What is the Universe?

The Universe is all of space and time, the sum of all things that exist everywhere. Earth and sky, humans, plants and animals – all these are a part of the Universe. Stars illuminating the night sky, the faintly glowing Milky Way, and distant galaxies that can only be seen through powerful telescopes are all part of the Universe. The Universe contains everything that we know, and everything that remains hidden in the farthest reaches of the sky.

Diagram of theUniverce

Elements were formed because the **Universe** was formed

U Chu Zu

Humans are born and **science** is born.

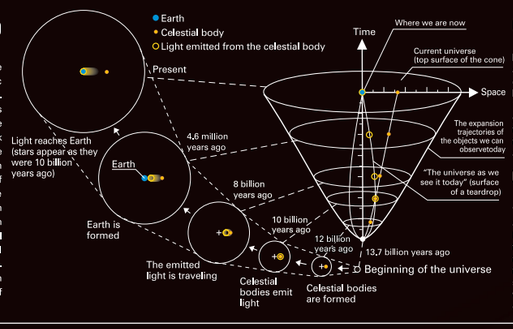
What is Science?

Science is a method for understanding our universe. When you see something curious and you wonder "why?" – you have taken your first step in scientific exploration. Science is investigating things that interest you by observing, experimenting and sharing your experience with others. If you gain a better understanding or even a new way of understanding through this process – that's scientific discovery.

How to Use this Map

Overview

This "map" depicts the Universe as revealed by recent scientific research, with Earth at the center. The vertical direction represents the flow of time, starting from the present at the top and going back to the beginning of the time at the bottom. The horizontal direction represents the spacial extent of the Universe. The map has the shape of an inverted cone, which means that the Universe has been expanding with time. This map will be your guide on a wonderful journey through time and space. Keep the following four points in mind, and uncover the secrets of the Universe.



Point 1 Looking into the distance means looking into the past

It seems strange, but when you look into space from Earth, you're actually seeing what the Universe looked like in the past. For example, when we look at the Sun, we are actually seeing what it looked like eight minutes ago. Our view of the Andromeda Galaxy is 2.3 million years old. 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 even for light to reach us. By the time that light gets here, the objects that emitted the light have already changed.

Point 2 There is a visible ("observable") universe and an invisible universe

The Universe as it exists today spreads out in all directions around us, but we can't see what it really looks like. Remember point 1; What we see is the Universe as it was in the past. If we limit this map to what is actually observable, the celestial bodies that we can see with the naked eye or through telescopes, we get a teardrop-shape like the one shown in the center. This is the only part of the Universe that we can see, and even these objects are visions from a different era, thousands or even millions of years ago.

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

When we talk about distances to celestial bodies, we talk about "the path that light has traveled to reach us." For example, light from the farthest point in the observable universe has traveled for 13.7 billion years, a distance that we refer to as "13.7 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 farther away. By the time the light reaches us, that starting point is estimated to be as far as 47 billion light-years away.

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

The observable universe (the teardrop-shaped image at the center of the map) 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 much just by examining the observable universe. How did the Universe come into existence (the tip of the cone)? How has it expanded (the outer surface of the cone)? Does anything exist beyond the outer limits of this cone? This Map of the Universe contains some answers.

Life in Our Solar System

Does life exist somewhere in the Universe, aside from planet Earth? First, let's look at the possibilities in our solar system. The Solar System is comprised of celestial bodies with various sizes and environments.

The Solar System includes: the Sun, eight planets, Plutonian objects, asteroids, comets, and other small objects.

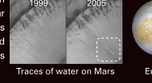
The Sun : One of more than 100 billion stars in the Milky Way galaxy

Terrestrial planets
Planets comprised mainly of rock

Jupiter-type or "Jovian" planets
Giant planets comprised mainly of hydrogen and helium gas

trans-Neptunian objects
in the outer solar system: Objects comprised of ice mainly, found outside of Neptune's orbit

In the 21st century, 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 the Solar System to look for traces of life. Among the main targets for these probes are Mars, where liquid water is thought to exist under 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 similar to those found on Earth.



Traces of water on Mars

Europa

Looking for "Another Earth"

Does life exist in the vast expanse of the Universe outside of our solar system? Since stars themselves do not have conditions that could sustain life, in order to find life outside of the Solar System we must first look for "extrasolar planets," planets outside the Solar System. The existence of such planets was first confirmed only just recently, in 1995. Since then, astronomers have discovered more than 200 planets outside of our solar system, using a variety of clues such as minute variations in the movement of stars resulting from the revolution of planets around them, or slight changes in the brightness of stars when planets pass in front of them.

Still, we have yet to find a planet that could be called "Another Earth." Although many planets of the size of Jupiter have been discovered, we have yet to find a planet as small as Earth. A new phase of discovery is about to begin,however. Satellites equipped with specialized telescopes have been launched into orbit, and these telescopes will be used to seek out terrestrial planets from space.

Celestial bodies outside of our solar system are so far away that even if we found a terrestrial planet, we could not send a probe to explore it directly. We must therefore use other methods to determine whether those planets could sustain life. For example, by observing the planet's environment or atmospheric components to confirm whether water exists in liquid form, or by looking for traces of "biomarkers" such as oxygen, ozone, and chlorophyll that are products of biological processes.

The "Transit Method" is used to find planets outside of the Solar system as they pass in front of stars.

The satellite "COROT," launched in December 2006, is using the transit method to search for terrestrial planets outside the Solar System.

How did the Universe come into existence?

This seemingly limitless Universe was once so small that it could not be seen. Modern science is closing in on the possibility that the Universe was created from "nothing," and is gradually gaining an understanding of the astounding scenario that took place immediately after the birth of the Universe. Let's look back at the history of the Universe, starting from the moment of its birth some 13.7 billion years ago.

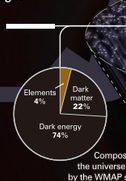
Galaxy Cluster Abell 1689

Spiral Galaxy NGC2403

The Universe as We Know It

stars in the dark

Observations now show that the over 70% of the Universe consists of a mysterious form of energy called "dark energy", over 20% is a mysterious form of matter called "dark matter", and only 4% is ordinary matter like stars and planets. We also know that ordinary matter shows a hierarchical structure. Stars gather in the hundreds of billions to form galaxies. Hundreds and thousands of galaxies collect to form galaxy clusters. Galaxies form mesh-like large scale structures that extend hundreds of millions of light years. Galaxies collide and merge, in a never-ending process of change.

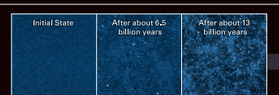


Composition of the universe shown by the WMAP satellite

A Mesh of Galaxies

large-scale structure traces dark matter

Why are galaxies distributed in the form of a mesh? The answer to this question can be found in "dark matter," a substance that remains unexplained, and cannot be observed using light. In areas where dark matter exists at higher densities than surrounding areas, even more dark matter collects, forming large-scale structures in the form of a three-dimensional mesh. Ordinary matter also collects where large masses of dark matter exist, eventually forming galaxies along these large-scale structures.



Results of computer simulations of the evolution of large-scale structures in space. The blue gaseous substance represents dark matter. In reality, dark matter is invisible.

The First Stars Illuminate the Universe

the birth of stars and galaxies

We know that galaxies already existed in the Universe about 13 billion years ago, but we don't know exactly when the first stars were born. The first stars were probably several hundred times more massive than our sun. A variety of chemical elements* were created inside these giant stars, after which the stars exploded as supernovas, disappearing into space. The elements scattered by these explosions became the seeds of a new generation of stars.

* Elements are 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 elements.

A simulation of the first star in the Universe

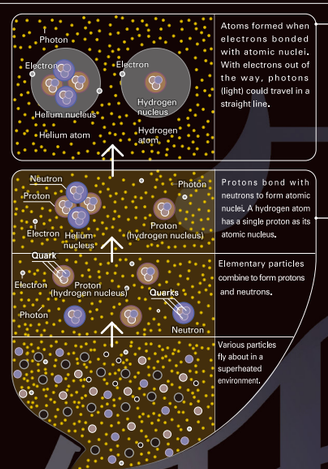
IOK-1 : The farthest galaxy currently known (12.88 billion years)

The Primordial Fog Lifts

electrons unite with atomic nuclei

About 380,000 years after its birth, the Universe was superheated, and large numbers of electrons* flying back and forth prevented light from moving in a straight line, making the entire universe opaque to light like fog. When the temperature dropped to around 3000°C, electrons were able to unite with atomic nuclei to form atoms of various elements. This enabled light to travel freely, and the Universe became clear for the first times. These atoms would eventually become the materials from which the first stars were formed.

* When substances are broken down into their most basic components, the smallest component, which cannot be broken down any further, is referred to as an "elementary particle." The electron is an elementary particle.



The First Three Minutes

the creation of matter

Three minutes. That's the time it took to create all the matter that exists in the Universe. During its first three minutes, the superheated universe cooled off as it rapidly expanded. Elementary particles were the first to form. These particles then formed protons and neutrons. Protons and neutrons bonded to form the atomic nuclei of hydrogen and helium, the lightest of all the elements. About 90% of all the atomic nuclei created at this time were hydrogen, and about 10% were helium.

A Superheated Fireball

the Big Bang

In its first few moments, the Universe became a superheated, super-condensed fireball with a radius of only about one light year, heated by an incalculable energy. This is the Big Bang. The fact that the Big Bang actually occurred is now virtually undisputed, based on observations of the expanding universe, the abundance ratio of elements in the Universe as we know it, and the existence of the Cosmic Microwave Background Radiation.*

* Light emitted back when the fog of the Universe lifted continues to arrive to us in the form of the Cosmic Microwave Background Radiation (CMBR). The CMBR is evidence that the Universe was once superheated.

Everything from Nothing

inflation: rapid expansion in the very early universe

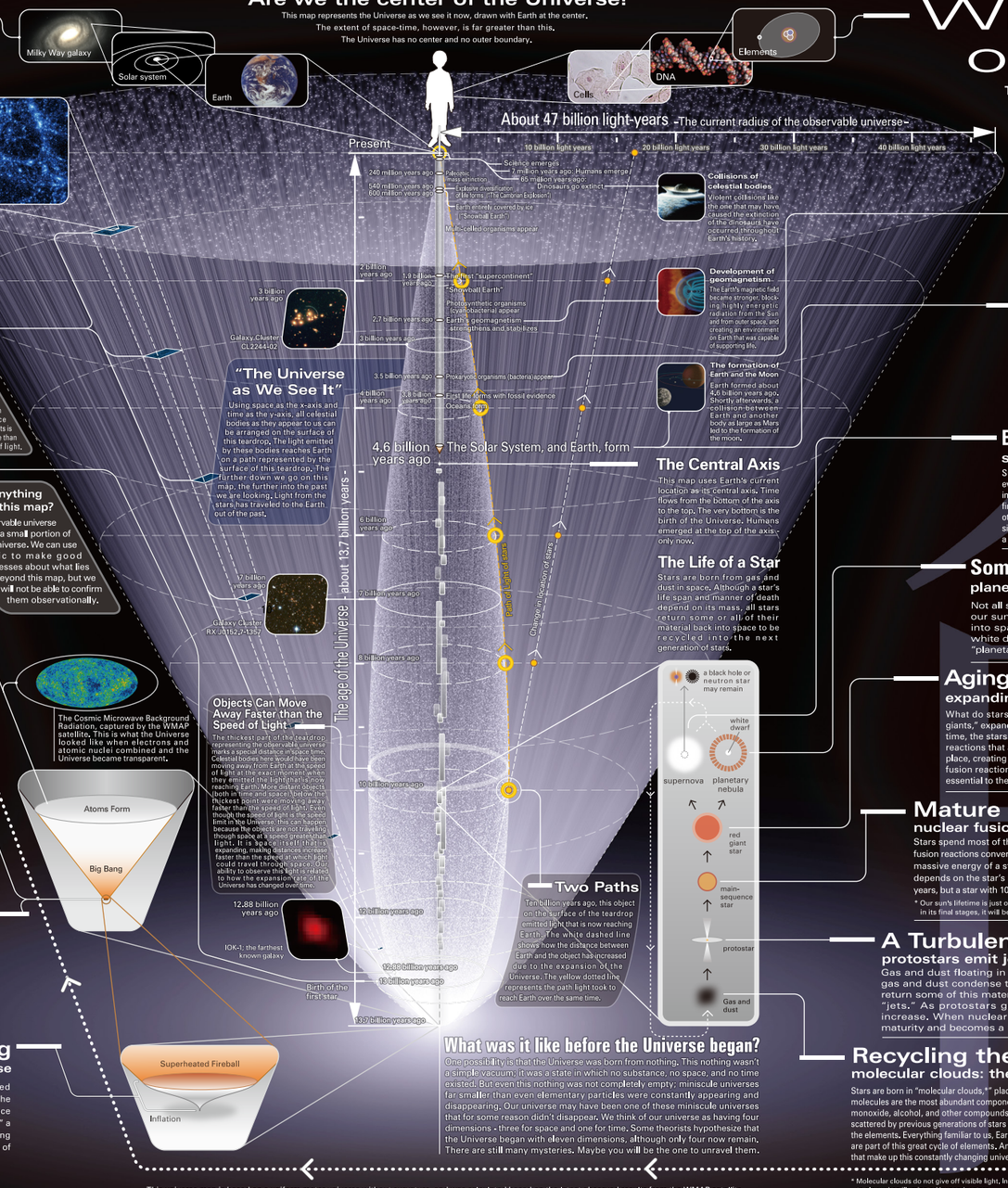
In the first 10^{-34} seconds* after its birth, the Universe went through a phase called "inflation" in which it expanded in size billions upon billions of times.** But what was the origin of the invisible micro-universe that existed before this inflation? Modern science suggests that the Universe may have originated suddenly from a "vacuum fluctuation," a fluctuation in nothing. Today, a still unexplained force known as dark energy is causing space to expand at a faster rate. Some similar form of "vacuum energy", but 100 orders of magnitude larger, may have caused the inflation of the early universe.

* One trillion of one trillionth of one 10 billionth of a second.

** For example, imagine a single bacterium instantly growing to become even larger than a galaxy.

Are we the center of the Universe?

This map represents the Universe as we see it now, drawn with Earth at the center.
The extent of space-time, however, is far greater than this.
The Universe has no center and no outer boundary.



"The Universe as We See It"

Using space as the x-axis and time as the y-axis, all celestial bodies as they appear to us can be arranged on the surface of this teardrop. The light emitted by these bodies reaches Earth on a path represented by the surface of this teardrop. The further down we go on this map, the further into the past we are looking. Light from the stars has traveled to the Earth out of the past.

The Path of Expansion

This cone shape represents the apparent extent of the observable universe from the beginning of space-time to the present. The objects on the outermost edge are the most distant objects we can observe today. The distance between Earth and these objects is currently increasing at more than three times the speed of light.

Is there anything beyond this map?

The observable universe is only a small portion of the Universe. We can use logic to make good guesses about what lies beyond this map, but we will not be able to confirm them observationally.

Objects Can Move Away Faster than the Speed of Light

The thickest part of the teardrop representing the observable universe marks a special distance in space time. Celestial bodies here would have been moving away from Earth at the speed of light at the exact moment when they emitted the light that's now reaching Earth. More distant objects (both in time and space, below the thickest part) were moving away faster than the speed of light. Even though the speed of light is the speed limit in the Universe, this can happen because the objects are not traveling though space at a speed greater than light. It is space itself that is expanding, making distances increase faster than the speed at which light could travel through space. Our ability to observe this light is related to how the expansion rate of the Universe has changed over time.

Two Paths

Ten billion years ago, this object on the surface of the teardrop emitted light that is now reaching Earth. The white dashed line shows how the distance between Earth and the object has increased due to the expansion of the Universe. The yellow dotted line represents the path light took to reach Earth over the same time.

The Cosmic Microwave Background Radiation, captured by the WMAP satellite. This is what the Universe looked like when electrons and atomic nuclei combined and the Universe became transparent.

What was it like before the Universe began?

One possibility is that the Universe was born from nothing. This nothing wasn't a simple vacuum, it was a state in which no substance, no space, and no time existed. But even this nothing was not completely empty; miniscule universes far smaller than even elementary particles were constantly appearing and disappearing. Our universe may have been one of these miniscule universes that for some reason didn't disappear. We think of our universe as having four dimensions - three for space and one for time. Some theorists hypothesize that the Universe began with eleven dimensions, although only four now remain. There are still many mysteries. Maybe you will be the one to unravel them.

This universe map is based on a uniform meter universe without curvature, and was calculated based on the latest observed results from the WMAP satellite.

What is the materials' origin of the humans?

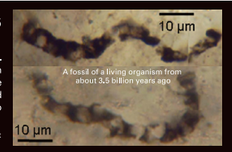
The human body, which could be compared to a small "universe," is comprised of different elements. We now know that these elements originated in stars, and were scattered through space eons ago. Let's go back in time to unravel the intimate connection between humans and the Universe.

Life Consists of a Variety of Elements

the birth and evolution of life on Earth

Today, many life forms, including humans, thrive on dry land on Planet Earth. Long ago, however, life only existed in the oceans. The first life forms on Earth came into being in the primeval seas*. It is believed that various elements in the ocean underwent chemical reactions, gradually forming complex structures, and eventually giving birth to the first life forms on Earth. But if Earth gave birth to life, then how did the Universe bring Earth into being?

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

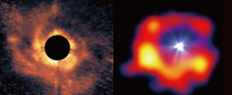


Setting the Stage for Life

the formation of the solar system, and Earth

Earth and the other planets of our solar system formed about 4.6 billion years ago. Gas and dust floating in space came together and gradually formed the Sun, and around the same time, other gas and dust floating nearby became Earth and the other planets*. But where did the gas and dust come from? They were the remnants of stars that have long since disappeared.

* Throughout the Universe, there are places where huge volumes of gas and dust, solid particles finer than grains of sand, float together.



A protoplanetary disk around the star AB Aurigae

A dust disk around the star Epsilon Eridani

Exploding Stars Scatter Newly Forged Elements

supernovae: alchemists of the Universe

Supernovae scattered various elements throughout the Universe, including some bits that eventually became our solar system. These explosions, which glow brighter than one billion suns, instantly transform elements in stars into other elements. There are two types of supernovae. The first is 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 create other elements such as gold and silver. The second type of supernova is an explosion occurring in a binary star system that includes a type of star called a white dwarf. These create iron, an essential element in the human body.

Some Stars Return Elements More Quietly

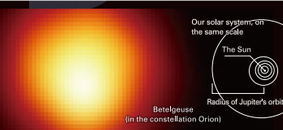
planetary nebulae: the final show of low-mass stars

Not all stars end their life as a supernova. When comparatively light stars like our sun approach the end of their lives, their outer portions slowly defuse into space. They gradually lose their form, leaving behind a core called a white dwarf. The matter that has drifted into space can often be seen as a "planetary nebula," which can take on a variety of shapes.

Aging Stars Are Element Factories

expanding red giants

What do stars look like just before they die? 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, which is the main fuel for the nuclear fusion reactions that allow stars to shine. Without hydrogen, new fusion reactions begin to take place, creating carbon and oxygen from helium. In stars far heavier than the sun, even more fusion reactions occur, creating elements such as silicon and iron. Many of the elements essential to the existence of human beings were created inside these aging stars.



Mature Stars Shine Steadily

nuclear fusion sustains a star's life

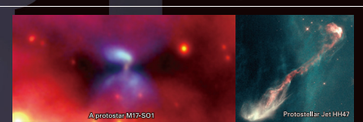
Stars spend most of their lives as "main-sequence" stars. At the center of such stars, nuclear fusion reactions convert four hydrogen atoms into one helium atom. These reactions generate the massive energy of a star. The length of time that a given star shines as a main-sequence star depends on the star's 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 lifetime 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.

A Turbulent Youth

protostars emit jets of gas

Gas and dust floating in space are the raw material for stars. Huge volumes of gas and dust condense to create baby stars called "protostars." The protostars return some of this material back into space in the form of streams of gas called "jets." As protostars grow in mass, their core temperature and pressure increase. When nuclear fusion reactions begin, the protostar finally reaches maturity and becomes a main-sequence star.

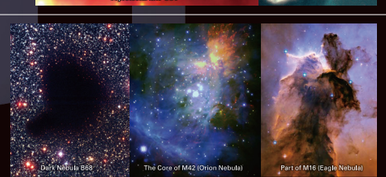


Recycling the Elements

molecular clouds: the birthplace of stars

Stars are born in "molecular clouds,"* places in galaxies where gas and dust are highly concentrated. Hydrogen molecules are the most abundant component, but molecular clouds also contain small amounts of water, carbon monoxide, alcohol, and other compounds. All of these complex molecules formed from elements created and scattered by previous generations of stars at the time of their death. Stars come from the elements, and return to the elements. Everything familiar to us, Earth, the Sun, the stars in the sky, and the bodies of every living creature, are 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 do not give off visible light. In astronomical images, they often appear as dark clouds, and sometimes appear to glow when illuminated by nearby stars.



One-per-Household Diagram of the Universe 2007. supervision : Ministry of Education, Culture, Sports, Science and Technology/The Astronomical Society of Japan Committee on Astronomical Teaching Resource **production and selling agency** : The Japan Foundation of Public Communication on Science and Technology **planning** : NINS, National Astronomical Observatory of Japan/the Tenpla Project **authors** : Hidehiko Agata, Jun Kosaka, Naohiro Takanashi, Masaaki Hiramatsu, Shiou Kawagoe, Norio Narita, Seiichiro Naito, Nobuhiko Kusakabe, Hiroyuki Takata, Naomi Ishikawa, Naoshi Sugiyama, Kiyotomo Ichiki, Hitoshi Yamaoka, Akira Katagiri, Shoken Miyama , Katsuhiko Sato, Wako Aoki, Hitoshi Miura, Sorahiko Nukatani, Masahiro Kishima, Masaharu Ishizaki, Catherine Ishida **references**: D. N. Spergel et al. (2007) "Wilkinson Microwave Anisotropy Probe (WMAP) Three Year Results: Implications for Cosmology" (The Astrophysical Journal, astro-ph/0603449) **Images provided by** : National Astronomical Observatory of Japan/Subaru Telescope at Hawaii Observatory/50 cm telescope at the Mitaka Campus/105 cm telescope at Ishigakijima Astronomical Observatory/Four-Dimensional Digital Universe Project, NAOJ/ Eiichiro Kokubo/Masahiro Nagashima/Hideki Yahagi/Nature Production/Naoki Yoshida/Anglo-Australian Observatory/David Malin Images/Caltech/CNES/ESA/ESO/HEIC/James Clerk Maxwell Telescope, Joint Astronomy Centre, Hawaii/JPL/J.J.Williams Schopf,University of California,Los Angeles/Malin Space Science Systems/NASA/NOAA/SOHO/Space Science Institute/STScI/The Hubble Heritage Team/PDB ID:1DNN Trifonov,E.N., Sussman, J.L., Smooth bending of DNA in chromatin.In:"Molecular Mechanisms of Biological Recognition"(Ed. M. Balaban),Elsevier/North Holland Biomed.Press,1979,pp.227-232/WMAP Science Team