Astrophysics and Cosmology: Crash Course Physics #46

Crash Course: Physics
https://youtube.com/watch?v=VYxYuaDvdM0
https://nerdfighteria.info/v/VYxYuaDvdM0

(0:02) After a year of studying the laws of the universe together, a year of studying and calculating, learning about motion and fluids, thermodynamics, electricity and magnetism, light and sound, we find our selves here - space, the final frontier.

(0:16) We're all voyagers on a mission to understand the universe using the power of physics. And even though we've been doing it for centuries, there's so much we have to learn about the cosmos. Some of the most exciting research in physics today is being done by astrophysicists and cosmologist.

(0:30) Astrophysicits study the physics of celestial bodies, such as planets, stars, and galaxies. Their research takes us inside phenomena like black holes and supernovae, but we can use physics to try and understand even bigger questions about the universe.

(0:44) Cosmologists study the universe overall and ask questions about the origin of everything as well as its future. It's their job, and yours, to continue looking into the night sky, searching for answers using the tools and knowledge that physics can provide.

(0:57) *Intro song*

(1:08) Before we can talk about something as big as the universe, we need to be able to describe just how big it is. When talking about things on Earth, we typically use measurements in the range of nanometers to kilometers. But when we're in space, we need something a whole lot bigger. For instance, I could say that the nearest star to the Earth, besides the sun, is 4×10^{13} kilometers from us. But that's a mouth full for something that's basically right next door, in cosmic terms. So it's easier to say that this star, Proxima Centauri, is 4.2 light years from Earth.

(1:37) A light-year is a unit of length, with one light-year equaling the distance that light would travel in a vacuum in one year. If you take the speed of light, about 300 million meters per second, and multiply it by how many seconds there are in a year, you find that one light-year is approximately 10^{16} meters, or ten million billion meters.

(1:56) To give you a sense of scale it takes light just over eight minutes to travel from the sun the Earth. And the milky way is roughly 100,000 light-years in diameter. Sometimes we also use a unit called a parsec, which is equal to 3.26 light-years. Now when we say that Proxima Centauri is 4.2 light-years away, this also means that when we look at the star through a telescope, we're seeing what Proxima Centauri looked like 4.2 years ago. It takes light that long to get here from Proxima Centauri, so we'll never know what that star, or any star or other distant object looks like at this exact moment. This means that as we observe celestial objects far away, we're looking into the past, seeing what stars and galaxies looked like millions if not billions of years ago.

(2:39) While we're observing these stars, we can use a spectrometer, the device that separates wavelengths, to reveal the star's absorption spectrum and its elemental composition. But when we study very distant bodies, we find that their absorption spectrum is slightly different from what we'd expect given our knowledge of typical star compositions.

(2:56) Remember the Doppler effect, how the pitch of an ambulance siren becomes higher as it approaches you and lower as it moves away. The same effect happens with light. If an object is moving away from you the speed of light doesn't change, but the peaks of the electromagnetic wave that it emits move farther apart. This effect, which occurs with light emitted by an object moving away from Earth, is called red shift because the longer the wave lengths get, the closer they are to red part of the visible spectrum.

(3:21) Once astronomers recognized and could measure red shift, they found that the spectrum from nearly every distant galaxy was red shifted, meaning that every galaxy was moving away from us.

(3:31) And if that wasn't strange enough, astronomers, such as Edwin Hubble, noted that the amount of red shift is proportional to the distance from Earth. So the farthest galaxies are moving away even faster than the close ones.

Georges Lemaître, a Belgian physicist, proposed this relationship as Hubble's Law. It expresses the velocity at which a galaxy is speeding away from Earth, in terms of its distance from us. The equation uses a proportionality constant called the Hubble parameter, which says that for every million light-years of distance from us, a galaxy is moving away at an additional 21 kilometers per second. Now, the fact is that nearby galaxies might be going away from us or toward us, based on how they're moving within their local cluster. But the overall tendency for distant galaxies to recede from us is much more common, so Hubble's Law holds true in most cases. And this trend of distant galaxies moving away from us, and from one another, is called cosmological redshift. By the way, this expansion looks the same whether you're on Earth or not. No matter where you are, all distant galaxies appear to be moving away from you. So this leads physicists to believe that at some point in time, all the stars and galaxies were closer to one another – a lot closer.

In the 1940s and 50s, Russian-American physicist George Gamov, developed a theory of the early universe that explained, among other things, why so many light elements, like hydrogen and helium, were observed throughout the cosmos. He suggested that the universe began in a state of highly compressed hot plasma – a sort of hot soup of elementary particles. His theory became known, somewhat dismissively by his colleagues, as the Big Bang Theory. And this same theory ultimately predicted that there should be radiation left over from the initial, rapid expansion of that compressed plasma. This is because hot plasma, like the plasma in the flame of a candle, is not transparent. But ordinary gas – like the air around a candle's flame – is transparent, and it lets light travel freely through it. So it would make sense that the early, hot universe was originally opaque, until it cooled down to the point where it became transparent. Once that happened, the thinking goes, light from the Big Bang was able to travel freely. But its wavelength kept stretching out, red shifting until it could only be detected as microwave radiation. Gamov's theory didn't gain much acceptance, and it was largely forgotten. Until, in 1964, American astronomers Arno Penzias and Robert Wilson pointed a radio antenna into space, and they discovered cosmic microwave background radiation. They basically discovered the radiation from the Big Bang, by accident. They found that a low-energy microwave radiation persisted at all times, day and night, and they concluded that the source of the radiation was the universe itself. This cosmic background radiation provides support for the Big Bang Theory, and it tells us a lot about the conditions of the early universe.

Thanks to these insights, along with the observed expansion of the universe and other evidence, we have learned that the universe began in a hot dense state, then cooled, and produced galaxies and clusters that we see today. However, many mysteries remain. For instance, if the universe started with such high density and temperature, wouldn't gravity make its expansion slow down? The fact is, the rate of expansion would slow down only if the universe was filled with nothing but matter and radiation. But that's not the case! Space is filled with a constant – or at least, slowly varying – form of energy known as dark energy. And because of the pervasive presence of this energy, according to general relativity, gravity is actually causing space to expand, and accelerate! This isn't just theoretical. Recent evidence suggests that the universe actually IS accelerating in its expansion, showing no signs of

slowing down. But beyond the fact that it exists, there's not much that we know about dark energy.

Another one of the universe's great mysteries is the existence of mass that we can't see, but we know that it, too, exists. When we study a galaxy's rotation, we can estimate how much mass is in it by measuring its radius and rotational velocity. But when we actually calculate that mass, the result is far greater than what's observable as stars and gas. The conclusion is that there's an immense amount of mass in the universe known as dark matter, which doesn't reflect or emit any light. By current estimates, dark matter makes up almost 85 percent of all the matter in the universe. This means that all visible matter, including stars and planets, make up just a small percentage of all energy in the universe, while the rest is mysterious dark energy and dark matter. Research in these fields is ongoing and new evidence is found every year, refining our understanding of the universe.

In the past year here on Crash Course, and for thousands of years, we have used physics to answer some of life's most important questions. Whether it's a ball flying through the air or the origin of the universe, we can use our knowledge from Newton's Laws to special relativity in order to move closer to the truth.

And there's still so much to discover, both in the stars and here on earth. Some of the most ground breaking research is happening on the smallest scales, as physicists seek to understand the building blocks of our universe and the nature of matter itself. It's not an easy task, and it's why we need scientists and enthusiastic supporters such as yourself to go out, be curious, ask questions, and to find answers through scientific methods.

Today we learned about light-years and how looking in the distance is also looking into the past. We discussed redshift and used Hubble's Law to calculate how much certain parts of the universe are expanding away from us. Finally, we introduced the Big Bang, cosmic background radiation, and the mysteries of dark energy and dark matter. Bye!

Crash Course Physics is produced in association with PBS Digital Studios. You can head over to their channel to check out a playlist of their latest amazing shows like The Art Assignment, Gross Science, and Deep Look. This episode of Crash Course was filmed in the Doctor Cheryl C. Kinney Crash Course Studio with the help of these amazing people and our equally amazing graphics team, is Thought Cafe.