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As our universe grows old, how will it change? | Explained

“It is difficult to make predictions,” goes the Danish quip, “especially about the future”.

Fortunately for cosmologists, this isn't quite the case. They need only make one reasonable assumption – that the fundamental laws of physics don't change – and with the help of a blackboard the fate of the universe is revealed to them.

To see how this works, let us first understand how physical laws have shaped the universe's past. For the sake of convenience, we will use a “logarithmic clock” – i.e. 10 raised to some number x , or 10^x – to measure the amount of time elapsed in years since the Big Bang.

For example, 13.8 billion years have passed since the Big Bang, so we are currently in the epoch of $10^{10.1}$.

We know Albert Einstein's general relativity dictates that space expands at a rate determined by the energy in it. We also know that when space expands, the matter and radiation in it cool down. And as they cool, smaller things stick together more easily to form ever larger structures.

Add these basic principles to the principles of particle physics, and you'll have a clear picture of how the universe evolved from a 100-billion-degree soup of subatomic particles at its infancy to become the 2-degree-C choreography of galaxy clusters it is today.

A brief history

There's nothing we can observe in the universe today that's older than 10^{-6} years. Yet ✓ Saved physicists are convinced that three things happened in this ancient time: first, at some point, the universe's volume grew by a factor of 10^{26} in 10^{-32} seconds; second, at around $10^{-17.5}$ years, a fundamental force called the electroweak force became the electromagnetic force; and third, at around $10^{-12.5}$ years, subatomic particles called quarks and gluons clumped together to form protons and neutrons.

This series of events set the stage for the universe to acquire its first nuclei – the things at the centre of atoms comprising protons and neutrons. The fact that the amounts of these nuclei observed in the cosmos matches the predictions of this event sequence is one of the two great triumphs of the Big Bang theory.

The other triumph happened at $10^{5.5}$ years, when the universe had cooled enough for clusters of nuclei and electrons – atoms – to be formed intact. Until then, light was trapped in a plasma of ions, so that the universe was a milky and opaque place. But when atoms formed, light could escape from the plasma and flow freely, making the universe transparent.

Then atoms formed molecules, molecules formed gas clouds, and after 10^6 years gas clouds formed stars. The first star-cradles were the spheres of dark matter surrounding galaxies, whose enormous gravity helped particles condense into the material structure of the universe.

Almost immediately after, heavier stars died in supernovae that were hot enough to cook the very first heavy metals, essential for the formation of latter-day stars and rocky planets. And finally, here we are.

Into the crystal ball

But we don't have much time. After $10^{10.3}$ years – just five billion years from now – the Sun will run out of nuclear fuel, expand into a red giant, and very likely swallow the earth. Around this time the Milky Way galaxy will be in the middle of a spectacularly messy collision with the Andromeda galaxy, although this won't alter the Sun's endgame.

After 10^{13} years, the universe's lightest stars, which live longest, will cease to shine. Around then galaxies will also begin to run out of gas – the raw material for making stars.

The last gas-formed star will be born after 10^{14} years. (As such, we're smack in the middle of our golden age, logarithmically speaking.)

At this point, the census of the universe reads: 55% stellar relics, comprising black holes (1%) and 'nuclear ash' in the form of neutron stars and white dwarfs (<1%), and 45% brown dwarfs, which are objects somewhere between gas-giant planets and stars.

Starting in the year 10^{16} , brown dwarfs will take part in a remarkable event: they will begin to come too close to each other and merge, in the process making hot hydrogen balls sustaining nuclear fusion. This will mark the second, but more muted, innings of star formation.

Over longer timescales, the remaining celestial bodies will encounter each other so often that deflections due to gravity may eject them from their host galaxies. By 10^{19} years, most stars will have evaporated out of their parent galaxies.

The only unmerged brown dwarfs will now be orbiting each other in pairs, but they will merge with each other as well, birthing new stars after 10^{23} years. After 10^{24} years, the now-dwindled population of stars will have lost enough gravitational energy to begin falling in towards the black hole at the galaxy's centre.

By 10^{30} years, the black hole would have eaten the stars and grown to have billions of solar masses. These behemoths will roam the observable universe, steadily syphoning off rogue stars that wander between them, and vanquish all of them by 10^{33} years.

Then will follow a long interval of quiet – until 10^{98} years after the Big Bang, when the black holes themselves will have evaporated away.

The very end

This, at least, is the standard expectation. In this picture, the future expansion of space on cosmic scales is exponentially rapid. But there is an unlikely, though not inconceivable, possibility: that at some untold date, space's expansion will reverse and the universe will shrink all the way down to a "Big Crunch".

In some theories, the Big Crunch precedes another Big Bang and the cycle continues interminably.

For its part, quantum field theory – a combination of special relativity and quantum mechanics that scientists use to study subatomic particles – presents a more dramatic vision of the universe's ultimate fate. The Higgs field, an energy field which permeates the universe, has a certain energy density today. But it may instantly drop to a lower energy configuration due to some esoteric quantum effects in the future, and in that instant the universe as we know it will cease to exist.

Then again, a somewhat mundane alternative awaits if protons begin to decay in future. Current theories suggest the lifetime of a proton is around 10^{173} years, i.e. longer than the expected lifetime of black holes. But in some theories, protons may disintegrate as early as after 10^{35} years. If this happens, white dwarfs and neutron stars could be kept warm by the energy released by proton decay until 10^{39} years, before planets and white dwarfs simply disappear into decay products.

Finally, the unknown nature of dark matter can write the universe's fate.

Since Copernicus, and via Newton, Darwin, and Einstein, revolutionary insights of science have increasingly confirmed the principle that our place in the universe is not special – nor, as we see, is our fleeting moment in the calendar of the universe.

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