Cosmology

Transcript

http://quantumspotacademy.org/videos/cosmology/

The most epic story the universe will ever know is none other than the story of the universe itself. Where did the universe come from? What's it like now? And what will be its ultimate fate? People have been asking these questions for millennia and physics offers some tentative answers in the field of cosmology.

Questions about the universe have captivated great thinkers since the beginning of human cognition and they have theological and philosophical implications, but we will examine the issue from a strictly physical standpoint. Naturally, we don't have all the answers — cosmology is at the forefront of physics today — but physics has revealed some intriguing insights about the universe we live in.

As with any great epic, the best place to begin is the beginning. How did the universe begin? What happened before the universe existed? For that matter, did the universe have a beginning at all? Could it be that the universe has simply always existed? Most importantly, what can we do to try to find out? To answer questions like these, physicists rely on making careful observations of the physical world in order to construct mathematical models.

Some important cosmological observations were made in the early 1900s, when physicists measured the movements of distant galaxies. They were surprised to notice that almost all of the galaxies they observed were moving rapidly away from our own galaxy. Furthermore, the farther away a galaxy was, the faster it moved away from us. From these observations, physicists conjectured that the universe itself was growing and expanding in all directions and that the galaxies were moving away from each other as a result of this expansion, just like points on the surface of a balloon move apart as the balloon expands.

They reasoned that, if the universe is currently expanding, and we assume that it always has been, then in the past, the universe must have been much smaller than it currently is, and at some point, about fourteen billion years ago, the entire universe must have been crammed into a very tiny size — possibly a single point. According to this theory, called the Big Bang theory, the universe would have originated in a rapid

© 2014 Quantum Spot Academy All rights reserved.

expansion. Many physicists were intrigued by this possibility and began to explore some of its implications.

According to the Big Bang theory, there must have been a time shortly after the Big Bang when there was so much matter and energy in such a small space that light would have been unable to travel freely, and for this reason, the entire universe would have been completely opaque. Only after 380,000 years would it have cooled down enough for light to travel freely. At this point, the universe would change from opaque to transparent, as we know it today. The mathematical models of the Big Bang theory informed physicists that the universe should be permeated with a faint radiant energy as a result of this transition.

Then, in 1965, two physicists using a very sensitive telescope discovered an unexpected static. At first, they assumed something was wrong with their measurements, but they couldn't find anything that would be causing the background noise. You can imagine their surprise and delight when they finally realized that the unexpected static from their telescope was the very signal that was predicted by the Big Bang theory. They had accidentally identified a faint relic from the dawn of the universe, billions of years ago.

The discovery of this cosmic microwave background radiation, as it is called, provided convincing support for the Big Bang theory. Since the time of that discovery, much more evidence has corroborated the Big Bang theory and it is currently accepted as the most accurate representation of the universe's origins.

Now, if the Big Bang happened fourteen billion years ago, then the next obvious question to ask is: what happened before the Big Bang? The short answer to this question is that we just don't yet know. It could be that the beginning of our universe was the end of another universe directly before ours. If this is the case, then someday we might be able to analyze the signals from the early universe for indications of some previous existence. Or, it could be that the Big Bang was the beginning of time itself. If this were the case, then there would be no such thing as "before" the Big Bang, just as there's no such thing as north of the North Pole.

But however it happened, we know that the Big Bang was an unimaginably violent event. It's important to remember, though, that the Big Bang wasn't an explosion of all the matter in space; rather it was the rapid expansion of space itself. It's hard to imagine, but that's exactly what happened.

Soon after the Big Bang, we know that there was a tremendous amount of energy in a hot particle soup that expanded along with the universe. The rapid expansion effectively

© 2014 Quantum Spot Academy All rights reserved.

cooled the plasma and allowed it to coalesce into small atoms (hydrogen, helium, and lithium). Interestingly, the mathematical models of the Big Bang theory predict that the universe should contain certain proportions of these elements as a result of the cooling process, and when we measure the quantities of different elements in outer space, we find the same proportions predicted by the theory. This is another example of strong corroborating evidence for the Big Bang.

As the universe continued to expand and cool, gravity pulled those small atoms together into gaseous blobs. When the blobs became big enough, their inward gravitational pressure ignited nuclear reactions in their cores, turning them into stars. These stars then clumped together into galaxies, and the galaxies formed clusters. Now, so far we've only accounted for the presence of three chemical elements — hydrogen, helium, and lithium — because they were formed shortly after the Big Bang. But where did all of the other elements come from? Where did we get all of the carbon, nitrogen, oxygen, phosphorous, sulfur, iron, silicon, magnesium, and dozens of other common elements?

Well, it turns out that all of the other elements on the periodic table are manufactured inside of stars when they die. When a star runs out of energy at the end of its life-cycle, it collapses onto itself. The intense inward force fuses hydrogen and helium into the other elements. The star then bounces off of its core in a massive explosion called a supernova. A supernova is an astonishingly energetic event; a single supernova explosion can outshine all of the other hundreds of billions of stars in its galaxy. During a supernova, all of the elements that were generated in the star's core are expelled into a giant cloud of matter. Eventually, gravity can pull some of that matter together into large massive bodies, and that's exactly how the earth and the other planets were formed. Just think — all of the atoms that make up the earth and everything on it originated in a supernova. In a way, we are made of stardust. We are constructed from the ashes of a primeval star explosion.

Physicists have been able to learn a lot about the organization of matter in the universe, but there's a slight inconsistency with the current theories. You see, the only reason galaxies are kept from flying apart is because all of their constituent stars are attracted together gravitationally. This mutual gravitational attraction acts like a sort of cosmic glue, holding galaxies together. However, when physicists measured the amount of matter in different galaxies, they found that it was vastly less than they were expecting. There wasn't enough mass to hold the galaxies together, and yet none of them seemed to be falling apart. This led to the conjecture that there's some invisible matter called dark matter, that's helping to hold galaxies together. Dark matter could just be normal matter that's hard to see for some reason, but most physicists believe that it's an

© 2014 Quantum Spot Academy All rights reserved.

altogether new form of matter made of weakly interacting massive particles (or WIMPs fir short). Although very little is currently known about what dark matter is made of and where it came from, there is growing evidence that it's very common, perhaps making up over eighty percent of all the matter in the universe.

Well, this brings us to the middle of our story of the universe and to the profound question: what is the nature of the universe? We've already discussed the contents of the universe (atoms, stars, galaxies), but what are the properties of the universe itself?

Physicists often describe the universe as four-dimensional. There are three space dimensions and one time dimension, that make up a four-dimensional continuum called space-time.

Now, it turns out that space-time is flexible kind of like a rubber sheet and it can be warped and stretched by its contents. Space-time is kind of like a trampoline. Just like heavy objects can make a trampoline bend, matter and energy warp the fabric of space-time. Then the resulting space-time geometry can affect other objects nearby. This was summarized very eloquently by a physicist named John Archibald Wheeler who said that "space-time tells matter how to move; matter tells space-time how to curve." Although this might sound quite fantastical, it's very true and we notice its effects daily because the warping of space-time is what we call gravity. For example, the mass of the sun warps the space-time around it and the earth is held in orbit because it reacts to the shape of the local space-time.

So, matter and energy can cause local distortions in space-time, but space-time might also have some natural curvature to it. By analogy, there are mountains and valleys on the surface of the earth, but the earth also has a global curvature, since it's a sphere. So what's the overall curvature of the universe? Well, broadly speaking, there are three possible cosmological geometries: closed, open, and flat.

With a closed geometry, space-time would curve inward onto itself like the surface of the earth. Now, since we're talking about the curvature of space *and time*, the curvature of space-time has some important implications regarding the future of the universe. In the case of a closed geometry, the universe's expansion would slow down and eventually reverse, collapsing back in upon itself in what's called the Big Crunch. This would be like the Big Bang in reverse. Much like the big bang, we really don't know what if anything would come after the Big Crunch.

With an open geometry, space-time would be infinite, curving away from itself in all directions. The universe would continue to expand faster and faster forever. If the

© 2014 Quantum Spot Academy All rights reserved.

acceleration were great enough, then the matter in the universe would eventually be violently torn apart in what has been called the Big Rip.

With a flat geometry, space-time would have no overall curvature. In this case, the universe would continue to expand forever, avoiding the Big Crunch and the Big Rip.

So how do we evaluate these possibilities and predict the most likely future of the universe? Well, this is at the cutting edge of cosmology today and there really aren't any definitive answers yet. One speculation is that the universe's geometry can be modeled as a balance between the universe's expansion and a sort of gravitational drag exerted on the universe as a result of the mutual gravitational attraction between all of its constituents. According to this theory, if the drag is strong enough it will overcome the expansion, resulting in eventual collapse and a closed geometry. If it's insufficient, then the universe will expand forever in an open geometry and if the two are in perfect balance, there the universe's geometry would be flat.

When physicists measured the expansion rate and the amount of matter in the universe, they deduced that there should be enough matter to reverse the expansion, resulting in an eventual collapse. However, the latest measurements indicate that the universe isn't slowing down at all. In fact, it appears to be rapidly accelerating.

It's as if there's something in the universe that's causing an outward expansive energy, contributing to the universe's acceleration. This mysterious substance has been called dark energy and, like dark matter, it's very prevalent. In fact, it appears that dark energy makes up about 71% of the universe's constituents, while dark matter makes up another 24%, leaving a mere 5% for normal matter like stars and planets. It looks like we still have a lot to learn about the universe.

Some people think that dark energy doesn't exist at all and those who do believe in it disagree about what it is and what it's made of. It could be that the universe's expansion isn't the result of some physical substance, but is simply a property of space-time that we haven't yet discovered . Until we resolve the mystery of dark energy, the fate of the universe will remain somewhat in doubt.

The truth of the matter, though, is that even if we avoid the Big Rip and the Big Crunch, our universe is not immune to eventual destruction. Unfortunately, a gradual decay called the Big Freeze will catch up with us eventually. As the universe expands larger and larger, it will continue to cool, just like it always has since the Big Bang. Eventually, all of the stars will die out and there will no longer be sources of useful energy to sustain life. The entire universe will be dark, cold, and barren. Although the universe came into

© 2014 Quantum Spot Academy All rights reserved.

existence with a bang, it might go out with an anticlimactic fizzle like the sparks of a cosmic firework.

Of course we don't have to be worried about the universe ending any time remotely close to the present day. As far as we know, it'll still be around for least another few billion years and by that time it could be that our theories of physics are extremely different. For now, though, there are still many questions to be answered about the past, present, and future of the universe.

Cosmology is a diverse and fascinating field. After all, the universe is, by definition, everything, or at least, everything that's "real." That includes us humans; we are part of the universe. We are made of atoms that were manufactured in a star explosion and the star that generated us was formed from a cloud of gas, which itself originally came from the energy of the big bang. Humans, then, are the natural result of the properties of the universe. It's humbling to realize that we tiny organisms on a miniature planet held in a fragile orbit around a star can ponder and comprehend the deepest truths of the universe.

© 2014 Quantum Spot Academy All rights reserved.