universe.

Then, about **380,000 years after the Big Bang**, the plasma ends. This is a very important sort of mini-threshold in the story for us for two reasons: first, when the plasma ended you could form atoms; and secondly, the ending of the plasma provided a powerful new piece of evidence for Big Bang cosmology.

7:17-8:25

COOLING CREATES CONDITIONS FOR ATOMS TO FORM

Let's look at the first reason why the ending of the plasma is so important for our story: the creation of atoms. About 380,000 years after the Big Bang, the temperature of the Universe has dropped to about 3,000 degrees; that's about the temperature at the surface of cooler stars. At that temperature, the charges of protons and electrons are powerful enough to bind them together. So suddenly, instead of a plasma, the Universe fills up with electrically neutral atoms because those two charges cancel each other out in each atom.

HYDROGEN AND HELIUM COME FIRST

Now let's pause for a moment to think about atoms. The first two types of atoms we get are **hydrogen** and **helium** atoms. Hydrogen atoms have one positively charged proton at the center and sometimes a neutron. Helium atoms have two positively charged protons and usually two neutrons. And whizzing around the centers in both types of atoms we have electrons, generally as many electrons as there are protons, which is why the charges cancel out.

8:25-9:18

THREE DRIVERS OF ATOMIC SCALE

I'd like to read you a wonderful description of an atom, by Natalie Angier, which will give you some sense of its structure. She writes: "If the nucleus of an atom were a basketball located at the center of Earth, the electrons would be cherry pits whizzing about in the outermost layer of Earth's atmosphere." So that's the sort of image of atoms that you should have in mind when you think about them.

Now because atoms are neutral, suddenly photons of light can move freely through the Universe. The velcro's gone; they don't get tangled up with charged particles. And that leads to the second reason why the ending of the plasma is so important for our story. It provided great evidence in support of Big Bang cosmology.

Transcript: Part 3

9:22-9:53

380,000 YEARS AFTER THE BIG BANG

Back in the 1940s some scientists had already figured out that as the Universe cooled there would be a moment when suddenly all the matter went electrically neutral, and at that point photons of light would be able to move freely through the Universe. And they figured out there would be a sort of flash of energy, and some even said, Why not look for that flash? It would be powerful support for Big Bang cosmology. But, strangely, no one went looking for it. And that's probably a sign that most scientists still regarded the idea kind of skeptically.

0:40-2:03

COSMIC RADIATION CLINCHES THE BIG BANG THEORY

Then in the 1960s, two astronomers, **Arno Penzias** and **Robert Wilson**, who were trying to build a very sensitive radio receiver, suddenly stumbled upon this flash of energy. Wherever they point their radio receiver, suddenly they've got this sort of hiss of energy, it comes from everywhere in the Universe, and it's extremely uniform. Now think about it for a moment; that is very strange. If you point towards the Universe, and you point towards a galaxy, you expect to detect energy. But even empty space? That was really weird. And at first they couldn't understand it. Then they talked around to one or two astronomers, and finally someone said, "I think you've found the flash of energy that was predicted back in the 1940s." It was a very exciting moment in science.

Now this was extremely powerful evidence for Big Bang cosmology because what it supported was a very strange prediction made back in the 1940s. And no other theory could explain why there should be this energy or where it could come from. And that's the moment at which most astronomers finally decided, yes, Big Bang cosmology is real, it's telling a real story about the real Universe.

11:16-12:10

SCIENCE IS BASED ON CLAIMS

Since then, many other forms of evidence in support of Big Bang cosmology have appeared, but still today Hubble's evidence and the evidence of the **cosmic background radiation** are the single most powerful single pieces of evidence to support Big Bang cosmology.

The story we have just seen is one we are going to see over and over again in the history of science. Someone comes up with a new claim about reality, and it's based on logic and it's based on evidence, but there is not quite enough evidence. So people around them treat it as interesting but they don't take it terribly seriously. And then, gradually, new evidence appears, and at a certain point suddenly everyone thinks, Oh yeah, I think this is the way things really happened, and then their claim becomes a new **orthodoxy**. We are going to see it over and over again in this course.

12:10-13:10

THE BIG BANG IS THE FIRST THRESHOLD OF COMPLEXITY

Now I would like you to think about the story we have just been telling. It's actually amazing. We humans, by sharing information over many generations, have slowly constructed a good, powerful, evidence-based story, not about what happened 10 years ago, or 100 years ago, or even 10,000 years ago, but 13.7 billion years ago, at the moment the Universe was created. Now I don't know about you, but I think that is quite mind-blowing.

Okay, so let's sum up: The Big Bang created everything around us, all the matter and energy. So it created the foundations for building further complexity later on. That's why it counts as the first major threshold in our course. After all, the move from nothing, before the Big Bang, to something, after the Big Bang, has to count as an increase in complexity.

In the next unit, we will look at the next major threshold: the creation of stars.