DIAGRAM OF OUR UNIVERSE 2013

Earth's orbit is about 100 trillion times the size of a pushpin hole.

What is the Universe?

The Universe is the breadth of time and space that includes all physical entities. Humans, the landscapes that we see, the plants and animals that live here - all of this is a part of the Universe. The stars that shine in the night sky, the Milky Way, which spreads its pale light among the stars, and galaxies so far away that they can only be seen with a huge telescope - all these things are part of the Universe as well. The Universe encompasses all the things that we know, and everything beyond.

This diagram is based on the assumption of the "Lemaitre Universe", which is a uniform, isotropic Universe with no curvature. Calculations are based on the latest observational results from the Planck spacecraft.

Planck spacecraft

In our Universe, elements were born — Stars were born from the elements — Humans were born from the stars and then Science was born

Early Chordates, Fishes, Amphibians, Early Mammals, Early Primates, Early Prosimians, Early Simians, Apes, Ape-men, Humanity

Living organisms evolved into beings that yearned to discover where they came from and where they are going, and about the Universe that gave them life. The result of this was the birth of science.

What is science?

Science is a method for understanding all of the objects and phenomena that comprise the Universe. When we notice something strange, we naturally ask "Why?" This is the first step in science. Scientific methodology means investigating the phenomena that interest us through experiments and observation, so that we can gain a deeper understanding. Through this process, we find new ways of seeing and new ways of thinking. This is scientific discovery. Science is one way of knowing the Universe around us.

Earth is about 10 billion times the size of a pushpin hole.

How to use this diagram
Experience the Universe using four rules

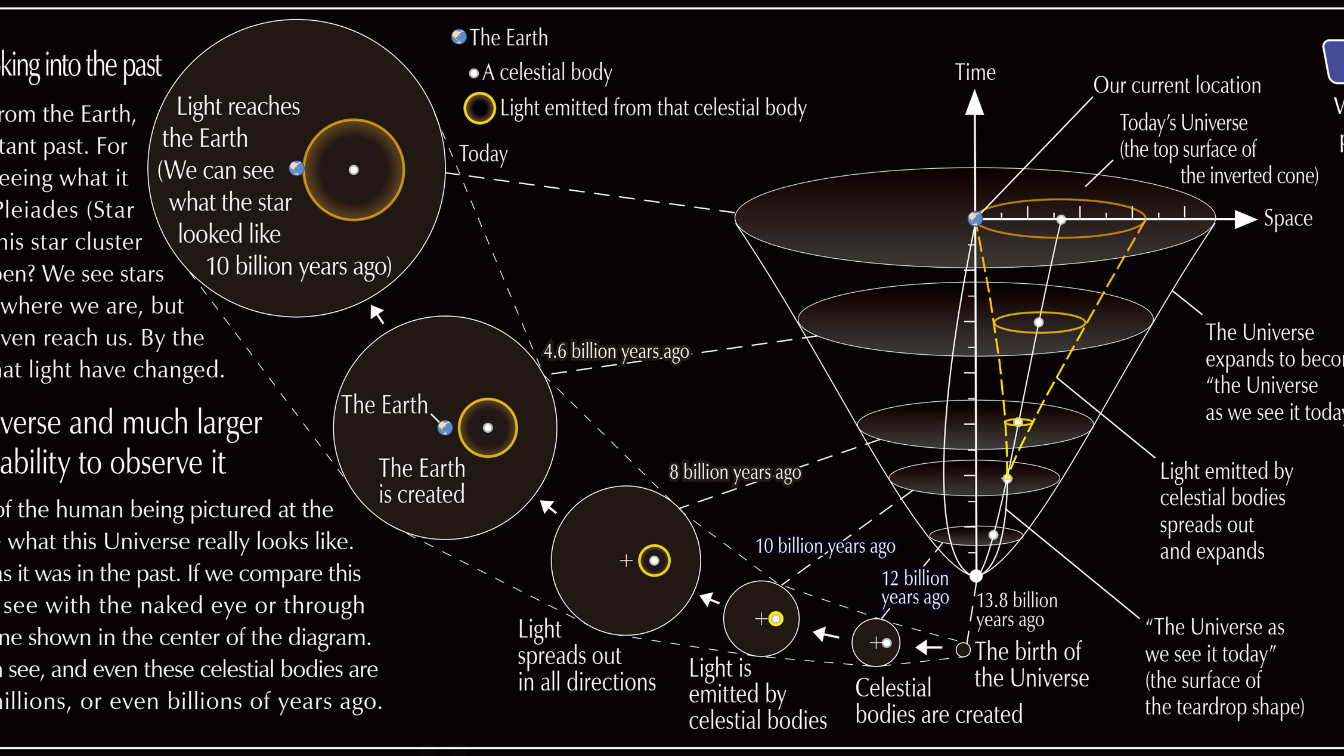
This diagram illustrates the Universe based on the latest research and observations, with humans at the center. The vertical represents the passage of time, from the age of humans back to the birth of the Universe. The horizontal represents the breadth of space that is the Universe. From its overall inverted cone shape, we can see that the Universe has been expanding constantly ever since it first came into existence. This diagram is a guide that will take you on a journey through time and space. Keep these four rules in mind as you uncover the secrets of the Universe with your own eyes.

Rule 1 Looking into the distant Universe means looking into the past

The strange thing is that when we look at the Universe from the Earth, what we see is actually the Universe as it was in the distant past. For example, when we look at the Sun, we are actually seeing what it looked like eight minutes ago. When we look at Pleiades (Star cluster M45), what we are actually seeing is what this star cluster looked like about 400 years ago. Why does this happen? We see stars and galaxies because the light they emit travels to where we are, but they are so far away that it takes time for light to even reach us. By the time that light gets here, the stars that emitted that light have changed.

Rule 2 There is an "observable" Universe and much larger volume that lies behind our ability to observe it

The "Current Universe" spreads out on all sides of the human being pictured at the center of the diagram, but we are unable to see what this Universe really looks like. Remember Rule 1: What we see is the Universe as it was in the past. If we compare this diagram to the celestial bodies that we can see with the naked eye or through telescopes, we find a teardrop shape like the one shown in the center of the diagram. This is the only part of the Universe that we can see, and even these celestial bodies are images from a different era, thousands, millions, or even billions of years ago.



Rule 3 In space, distances are not always what they seem to be

When we talk about the distances to celestial bodies, we talk about "the path that light has traveled to reach us". For example, light from the furthest point in the observable Universe has traveled for 13.8 billion years, a distance that we refer to as "13.8 billion light years". During that time, however, the Universe has continued to expand, so the path that light takes has grown increasingly longer from the time the journey began, and the starting point is much further away. By the time the light reaches us, that starting point is estimated to be as far as 47 billion light years away.

Rule 4 The Universe becomes visible through the "Eyes of Science"

The observable Universe (the teardrop-shaped image at the center of the diagram) is only a drop in the bucket compared to the vast expanse of the actual Universe. Through the "Eyes of Science", however, we have learned a great deal using clues from the observable Universe. How was the observable Universe created (the bottom of the inverted cone)? How has it expanded (the outer surface of the cone)? And does a Universe exist beyond the outer limits of this cone? This diagram contains the results of many such scientific discoveries. The Universe is waiting for you to unravel its mysteries.

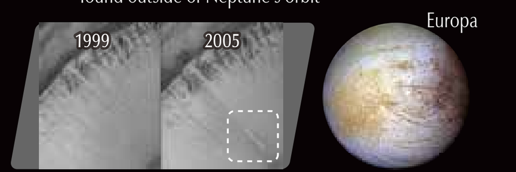
DIAGRAM OF OUR UNIVERSE ? Light Cone — The slope of this yellow line represents the speed of light on the Earth.

Looking for life on the planets of our Solar System

Does life exist somewhere in the Universe, aside from on the planet Earth? First, let's look at the possibilities in our own Solar System. Our Solar System comprises several celestial bodies of various sizes and environments.

Our Solar System includes: the Sun, eight planets, asteroids and comets (including trans-Neptunian objects and dwarf planets such as Pluto), and satellites.

Developments in space exploration technologies have enabled new scientific research aimed at seeking out life on other planets. We can now send probes directly to other planets in our Solar System to look for traces of life. Among the main targets for these probes are Mars, where liquid was thought to exist on the planet's surface, and Europa (one of Jupiter's moons), where an ocean is believed to lie hidden under a thick layer of ice. There is little likelihood of finding intelligent life or advanced life forms there, but one day, we may discover microorganisms on these celestial bodies similar to those found on Earth.



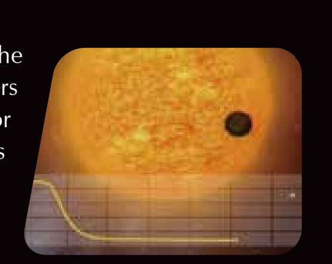
Marks found on Mars, where water is thought to have flowed

Looking for "Another Earth"

Does life exist in the vast expanses of the Universe outside of our Solar System? In 1995, for the first time in history, astronomers discovered a planet around a distant star. Since then, astronomers have discovered more than 800 planets outside of our Solar System, using a variety of clues; for example, minute variations in the movement of stars resulting from the revolution of planets around the stars, or slight changes in the brightness of stars when planets pass in front of them.

Based on observations by astronomers up to now, we have learned that there are many diverse planetary systems outside of our own. Recently, in addition to large, heavy "Jovian" planets, astronomers have discovered planets that are similar to Earth in both size and mass. Furthermore, a number of the planets discovered could potentially sustain large bodies of liquid water on the surface, given that they maintain an appropriate distance from their host stars, as is the case of Earth. It may not be long before we finally discover a planet that could be called "Another Earth".

Celestial bodies outside of our Solar System are so far away that even if we found a planet that could be called another Earth, we would not be able to send a probe to explore it directly. Therefore we must use other methods to determine whether those planets could sustain life; for example, by observing the planet's surface environment or atmosphere using space telescopes or extremely large telescopes on Earth to confirm whether water exists there in liquid form, or by looking for traces of substances such as oxygen, ozone, and methane (referred to as "biomarkers"), which living organisms could potentially form. Future research will help to clarify whether analogs to terrestrial planets and terrestrial life exist elsewhere in the Universe.



The "Transit Method" used to find planets outside of our Solar System as they pass in front of stars

Thirty Meter Telescope (TMT) will be built at the top of Mauna Kea in Hawaii by international cooperation

HOW DID OUR UNIVERSE COME INTO EXISTENCE?

This vast Universe we can observe was once so small that it could not be seen. Modern science is closing in on the secrets of the Universe, and is gradually gaining an understanding of the astounding origin behind the formation of the Universe itself. Let's look back at the history of the Universe, starting from the moment of its formation some 13.8 billion years ago.

Electromagnetic waves

Short — Wavelength — Long: Gamma rays, X-rays, Ultraviolet rays, Visible light, Infrared light, Radio waves

Visible light is not the only form of "light"; radio waves, X-rays and gamma rays are also a sort of "light". Collectively they are called "electromagnetic waves". We can observe the Universe by using telescopes to capture the electromagnetic waves emitted by celestial bodies. Through a variety of observation methods, we can gain hints that help us to learn about our Universe.

Subaru Telescope

Center of the diagram

This diagram, shaped like an inverted cone, is a graphical representation of the expansion of the Universe. At the center is the Earth, where we stand as we observe the Universe. We are thus at the center of the diagram. But where is the center of the Universe? In fact, astronomers believe that the Universe is homogeneous and isotropic; that is, in "the Universe as we see it today", there is no unique location that could be called the "center of the Universe".

Our Galaxy — Our Solar System — The Earth — Nerve cell — DNA — Element

The human body is made up of cells. Within these cells, human genomes, which are the blueprints for the human body, are drawn with DNA. These cells and DNA are in turn made up of elements.

WHAT IS THE MATERIALS' ORIGIN OF HUMANS?

The human body, which could be compared to a small "Universe", comprises materials called elements. Modern science has determined that these elements originated in the stars and were scattered through space eons ago. Let's go back in time to unravel the mysteries of human beings and the Universe.

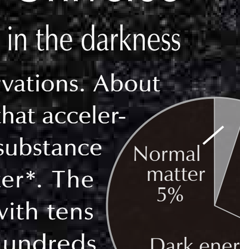
Table of human materials (from the periodic table) — Segments in white are the elements that form the materials of the human body

The presumed current state of the Universe
Countless stars shining in the darkness

This is the state of the Universe, as brought to light by recent observations. About 70% of the Universe is "dark energy", a mysterious form of energy that accelerates the expansion of the Universe. About 30% is an unidentified substance called "dark matter", and about 5% is made up of normal matter*. The Universe has a diverse layered structure comprising galaxies with tens or hundreds of billions of stars, galaxy clusters that contain hundreds or even thousands of galaxies, and a large, mesh-like structure of galaxies that are spread out across hundreds of millions of light years.

* 'Normal matter' is the basic components that comprise all substances in the world around us. All things, from animals to stars in the night sky, including our own bodies, are made up of combinations of normal matter.

Galaxy cluster Abell 426 — Spiral galaxy M 101



Composition of the Universe, as determined by the WMAP spacecraft and other sources

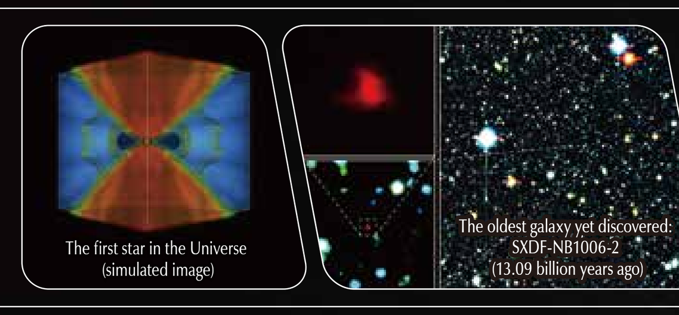
The mesh of the Universe
Dark matter and large-scale structures

Why are galaxies distributed in the form of a mesh? The answer is "dark matter", a substance that remains unexplained, and which cannot be directly observed. It is believed that in volumes containing dark matter, gravity caused even more dark matter to gather and create "large-scale structures" in the form of a three-dimensional mesh. Normal matter then collapsed onto the sites where large amounts of dark matter resided, eventually forming galaxies embedded in these large-scale structures.

These are simulated images of the evolution of large-scale structures in the Universe. The blue gaseous substance represents dark matter. In reality, dark matter is invisible.

The first star brings light to the Universe
The birth of stars and galaxies

We know from observations that galaxies already existed in the Universe about 13.1 billion years ago, but we don't know exactly when the first stars were born. We believe that the first star had about 40 times more mass than our Sun. A variety of elements were created inside this giant star. These elements were scattered by a supernova explosion and they became seeds of new generations of stars.



The first star in the Universe (simulated image) — The oldest galaxy yet discovered: SXDF-NB1006-2 (13.09 billion years ago)

Atoms appear, and the fog of the Universe lifts
Electrons combine with atomic nuclei

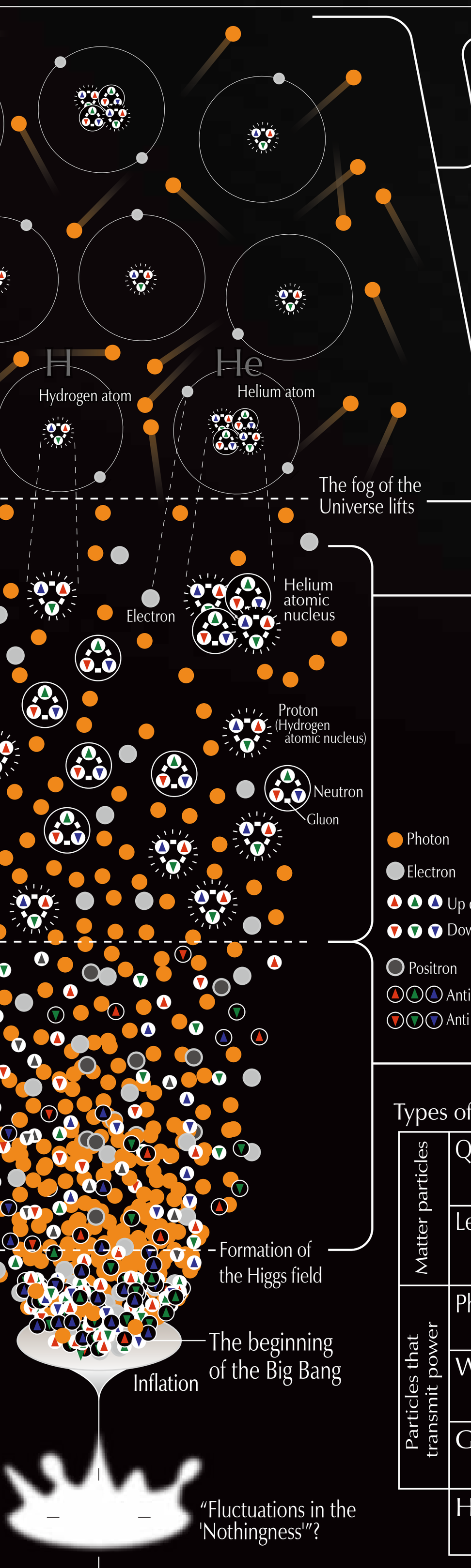
About 370,000 years after the birth of the Universe, "the fog of the Universe lifted". Up until that time, the Universe was superheated, with huge volumes of "electrons*1" flying back and forth. These electrons crashed into photons, preventing light from moving in a straight line, and making the entire Universe opaque, as though in the middle of a fog. When the temperature of the Universe dropped to around 3,000K, however, electrons bonded with atomic nuclei to form "atoms", which no longer impeded the movement of light. In this way, the Universe became much clearer*2. Atoms with similar properties, referred to as elements, would eventually become the materials from which the first stars formed.

*1: When substances are broken down into their most basic ingredients, the smallest component, which cannot be broken down any further, is referred to as an "elementary particle". Electrons and photons are examples of these elementary particles.

*2: The light that was dispersed when this happened can still be observed by humans today, as "cosmic microwave background radiation".

The three minutes in which everything was created
The starting point in the creation of matter

About three minutes after the birth of the Universe: that's the time it took to create all of the matter that exist in the Universe around us. During these three minutes, the superheated Universe cooled off as it expanded at an incredible rate. Quarks, another type of elementary particle and a building block of matter, gathered to form protons and neutrons. Then, these protons and neutrons came together to form the "atomic nuclei" of hydrogen and helium, the lightest of all the elements. About 92% of all the atomic nuclei created at this time were hydrogen, and the remaining 8% were helium. Now, let's take a closer look at the instant in which the Universe was born.



The Universe as a superheated fireball
The "Big Bang"

Immediately after its formation, the Universe was a superheated, super-condensed fireball, heated by an incalculable energy*1. This is what is now referred to as the Big Bang. During this event, huge volumes of elementary particles, including photons, were created. These photons flew about at the speed of light, but about 1 trillionth of a second after the beginning of the Big Bang, a "Higgs field" was formed. Interactions with this field impeded the movement of specific elementary particles, slowing them down below the speed of light. With this hindered movement, the elementary particles gained inertial mass*2. There are two types of elementary particles: particles, and antiparticles. When these two substances collide, they cease to exist, becoming weightless particles similar to light. Because there were about 1 billion times more particles than antiparticles, the former were left behind*3. These left-over particles are believed to have become the substance of the Universe as we know it today.

*1 The temperature at this time was a billion billion billion degrees ($1x10^{27}$K).

*2 There are two types of mass: inertial mass, which manifests as hindered movement, and gravitational mass, which causes universal gravitation. These two types of mass are exactly the same, but the reason for this is still unknown.

*3 Antiparticles are still being created and disappearing today.

Particle: Photon, Electron, Up quark, Down quark
Antiparticle: Positron, Anti up quark, Anti down quark

The beginning of space and time
"Inflation": The rapid expansion of the Universe

In the incredible heat of the Big Bang, the energy that had pervaded the Universe up to that time was transformed into heat. In the very short time of less than one second from just after the birth of the Universe to just before the Big Bang - the period called "inflation" - the Universe expanded at a fantastic rate, increasing in size billions upon billions of times*. The newborn Universe is believed to have been inflated at a fantastic pace by "vacuum energy", which is similar to the dark energy that accelerates the current expansion of the Universe but is much larger, on a scale of 10^{100} times. And with this inflation, time and space became integral parts of the Universe.

* For example, imagine a single virus instantly growing larger than a galaxy cluster.

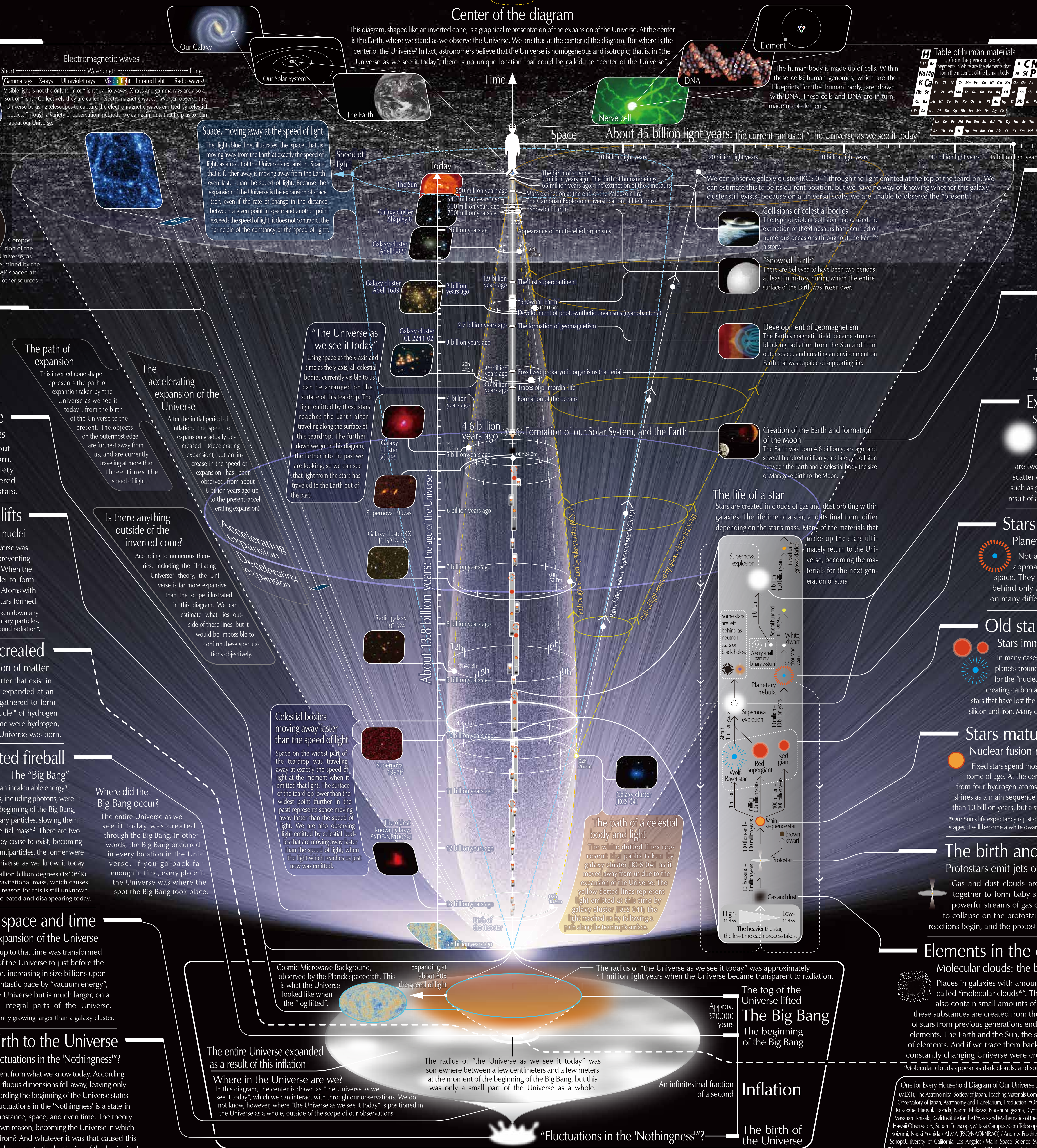
Types of elemental particles

Matter particles	Quark	Up quark, down quark, etc.
	Lepton	Electron, neutrino, etc.
Particles that transmit power	Photon	A medium for electromagnetic power
	Weak boson	A medium for the weak force that acts between elemental particles
	Gluon	A medium for the strong force that connects quarks
	Higgs particle	Particles that accompany activity in the Higgs field

Giving birth to the Universe
Starting from "Fluctuations in the 'Nothingness'"?

It is possible that in the newborn Universe, the number of dimensions was different from what we know today. According to one theory, the Universe originally had 11 dimensions, but eventually, superfluous dimensions fell away, leaving only the three dimensions of space and one dimension of time. Another theory regarding the beginning of the Universe states that the Universe was born from "Fluctuations in the 'Nothingness'". This Fluctuations in the 'Nothingness' is a state in which minuscule universes are born and then disappear in an absence of substance, space, and even time. The theory goes that one of these universes grew without disappearing, for some unknown reason, becoming the Universe in which we now live. But where did this Fluctuations in the 'Nothingness' come from? And whatever it was that caused this Fluctuations in the 'Nothingness', where did it come from? Will we ever find our way to the beginning of the beginning?

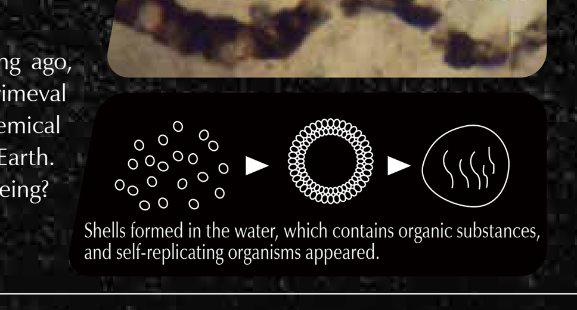
A pushpin hole is about a hundred thousand billion billion billion ($1x10^{32}$) times the size of the Universe when it first came into being.



Life was formed from a variety of elements
The birth and evolution of life on the Earth

Currently, many life forms, including human beings, thrive on dry land on the Earth. Long ago, however, life only existed in the oceans. The first life on the Earth came into being in the primeval seas*. Various elements in the ocean are believed to have combined and undergone chemical reactions, gradually forming complex organisms, and eventually giving birth to the first life on Earth. But if the Earth gave birth to life, then how did the Universe bring the Earth into being?

*It is still not clearly understood when the first life on Earth was formed, but the oldest known fossil of a living organism is about 3.5 billion years old.



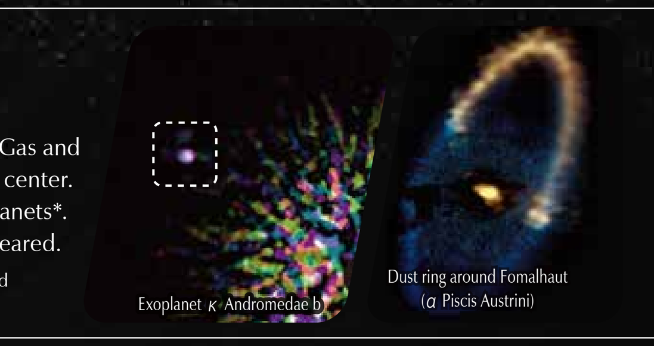
A fossil of a living organism from about 3.5 billion years ago — 10 μm

Shells formed in the water, which contains organic substances, and self-replicating organisms appeared.

The stage is set for the formation of life
The formation of our Solar System, and the Earth

The Earth and the other planets of our Solar System were formed about 4.6 billion years ago. Gas and dust floating in interstellar space gradually condensed into a disk and formed the Sun at the center. Around the same time, material further out in this disk collapsed to form the Earth and other planets*. But where did this material come from? It was the remnants of stars that have long since disappeared.

*In galaxies throughout the Universe, there are innumerable places where gas and dust particles finer than grains of sand coalesce together in huge volumes.



Exoplanet κ Andromedae b — Dust ring around Fomalhaut (α Piscis Austrini)

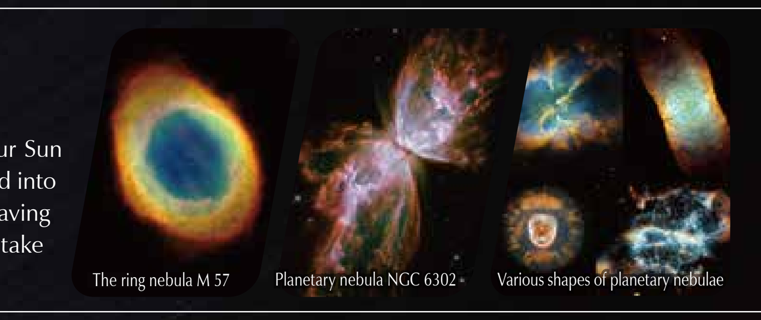
Exploding stars scatter elements throughout the Universe
Supernovae: The alchemy of the Universe

The fragments that became the material of our Solar System were formed in part by "supernovae" that scattered various elements throughout the Universe. Explosions that glowed more than one billion times brighter than the Sun instantly transformed the elements in the stars into other elements. There are two types of supernovae. The first is explosions occurring in stars far more massive than the Sun, which scatter oxygen and other elements created inside the star, and at the same time synthesize other elements such as gold and silver. Iron, which is an essential element in the formation of the human body, is formed as a result of a supernova explosion that occurs in a very small segment of a binary star that includes a white dwarf.

Supernova 1987A — Supernova remnant M 1 (Crab Nebula) — Part of a supernova remnant (Veil Nebula)

Stars that melt into the Universe
Planetary nebulae with various shapes

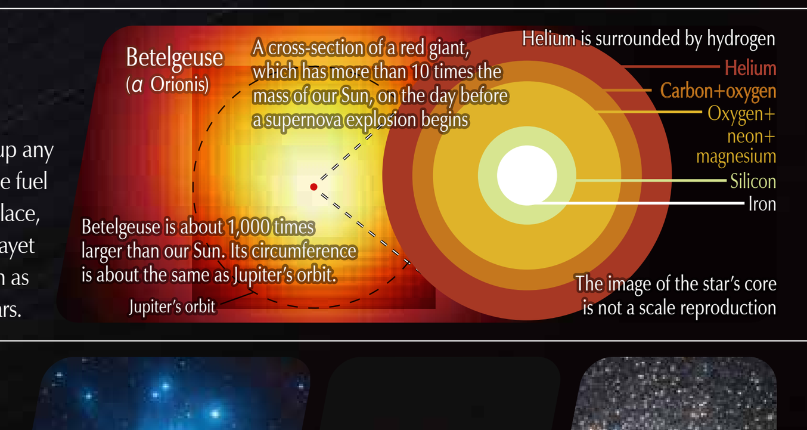
Not all stars meet their end in supernovae. When comparatively low-mass stars like our Sun approach the end of their lives, they slowly begin to diffuse the materials they have created into space. They gradually lose their outer envelopes which spread into the far reaches of space, leaving behind only a core. The remains of this phenomenon, referred to as a "planetary nebula", can take on many different shapes, some round and some long and narrow.



The ring nebula M 57 — Planetary nebula NGC 6302 — Various shapes of planetary nebulae

Old stars are element factories
Stars immediately before the end of their lives

In many cases, when stars grow old, they become "red giants", expanding so much that they swallow up any planets around them. At around this time, the stars begin to run out of hydrogen at their center, which is the fuel for the "nuclear fusion reactions" that allow the stars to shine, and new fusion reactions begin to take place, creating carbon and oxygen from helium. Stars far heavier than the Sun become red supergiants or Wolf-Rayet stars that have lost their outer layer, and even more fusion reactions occur in the star's core, creating elements such as silicon and iron. Many of the elements essential to the existence of human beings were created inside these aging stars.



Stars mature and shine in space
Nuclear fusion reactions and the life of a star

Fixed stars spend most of their lives as "main sequence stars", which is the name given to fixed stars that have come of age. At the center of the stars, there is a series of nuclear fusion reactions that creates a helium atom from four hydrogen atoms. This reaction generates huge volumes of light. The period of time that a given star shines as a main sequence star depends on the star's mass. Stars that are lighter than our Sun will live for more than 10 billion years, but a star with 10 times the mass of our Sun will only live for a few tens of millions of years*.

*Our Sun's life expectancy is just over 10 billion years. More than 5 billion years in the future, it will become a red giant, and in its final stages, it will become a white dwarf.

Open cluster M 45 (Pleiades) — Double Star Albireo (β Cygni) — Globular cluster M 15

The birth and growth of stars
Protostars emit jets of gas

Gas and dust clouds are the materials that form stars. Huge volumes of this material come together to form baby stars or "protostars". Some of this material is later ejected in fine but powerful streams of gas called "jets" that are emitted from protostars. Fresh material continues to collapse on the protostar, and as the core temperature and pressure increases, nuclear fusion reactions begin, and the protostar finally begins to shine as a main sequence star.

Protostar M17-SO1 — Protostellar Jet HH 47

Elements in the constantly changing Universe
Molecular clouds: the birthplace of stars

Places in galaxies with amounts of gas and dust at particularly high levels of concentration are called "molecular clouds*". These clouds are composed mainly of hydrogen molecules, but they also contain small amounts of water, carbon monoxide, alcohol, and other components. All of these substances are created from the diverse elements scattered through the Universe when the lives of stars from previous generations end. In other words, stars come from the elements, and return to the elements. The Earth and the Sun, the stars in the sky, and even our bodies are all part of this great cycle of elements. And if we trace them back far enough, we find that all of the substances that make up this constantly changing Universe were created in the first three minutes after the Universe was born.

*Molecular clouds appear as dark clouds, and sometimes appear to glow as they are illuminated by the light of nearby stars.

Dark nebula LDN 57 — The core of M42 (the Orion Nebula) — Part of M16 (the Eagle Nebula)

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