

This thing is -270°C and is EVERYWHERE

Youtube Video Script written for Physics Girl, 2020. [Watch the video here.](#)

We eliminated just about everything, and then the only possibility was that it was coming from someplace outside our galaxy, and that seemed like such a far-out idea. We just didn't know what to do with that result. Hey, I'm Diana, and you're watching Physics Girl. There's this thing that's all around us, literally everywhere at all times. It's on Earth, it's in our solar system, it's in the whole universe. This stuff is actually a signal. It is utterly bizarre and was discovered by accident. Let's take it back to the 1960s in Bell Labs in New Jersey. Two radio astronomers, Robert Wilson and Arno Penzias, were working on radio communications using a sensitive microwave antenna. When the antenna was ready, they turned it on for a test and noticed something odd: a constant messy background noise.

They tried pointing the antenna in a different direction to try to get rid of this unexpected background, but got the same exact noise—same strength, same frequencies. They even scrubbed the antenna thoroughly clean because they thought it could be pigeon poop. No joke, but alas, it was not poop. So they had a mystery, an unchanging noise no matter which direction the antenna was pointed, a noise independent in time, and they had no idea where it was coming from. Eventually, they got in touch with a research group at Princeton University led by Robert Dickey and learned the origin of the noise. They were picking up the cosmic microwave background signal. I get chills talking about this because wait till we get to the significance of what they just discovered. What the heck is it?

Well, it's a signal from the beginning of the universe. It's a type of radiation that could only be caused by a strange and unique process right after the Big Bang. So let's dig into that. The first thing that we need to understand about the cosmic microwave background, or the CMB, is that it is everywhere, absolutely everywhere in the universe at all times; hence, cosmic. The other clue from the name is that it's made up of microwaves or electromagnetic radiation, just like red light or green light, ultraviolet light, X-rays, all that stuff, all electromagnetic radiation. But this signal was in the microwave range, which has wavelengths of millimeters to centimeters. Yes, I'm talking about the stuff that's used in your microwave oven to heat up popcorn and soup.

And as far as light goes, that's actually a pretty long wavelength, so it's on the colder side. I think the next question a lot of people ask when they hear that there's radiation flying around everywhere, like the CMB, is should we be worried? No, the CMB is everywhere, yes. But it has way less energy than you would need to turn the entire universe into a gigantic microwave oven. That would be cool, though, I mean hot. This omnipresent microwave radiation was so bizarre when they discovered it that they thought it was a mistake. So where did the CMB come from and how did it get to be everywhere? This is a question that cosmologists, or the people that study the beginning of the universe, care about a lot because the CMB tells us a lot about the origin of our universe.

The source of the CMB goes all the way back to the beginning of everything, nearly all the way back to the Big Bang. So let's start there. Right after the Big Bang, the universe was hot, very, very hot. And it was densely filled with matter and antimatter, all kinds of particles and radiation. There were electrons and protons, but they were not able to combine into atoms because whenever an electron and proton got close enough to bond, they'd be knocked apart by the many energetic photons flying around, so the universe was essentially opaque. It was so dense. Light couldn't make it through because it was constantly bumping into the primordial plasma. Plasma is just a cloud or a gas of charged particles, so it's just referring to those free electrons and protons.

The early universe was just a bunch of plasma, particles, and radiation, and radiation. And we're gonna ignore the other stuff like dark matter and dark energy for now. But the point is the universe was incredibly dense, very homogeneous, which just means that if you took any small sample of universe from over here, it would likely look just like any sample of universe from over here or anywhere across the universe. And it was very isotropic, which means that if you look in any direction, the universe would essentially look the same. And it was hot, as we said. Remember that because the early universe was then expanding quite fast. And what happens to things when they expand? Well, if you've ever discovered the magic of dry shampoo,

like I have, when you spray it from the can or use any compressed can of gas, you notice the can immediately gets colder because you're letting the pressure drop in the can when you allow the contents to expand. There's a bit more to this process, which Henry from MinutePhysics does a great job explaining in this video, which you should definitely check out. But the point is, releasing the pressure on a gas or plasma tends to cause it to cool down. Come feel it. Ah! It's so cold! Oh my gosh. Ah! Now, the early universe went through an intense initial expansion, which you can now piece together from my excellent metaphor about dry shampoo, meant that it was cooling down.

The universe is still expanding and cooling now, today, but it was doing so at an extreme rate back in the day, before there were days, because there was no Earth yet. As the early universe expanded, there was more space for all the energetic particles. So then, after about 380,000 years, the universe had cooled enough for electrons, neutrons, and protons to start combining into atoms, an epic called recombination, which is kind of misleading because they weren't recombining; they were combining for the first time. But whatever. So then, some of the light that before was blocked from flying free in the hot, dense universe was finally able to start traveling across the universe, unobstructed. That light has been traveling across the universe since the moment of recombination, 13.

8 billion years ago, and that is what we see today as the cosmic microwave background radiation, which is the whole point of this entire video. But there's more, because when it first began, the cosmic microwave background was not so microwavey. It had wavelengths with a peak in the infrared, so actually, some of the light would have been in the visible part of the spectrum. We would have been able to see our entire universe glowing with our own eyes if it had been a strong enough signal and if we'd been around. But how is that possible if it's the

same light? Well, as the universe further expanded, this light, which was everywhere, got redshifted. Yes, this happens. As light travels across space that's expanding, it will get to its destination appearing with a longer wavelength.

So the wavelength of the CMB light is much longer than when it started. But now, that radiation is in the microwave range, and eventually, it'll expand into radio wavelengths and be the cosmic radio background. This was all detected by accident. Even so, the two scientists who worked on that first radio antenna in 1964, Wilson and Penzias, ended up winning the Nobel Prize for the discovery. Not bad, so the mystery signal, in the end, was a portrait of the Big Bang. You would need a camera that can detect microwaves in order to capture that portrait, but oh wait, we've done that. Scientists have sent specialized probes into space to create complete images of the CMB. The first such probe was NASA's Cosmic Background Explorer in 1989, and then in the early 2000s, NASA sent up the Wilkinson Microwave Anisotropy Probe.

It would take those oval maps of the CMB. Then the ESA's Planck spacecraft took over imaging the CMB in even more detail. We can learn a ton of information from these maps, like the strange slight temperature fluctuations in the early universe, which are tiny. The current average temperature of the CMB is 2.7 Kelvin, and the relative variations are only on the order of 10 to the minus four. We talked about how the early universe was homogeneous, so these variations could give us insight into quantum fluctuations or random blips in the early universe. The fluctuations also hint at the existence of dark energy. We don't know exactly what dark energy is, but we do know what it's doing, accelerating the expansion of the universe.

One way the CMB can help understand dark energy better is through the Sanyayev-Zel'dovich effect, or SZ effect for short or EASE. The SZ effect is caused by distortion of the CMB by stuff that it passes through, like galaxy clusters. Photons scatter off the gas in galaxy clusters, affecting the brightness of the CMB map in some places. So with the help of the SZ effect, we can find galaxy clusters, which in turn helps us understand the effect of dark energy on how the universe is expanding. We can learn other things too, like how the CMB is blue-shifted on one side and red-shifted on the other side, which means we can measure how fast our Milky Way galaxy is moving through the universe. It turns out to be around 600 kilometers per second.

That's fast. The CMB has cooled off significantly from 3,000 Kelvin at recombination to three Kelvin now. So we can't use it for popping corn, but we can still see it in an old-timey television. A small percentage of the snow static you can see is due to the CMB. The CMB was groundbreaking. It was solid, strong evidence that the Big Bang really happened. It's this fossil of our universe from when it was only 380,000 years old. And now, billions of years later, we see it everywhere, and it provides an exciting new pool of information about our universe. Thanks for watching and happy physicsing. Hey, fizzlers. Just trying that out. If you like Physics Girl videos, I have a feeling that you will love Nova, which is available on the PBS video app. If you live in the US and you have one of these or any other device where you can stream the internet, you can find Nova plus 4,000 other PBS shows. Not bad. I dare you to watch all of them. Check out the link in the description to find the best of PBS to stream whenever you want.