**What is the Universe?**

**The universe is everything. It includes all of space, and all the matter and energy that space contains. It even includes time itself and, of course, it includes you.**

Earth and the Moon are part of the universe, as are the other planets and their many dozens of moons. Along with asteroids and comets, the planets orbit the Sun. The Sun is one among hundreds of billions of stars in the Milky Way galaxy, and most of those stars have their own planets, known as exoplanets.

The Milky Way is but one of billions of galaxies in the observable universe — all of them, including our own, are thought to have supermassive black holes at their centers. All the stars in all the galaxies and all the other stuff that astronomers can’t even observe are all part of the universe. It is, simply, everything.

The star-forming nebula W51 is one of the largest "star factories" in the Milky Way galaxy. "Star factories" like this one can operate for millions of years. The cavernous red region on the right side of W51 is older, evident in the way it has already been carved out by winds from generations of massive stars (those at least 10 times the mass of our Sun). The dust and gas in the region are swept around even more when those stars die and explode as supernovas. On the nebula's younger left side, many stars are just beginning to clear away the gas and dust.

NASA/JPL-Caltech

Though the universe may seem a strange place, it is not a distant one. Wherever you are right now, outer space is only 62 miles (100 kilometers) away. Day or night, whether you’re indoors or outdoors, asleep, eating lunch or dozing off in class, outer space is just a few dozen miles above your head. It’s below you too. About 8,000 miles (12,800 kilometers) below your feet — on the opposite side of Earth — lurks the unforgiving vacuum and radiation of outer space.

In fact, you’re technically in space right now. Humans say “out in space” as if it’s there and we’re here, as if Earth is separate from the rest of the universe. But Earth is a planet, and it’s in space and part of the universe just like the other planets. It just so happens that things live here and the environment near the surface of this particular planet is hospitable for life as we know it. Earth is a tiny, fragile exception in the cosmos. For humans and the other things living on our planet, practically the entire cosmos is a hostile and merciless environment.

This true-color image shows North and South America as they would appear from space 22,000 miles (35,000 km) above the Earth. The image is a combination of data from two satellites. The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard NASA’s Terra satellite collected the land surface data over 16 days, while NOAA’s Geostationary Operational Environmental Satellite (GOES) produced a snapshot of the Earth’s clouds and the Moon.

Reto Stöckli, Nazmi El Saleous, and Marit Jentoft-Nilsen, NASA GSFC

**How old is Earth?**

Our planet, Earth, is an oasis not only in space, but in time. It may feel permanent, but the entire planet is a fleeting thing in the lifespan of the universe. For nearly two-thirds of the time since the universe began, Earth did not even exist. Nor will it last forever in its current state. Several billion years from now, the Sun will expand, swallowing Mercury and Venus, and filling Earth’s sky. It might even expand large enough to swallow Earth itself. It’s difficult to be certain. After all, humans have only just begun deciphering the cosmos.

While the distant future is difficult to accurately predict, the distant past is slightly less so. By studying the radioactive decay of isotopes on Earth and in asteroids, scientists have learned that our planet and the solar system formed around 4.6 billion years ago.

**How old is the universe?**

The universe, on the other hand, appears to be about 13.8 billion years old. Scientists arrived at that number by measuring the ages of the oldest stars and the rate at which the universe expands. They also measured the expansion by observing the Doppler shift in light from galaxies, almost all of which are traveling away from us and from each other. The farther the galaxies are, the faster they’re traveling away. One might expect gravity to slow the galaxies’ motion from one another, but instead they’re speeding up and scientists don’t know why. In the distant future, the galaxies will be so far away that their light will not be visible from Earth.

Put another way, the matter, energy and everything in the universe (including space itself) was more compact last Saturday than it is today.

Put another way, the matter, energy and everything in the universe (including space itself) was more compact last Saturday than it is today. The same can be said about any time in the past — last year, a million years ago, a billion years ago. But the past doesn’t go on forever.

By measuring the speed of galaxies and their distances from us, scientists have found that if we could go back far enough, before galaxies formed or stars began fusing hydrogen into helium, things were so close together and hot that atoms couldn’t form and photons had nowhere to go. A bit farther back in time, everything was in the same spot. Or really the entire universe (not just the matter in it) *was* one spot.

Don't spend too much time considering a mission to visit the spot where the universe was born, though, as a person cannot visit the place where the Big Bang happened. It's not that the universe was a dark, empty space and an explosion happened in it from which all matter sprang forth. The universe didn’t exist. Space didn’t exist. Time is part of the universe and so it didn’t exist. Time, too, began with the big bang. Space itself expanded from a single point to the enormous cosmos as the universe expanded over time.

**What is the universe made of?**

The universe contains all the energy and matter there is. Much of the observable matter in the universe takes the form of individual atoms of hydrogen, which is the simplest atomic element, made of only a proton and an electron (if the atom also contains a neutron, it is instead called deuterium). Two or more atoms sharing electrons is a molecule. Many trillions of atoms together is a dust particle. Smoosh a few tons of carbon, silica, oxygen, ice, and some metals together, and you have an asteroid. Or collect 333,000 Earth masses of hydrogen and helium together, and you have a Sun-like star.

For the sake of practicality, humans categorize clumps of matter based on their attributes. Galaxies, star clusters, planets, dwarf planets, rogue planets, moons, rings, ringlets, comets, meteorites, raccoons — they’re all collections of matter exhibiting characteristics different from one another but obeying the same natural laws.

Scientists have begun tallying those clumps of matter and the resulting numbers are pretty wild. Our home galaxy, the Milky Way, contains at least 100 billion stars, and the observable universe contains at least 100 billion galaxies. If galaxies were all the same size, that would give us 10 thousand billion billion (or 10 sextillion) stars in the observable universe.

But the universe also seems to contain a bunch of matter and energy that we can’t see or directly observe. All the stars, planets, comets, sea otters, black holes and dung beetles together represent less than 5 percent of the stuff in the universe. About 27 percent of the remainder is dark matter, and 68 percent is dark energy, neither of which are even remotely understood. The universe as we understand it wouldn’t work if dark matter and dark energy didn’t exist, and they’re labeled “dark” because scientists can’t seem to directly observe them. At least not yet.

Two views from Hubble of the massive galaxy cluster Cl 0024+17 (ZwCl 0024+1652) are shown. To the left is the view in visible-light with odd-looking blue arcs appearing among the yellowish galaxies. These are the magnified and distorted images of galaxies located far behind the cluster. Their light is bent and amplified by the immense gravity of the cluster in a process called gravitational lensing. To the right, a blue shading has been added to indicate the location of invisible material called dark matter that is mathematically required to account for the nature and placement of the gravitationally lensed galaxies that are seen.

NASA, ESA, M.J. Jee and H. Ford (Johns Hopkins University)

**How has our view of the universe changed over time?**

Human understanding of what the universe is, how it works and how vast it is has changed over the ages. For countless lifetimes, humans had little or no means of understanding the universe. Our distant ancestors instead relied upon myth to explain the origins of everything. Because our ancestors themselves invented them, the myths reflect human concerns, hopes, aspirations or fears rather than the nature of reality.

Several centuries ago, however, humans began to apply mathematics, writing and new investigative principles to the search for knowledge. Those principles were refined over time, as were scientific tools, eventually revealing hints about the nature of the universe. Only a few hundred years ago, when people began systematically investigating the nature of things, the word “scientist” didn’t even exist (researchers were instead called “natural philosophers” for a time). Since then, our knowledge of the universe has repeatedly leapt forward. It was only about a century ago that astronomers first observed galaxies beyond our own, and only a half-century has passed since humans first began sending spacecraft to other worlds.

In the span of a single human lifetime, space probes have voyaged to the outer solar system and sent back the first up-close images of the four giant outermost planets and their countless moons; rovers wheeled along the surface on Mars for the first time; humans constructed a permanently crewed, Earth-orbiting space station; and the first large space telescopes delivered jaw-dropping views of more distant parts of the cosmos than ever before. In the early 21st century alone, astronomers discovered thousands of planets around other stars, detected gravitational waves for the first time and produced the first image of a black hole.

Using the Event Horizon Telescope, scientists obtained an image of the black hole at the center of galaxy M87.

Event Horizon Telescope collaboration et al.

With ever-advancing technology and knowledge, and no shortage of imagination, humans continue to lay bare the secrets of the cosmos. New insights and inspired notions aid in this pursuit, and also spring *from* it. We have yet to send a space probe to even the nearest of the billions upon billions of other stars in the galaxy. Humans haven’t even explored all the worlds in *our own* solar system. In short, most of the universe that *can* be known remains *unknown*.

The universe is nearly 14 billion years old, our solar system is 4.6 billion years old, life on Earth has existed for maybe 3.8 billion years, and humans have been around for only a few hundred thousand years. In other words, the universe has existed roughly 56,000 times longer than our species has. By that measure, almost everything that’s ever happened did so before humans existed. So of course we have loads of questions — in a cosmic sense, we just got here.

Our first few decades of exploring our own solar system are merely a beginning. From here, just one human lifetime from now, our understanding of the universe and our place in it will have undoubtedly grown and evolved in ways we can today only imagine.

**What is an Exoplanet?**

**So far scientists have categorized exoplanets into the following types: Gas giant, Neptunian, super-Earth and terrestrial.**

The planets beyond our solar system are called “exoplanets,” and they come in a wide variety of sizes, from gas giants larger than Jupiter to small, rocky planets about as big around as Earth or Mars. They can be hot enough to boil metal or locked in deep freeze. They can orbit their stars so tightly that a “year” lasts only a few days; they can orbit two suns at once. Some exoplanets are sunless rogues, wandering through the galaxy in permanent darkness.

When we describe different types of exoplanets – planets outside our solar system – what do we mean by "hot Jupiters," "warm Neptunes," and "super-Earths"? Since we're still surveying and learning about the variety of worlds out there among the stars, it's sometimes helpful to refer to characteristics they share with planets we're familiar with in our own planetary system.  
**NASA/JPL-Caltech**

**A galaxy of stars – and planets**

Our galaxy, the Milky Way, is the thick stream of stars that cuts across the sky on the darkest, clearest nights. Its spiraling expanse contains at least 100 billion stars, our Sun among them. And if each of those stars has not just one planet, but, like ours, a whole system of them, then the number of planets in the galaxy is truly astronomical: We’re already heading into the trillions.

We humans have been speculating about such possibilities for thousands of years, but ours is the first generation to know, with certainty, that exoplanets are really out there. In fact, way out there. Our nearest neighboring star, Proxima Centauri, was found to possess at least one planet – probably a rocky one. It’s about 4 light-years away – more than 25 trillion miles (40 trillion kilometers). The bulk of exoplanets found so far are hundreds or thousands of light-years away.

The bad news: As yet we have no way to reach them, and won’t be leaving footprints on them anytime soon. The good news: We can look in on them, take their temperatures, taste their atmospheres and, perhaps one day soon, detect signs of life that might be hidden in pixels of light captured from these dim, distant worlds.

**Exoplanet discovery – and mystery**

The first exoplanets were discovered in the early 1990s, but the first exoplanet to burst upon the world stage was 51 Pegasi b, a “hot Jupiter” orbiting a Sun-like star 50 light-years away. The watershed year was 1995. Since then we’ve discovered thousands more.

Size and mass play a crucial role in determining planet types. There are also varieties within the size/mass classifications. Scientists also have noted what seems to be a strange gap in planet sizes. It’s been dubbed the “radius valley,” or the Fulton gap, after Benjamin Fulton, lead author on a paper describing it. Data from NASA’s Kepler spacecraft showed that planets of a certain size-range are rare – those between 1.5 and 2 times the size (diameter) of Earth, which would place them among the super-Earths. It’s possible that this represents a critical size in planet formation: Planets that reach this size quickly attract thick atmospheres of hydrogen and helium gas, and balloon up into gaseous planets, while planets smaller than this limit are not large enough to hold such an atmosphere and remain primarily rocky, terrestrial bodies. On the other hand, the smaller planets that orbit close to their stars could be the cores of Neptune-like worlds that had their atmospheres stripped away.

Explaining the Fulton gap will require a far better understanding of how planetary systems form.

Variety is a major theme in exoplanet discoveries over the past quarter century, as shown in this illustration. Most have been discovered by the "transit" method – watching for the tiniest of shadows as a planet crosses the face of its star.

NASA/JPL-Caltech

**Types of exoplanets**

Each planet type varies in interior and exterior appearance depending on composition.

[**Gas giants**](https://exoplanets.nasa.gov/what-is-an-exoplanet/planet-types/gas-giant/) are planets the size of Saturn or Jupiter, the largest planet in our solar system, or much, much larger.

More variety is hidden within these broad categories. Hot Jupiters, for instance, were among the first planet types found – gas giants orbiting so closely to their stars that their temperatures soar into the thousands of degrees (Fahrenheit or Celsius).

[**Neptunian planets**](https://exoplanets.nasa.gov/what-is-an-exoplanet/planet-types/neptune-like/) are similar in size to Neptune or Uranus in our solar system. They likely have a mixture of interior compositions, but all will have hydrogen and helium-dominated outer atmospheres and rocky cores. We’re also discovering mini-Neptunes, planets smaller than Neptune and bigger than Earth. No planets of this size or type exist in our solar system.

[**Super-Earths**](https://exoplanets.nasa.gov/what-is-an-exoplanet/planet-types/super-earth/) are typically terrestrial planets that may or may not have atmospheres. They are more massive than Earth, but lighter than Neptune.

[**Terrestrial planets**](https://exoplanets.nasa.gov/what-is-an-exoplanet/planet-types/terrestrial/) are Earth sized and smaller, composed of rock, silicate, water or carbon. Further investigation will determine whether some of them possess atmospheres, oceans or other signs of habitability.

**In Depth: Exoplanets**

**An exoplanet, or extrasolar planet, is a planet outside of our solar system that usually orbits another star in our galaxy.**

Exoplanets – planets outside our solar system – are everywhere. But why do we study them? What makes them so interesting? At NASA, we're surveying and studying exoplanets to learn all about their weirdness, their variety, and all the fascinating things they can tell us about how planets form and develop.  
**NASA/JPL-Caltech**

Most of the exoplanets discovered so far are in a relatively small region of our galaxy, the Milky Way. ("Small" meaning within thousands of light-years of our solar system; one light-year equals 5.88 trillion miles, or 9.46 trillion kilometers.) That is as far as current telescopes have been able to probe. We know from NASA’s Kepler Space Telescope that there are more planets than stars in the galaxy.

Although exoplanets are far – even the closest known exoplanet to Earth, [Proxima Centauri b](https://science.nasa.gov/universe/exoplanets/eso-discovers-earth-size-planet-in-habitable-zone-of-nearest-star/), is still about 4 light-years away – scientists have discovered creative ways to spot these seemingly tiny objects.

At only four light-years away, Proxima b is our closest known exoplanet neighbor.

**How Do We Find Exoplanets?**

There are [five methods](https://exoplanets.nasa.gov/alien-worlds/ways-to-find-a-planet/) scientists commonly use to discover exoplanets.

The two main techniques are the*transit*and*radial velocity* methods.

When a planet passes directly between an observer and the star it orbits, it blocks some of that starlight. For a brief period of time, that star’s light actually gets dimmer. It's a tiny change, but it's enough to clue astronomers in to the presence of an exoplanet around a distant star. This is known as the transit method.

Orbiting planets cause stars to wobble in space, changing the color of light astronomers see when observing a star. Stars are affected by the gravitational tug of their orbiting planets and, when observed through a telescope, this affects the star's light spectrum. If the star moves in the direction of the observer it will appear to be shifted toward blue. If it is moving away from the observer, it will shift toward the red. Observing this is known as the radial velocity method.

**NASA’s Exoplanet Space Telescopes**

Thousands of exoplanets have been discovered and confirmed orbiting other stars. The first evidence of exoplanets dates to [1917 when Van Maanen identified the first polluted white dwarf](https://www.jpl.nasa.gov/news/news.php?feature=6991), however, the first confirmed detection of an exoplanet would not come until the 1990s. The discovery of exoplanets grew exponentially in the years to follow with the launch of the [Kepler Space Telescope](https://exoplanets.nasa.gov/resources/1013/overview-of-kepler-mission/).

The Kepler mission was specifically designed to survey our region of the Milky Way galaxy to discover hundreds of Earth-size and smaller planets in or near the habitable zone (also called the “Godilocks zone,” the area around a star where rocky planets could have liquid water on the surface) and determine the fraction of stars that might have such planets around them. After the second of Kepler’s four gyroscope-like wheels failed in 2013, Kepler completed its prime mission that November and began its extended mission, K2. The spacecraft was retired in 2018, but Kepler data are still being used to find exoplanets (more than 2,700 confirmed so far).

NASA’s [Spitzer Space Telescope](https://science.nasa.gov/missions/spitzer/nasa-celebrates-the-legacy-of-the-spitzer-space-telescope/) (2013-2020) was not designed to search for exoplanets, but its infrared instruments made it an excellent exoplanet explorer. It was used in the notable discovery of the [TRAPPIST-1](https://exoplanets.nasa.gov/news/1487/10-things-all-about-trappist-1/) system. In 2018 the [Transiting Exoplanet Survey Satellite (TESS)](https://science.nasa.gov/mission/tess) was launched as a successor to Kepler to discover exoplanets in orbit around the brightest dwarf stars, the most common star type in our galaxy. NASA’s James Webb Space Telescope and the future Nancy Grace Roman Space Telescope hold great promise for what we can learn from exoplanets. Through spectroscopy, reading light signatures for information, astronomers hope to learn more about planet atmospheres and the conditions of the planets themselves.

The Milky Way, our own galaxy, stretches across the sky above the La Silla Observatory in Chile. Hidden inside our own galaxy are trillions of planets, most waiting to be found.

ESO/S. Brunier

**Confirmed vs. Candidate**

An exoplanet candidate is a likely planet discovered by a telescope but has not yet been proven to actually exist.

It is possible for some candidates to turn out to be "false positives." A planet is considered "confirmed" once it is verified through additional observation using two other telescopes. There are currently thousands of planet candidates awaiting confirmation. But time on telescopes is considered a precious resource and it takes a lot of computing time to find which targets to investigate. This is one area where amateur scientists can work with NASA data to help refine targets and even discover exoplanets. Where computers might miss a single transit, humans can detect small brightness dips in data that might tell us there is a planet to be found.

**How Do We Name Exoplanets?**

Exoplanet names can look long and complicated at first, especially when compared to names like Venus and Mars. However, there is a logic behind their naming system that is important to how scientists catalog thousands of planets. Astronomers differentiate between the alphanumeric "designations" and alphabetical "proper names." All stars and exoplanets have designations, but very few have proper names.

The first part of an exoplanet name is usually the telescope or survey that discovered it. The number is the order in which the star was cataloged by position. The lowercase letter stands for the planet, in the order in which the planet was found. The first planet found is always named b, with ensuing planets named c, d, e, f and so on. The star that the exoplanet orbits is usually the undeclared "A" of the system, which can be useful if the system contains many stars, which themselves may be designated B or C. (Stars get capital letters; planets receive lowercase designations.) If a bunch of exoplanets around the same star are found at once, the planet closest to its star is named b with more distant planets named c, d, e and so on.

An example of an exoplanet name is Kepler-16b, where "Kepler" is the name of the telescope that observed the system, 16 is the order in which the star was cataloged and "b" is the closest planet to the star. If we were naming Earth as an exoplanet, it would be called Sun d (Sun is the name of our star, and Earth is the third planet, starting with b, Mercury).