

THE HISTORY AND FATE OF THE UNIVERSE

Four eras and eight major stages in the evolution of the universe

The Big Bang occurred everywhere in the universe. Here one region has been illuminated and followed through time. The expansion is far greater than can be shown here.

The Big Bang and Expanding Universe

Space is expanding from an initial moment called the Big Bang. As it expands, the universe becomes less dense and cools. All distant galaxies are moving apart from each other and away from us. On large scales, the universe looks the same in all directions and in all parts of space. There is no center. Our current understanding of the early universe is called the Big Bang model. We are continuing to learn from astronomical observations and from accelerator-based experiments.

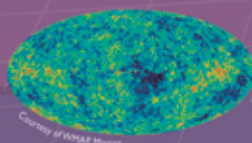
History of the Universe

Cosmology and
Relics of History

Cosmology is the study of the universe as a whole. As in archaeology, cosmology finds clues to the past in relics. We can look back in time by looking out in space. Since light travels at a finite speed c , the time t we are looking back is $t = d/c$, where d is the distance. The laws of nature discovered on Earth are applied to the early universe and tested by observing relics.

A Relic from the Early Universe

The Cosmic Microwave Background (CMB) is a universal bath of lightwaves (photons) from the hot, dense, early universe. To one part in 100,000, the CMB is the same no matter where you look. The remaining tiny variations in the density of mass-energy (shown in figure) are seeds that later form galaxies and larger cosmic structures.



This is an image of the universe from the time when atoms first formed. It is a map of the entire sky showing CMB light with the uniform part subtracted.

Age of the Universe

Studying the cosmic microwave background, the expansion of the universe, and the life cycles of stars leads to a marvelous agreement that the age of the universe is about 14 billion years (14×10^9 years).

Learn more at
UniverseAdventure.org
and at CPEPweb.org

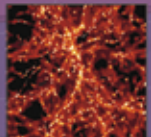
Era I – Acceleration: Inflation Speeds Expansion

Observations seem to imply that the very early universe underwent an extremely rapid, accelerating expansion, called inflation. In a tiny fraction of a second, inflation expanded each part of space by a factor of at least 10^{26} . Before inflation, the portion of the universe visible to us today was a smooth patch much smaller than a proton. As inflation ended, the visible universe had grown (very approximately) to the size of a ball.

Eras 2-3 – Deceleration: Expansion Slows and Structure Forms

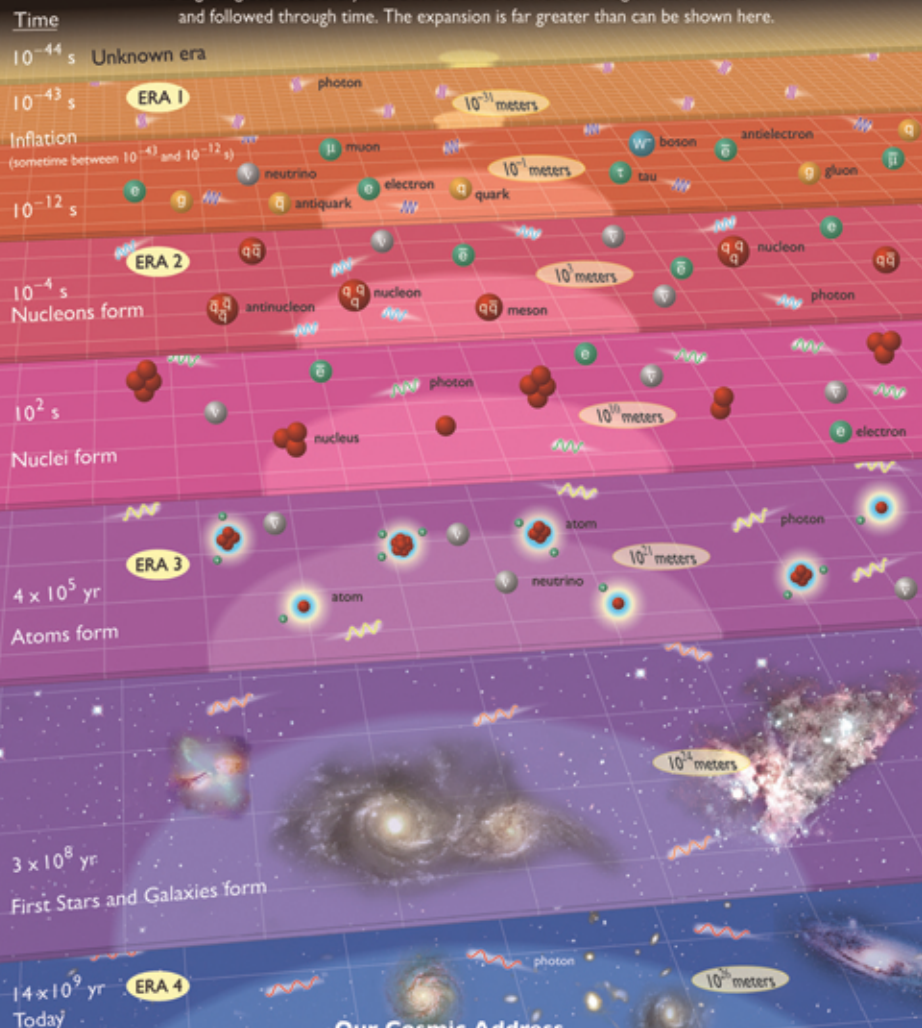
After inflation, the universe was a soup of fundamental particles, called a quark-gluon plasma. Photons and fast moving particles, generically called radiation, gradually lost energy (cooled) as the universe expanded (the energy went into the expansion). Eventually, slow-moving matter became dominant over radiation. Over time, larger and larger structures grew, from galaxies to clusters of galaxies to superclusters.

Simulation of matter distribution in the early universe that eventually yielded galaxies and clusters of galaxies.



Era 4 – Acceleration: Dark Energy Speeds Expansion

Astronomers had assumed that the current universe is dominated by matter, which would cause deceleration and might even reverse the expansion. So it was a great surprise in 1998 when observations showed that the expansion of the universe is now accelerating (see the "Accelerating Universe" plot). This implies the existence of a bizarre new form of energy, referred to as dark energy.



Our Cosmic Address

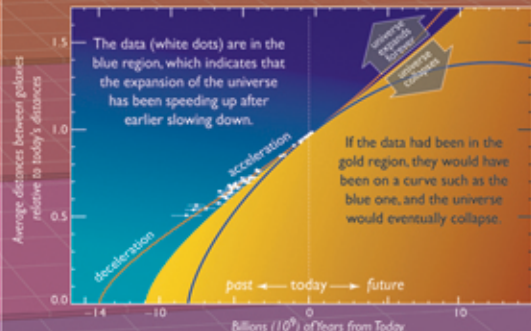
Our sun is one of 4×10^{11} stars in the Milky Way galaxy, which is one of more than 10^9 galaxies in the visible universe.



The Accelerating Universe

By observing other astronomical relics, distant exploding stars called supernovae, astrophysicists are digging ever further back into the history of the universe.

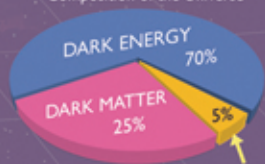
The plot shows data (white dots) from distant supernovae. The orange curve, with the best fit to the supernovae data, shows that billions (10^9) of years ago the expansion of the universe began to accelerate (the data curve upward slightly). This acceleration is attributed to a new form of energy called "dark energy" that pulls space apart.



Before the supernova research, physicists believed that the whole expansion history of our universe would lie in the gold region, where the expansion would be slowed by the attractive force of gravity. Now we see from the supernova data that the expansion history lies in the blue region, where attractive and repulsive forces compete for dominance.

The Fate of the Universe

Composition of the Universe



ORDINARY MATTER

The nature of dark energy and dark matter are two of the great questions facing cosmology and particle physics. Perhaps dark energy is the cosmological constant, introduced by Albert Einstein in 1917. Perhaps both are new parts of particle physics, tied to the very earliest moments of the universe and having to do with the nature of physics and spacetime itself.

Not all answers in science are known yet! With research and experiments under way in astrophysics, particle physics, and nuclear physics, we may be the first generation to learn what most of the universe is made of and what is the fate of the universe.

Whether the expansion of the universe will speed up, slow down, or even possibly reverse into collapse depends (according to gravitation theory) on the amount and types of matter and energy in it.

The ordinary matter—atoms and nuclei—that formed in the early universe can account for the visible mass in galaxies and clusters. But the amount of ordinary matter is a tiny fraction of the total mass needed to bind a galaxy or cluster together gravitationally and explain its internal motions. So an extraordinary new type of matter, not made of atoms or nuclei, must exist; it is called dark matter because it is not directly visible.

Even stranger, recent observations of supernovae in distant galaxies show that the expansion of the universe is in fact accelerating. An exotic dark energy may be causing this acceleration through a cosmic repulsion that overwhelms the pull of gravity due to matter.

THE HISTORY AND FATE OF THE UNIVERSE

Gravity and Expansion

Isaac Newton realized in the 1600s that a universe of a finite size could not be motionless. Since gravity always pulls matter together, the galaxies should all either be collapsing together or be expanding away from each other (though slowed by gravity). In expansion, the relative velocities of galaxies are simply proportional to the distance apart – exactly what Edwin Hubble later discovered.

The Big Bang Had No Center

The Big Bang (which started the expansion) happened every place at the same time. Thus, while galaxies today are receding from each other, they are not moving away from one central point. Indeed, each point in space can be considered the center.

This kind of expansion is not as unusual as you might think. Think about the raisin bread (shown above) as a portion of the universe, with the raisins as galaxies and the dough as the expanding space around them. Due to the rising of the bread (the expansion of space), distances increase and raisins move apart, though the raisins themselves do not expand.



Redshifts and Expansion

Another consequence of the expansion of space is that lightwaves stretch with the expansion. As the wavelength of visible light increases, it becomes redder (as shown for the photons in the central figure on the other side). Observing this redshift reveals the amount of expansion, from which we can measure the time between when the photons were emitted and now. To build up a picture of the expansion history of the universe (distances versus time), we also need to measure distances.

Measuring Cosmic Distances



To determine the distance to objects that are far across the universe, we can begin by measuring the brightness of the object. Objects that are far away look less bright as seen from Earth. But if an object appears less bright, is it farther away or is it just a dimmer object? To answer this, we use objects that all have the same intrinsic brightness. These are called "standard candles."

Type Ia supernovae are very bright, distant exploding stars that all have the same intrinsic brightness, so they can be used as standard candles. By comparing the distances to these exploding stars with the redshifts of their host galaxies, we observe that the redshift is greater for more distant objects.

Since the light reaching Earth from very distant objects was emitted billions of years ago, we see the most distant objects as they were billions of years ago. Putting the distances and times together, researchers can calculate how fast the universe was expanding at different times in its history and even estimate the age of the universe to be 14 billion (14×10^9) years.

Apparent Brightness and Actual Luminosity

The sun (which is an ordinary star) stands out in our sky because it is close to Earth. Many other stars (and galaxies) have far greater actual luminosity but appear much dimmer because they are much farther away.

To read a book by the light of a lamp, you need the lamp sitting beside you, not across the room. Even though the actual luminosity L (the amount of light it is giving off) is the same no matter where the lamp is, its apparent brightness b at your book is much higher with it nearby.

You can calculate how the apparent brightness of a star (or other bright object) diminishes with the distance from it by imagining a sphere of radius R with the star at the center. The luminosity (L) of the star is spread out over the surface of the sphere, which has area $4\pi R^2$. So the brightness at any point on the sphere is $b = L/4\pi R^2$.

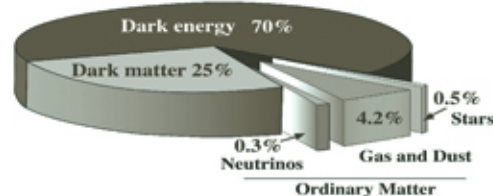
This is the inverse square law of brightness. This equation can be solved for the distance R , so you can measure the distance to a star if you know its intrinsic luminosity: $R = \sqrt{L/4\pi b}$

Antimatter

During the first microsecond of the universe, great numbers of particles and antiparticles were created and destroyed at a rapid rate. Almost imperceptible effects led to a tiny excess of particles (rather than antiparticles), about one more particle than antiparticle out of each 30 million created. Matter and antimatter met and annihilated, leaving only one particle out of each 30 million to survive today. These particles make up ordinary matter.

Formation of Nuclei

The lightest elements in the periodic table were all formed in the first few minutes of the universe; this is called primordial nucleosynthesis. The amount of each relic element that formed and survived to the present gives us a picture of the temperature, density, and expansion of the universe at that early time. The consistency of this picture with those from measurements of the expansion today and the relic cosmic background radiation gives a strong foundation for the Big Bang model.



Current Composition of the Universe

The stars we see in the night sky, even with the most powerful telescopes, are only a very small part of the mass-energy of the universe. More mass-energy is in the form of atoms contained in gas and dust as well as in fleeting particles called neutrinos. Still more is in unidentified nonluminous material called "dark matter." But two-thirds of all mass-energy is the mysterious dark energy.

Dark Matter and Particle Physics

Physicists believe there are close connections between particle physics and astrophysics. New types of particles could make up the dark matter in galaxies and clusters of galaxies. Such particles (for example supersymmetric particles) would solve long-standing puzzles in particle physics. If they exist, these particles would interact with the rest of matter only weakly, giving off no light, but would be detectable through their gravity.

Dark Energy

At the time of Albert Einstein, astronomers thought that the universe was not expanding or contracting. Einstein knew this was inconsistent with the predictions of gravity. He thought he needed something to counteract the attraction of gravity, so he hypothesized a "cosmological constant" in his general theory of relativity. A few years later, observations showed the universe to be expanding, and he abandoned this idea.

But when very recent measurements discovered the universe to be not only expanding, but expanding more and more quickly (accelerating), the idea of something to oppose gravitational attraction was revived. Physicists have come up with many other ideas besides the cosmological constant that could achieve this, so we don't yet know which type of physics is the real explanation. Since the cause of the accelerating universe is unknown, it is just called "dark energy." Future measurements should tell us whether Einstein's abandoned idea or some other exciting idea is correct.

Attributes of the Universe

Three attributes of the universe at various times in its history are shown in this table. The distance scale (or size scale) reflects expansion of the visible universe. Temperature and energy are characteristics of radiation at a given time.

Time	Distance Scale (m)	Temperature (K)	Energy (MeV)
10^{-43} s	10^{-31}	10^{32}	10^{22}
10^{-12} s	0.1	10^{16}	10^6
10^{-4} s	1000	10^{12}	100
10^2 s	10^{10}	10^9	0.1
4×10^5 y	10^{21}	3000	3×10^{-7}
3×10^8 y	10^{24}	30	3×10^{-9}
Today	10^{26}	3	3×10^{-10}

Recommended Reading

More information about the content of this chart appears in an article by Lawrence Krauss (author of *The Physics of Star Trek*) in the March 2003 issue of *The Physics Teacher* magazine.
<http://UniverseAdventure.org/krauss>

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