

# THE HISTORY AND FATE OF THE UNIVERSE

## Gravity and Expansion

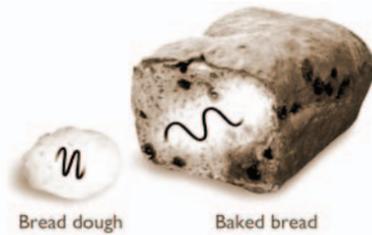
Isaac Newton realized in the 1600s that a universe of a finite size could not be motionless. Since gravity always pulls matter together, the galaxies should be moving toward each other, or they might be moving away from each other, though still slowed by gravity. In an expanding universe, the relative 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 observed brightness of the object (as seen from Earth). 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 combining with other input can even estimate the age of the universe to be 13.8 billion ( $13.8 \times 10^9$ ) years.

## Observed 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 observed brightness  $b$  at your book is much higher with it nearby.

You can calculate how the observed 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 observed brightness at any point on the sphere is  $b = L/4\pi R^2$ .

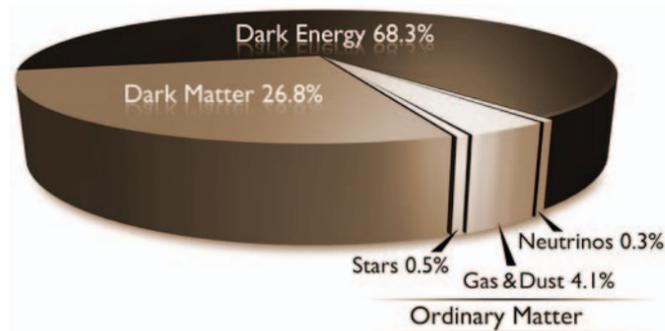
This is the inverse square law of brightness. This equation can be solved for the distance  $R$ , so you can measure the distance to a star if you know its actual luminosity:  $R = \sqrt{L/4\pi b}$

## 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 10 billion created. Matter and antimatter met and annihilated, leaving only one particle out of each 10 billion 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

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 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 equivalent characteristics of photons (particles of light) at a given time.

Time	Distance Scale (m)	Temp. (K)	Energy (GeV)
$3 \times 10^{-44}$ s	$10^{-35}$	$10^{32}$	$10^{19}$
$10^{-12}$ s	$3 \times 10^{-4}$	$10^{16}$	$10^3$
$10^{-4}$ s	30,000	$10^{12}$	0.1
$10^2$ s	$3 \times 10^{10}$	$10^9$	$10^{-4}$
$3 \times 10^5$ y	$3 \times 10^{21}$	3000	$3 \times 10^{-10}$
$10^9$ y	$10^{25}$	20	$10^{-12}$
$13.8 \times 10^9$ y (today)	$10^{26}$	2.7	$2.3 \times 10^{-13}$

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