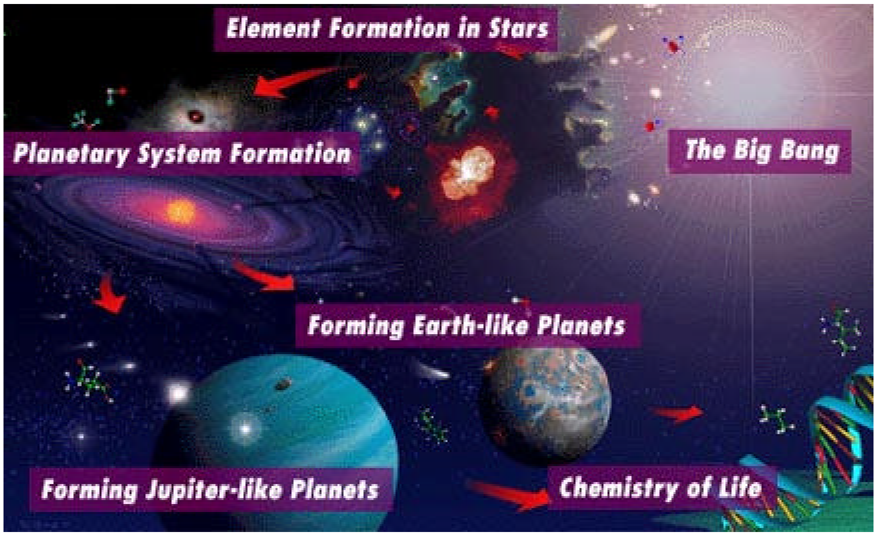
Time Line of the Universe



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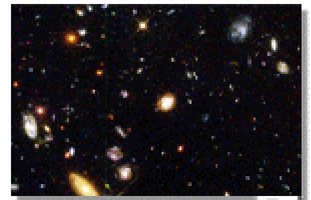
This tutorial follows the 15-billion-year-long history of the Universe. The image above illustrates the major chain of events that eventually led to life on Earth. The sequence starts at upper right with the Big Bang and proceeds counter-clockwise following the red arrows to the Chemistry of Life at lower right. Click on the major events above to learn more about them, or start with the Big Bang.

The Big Bang

Scientists believe that the universe was created about 15 billion years ago in a single violent event known as the **Big Bang**. All the space, time, energy, and matter that constitute today's universe originated in the Big Bang. The early universe was extremely small, dense, and hot. For the first fraction of a second, only energy existed.

As the universe expanded and cooled, the four fundamental forces (gravity, electromagnetism, and the strong and weak nuclear forces) became distinct. Quarks, then atomic particles and their antimatter partners, appeared. As matter and antimatter met, they annihilated each other, leaving behind energy and a slight excess of ordinary matter -- almost exclusively the lightest elements, hydrogen and helium. The faint residual heat from the Big Bang can be observed coming from everywhere in the sky.

Galaxies



The Hubble Deep Field.

The young universe did not have a perfectly even distribution of energy and particles. These irregularities allowed forces to start to collect and concentrate matter. Accumulations started to develop ever more complicated structures. Concentrations of matter formed into clouds, then condensed into stars and the collections of stars we call galaxies. The way in which galaxies spin indicates that their visible portions of stars and diffuse gas and dust clouds known as nebulae constitute only one tenth of the total mass. The so-called "missing mass" could hold the key to the ultimate fate of the universe -- that is whether it expands forever or is pulled back together by the combined gravitational attraction of all of its mass.

From the standpoint of the development of life, what matters is that each galaxy is a stellar factory, producing stars out of giant gas clouds; each star is a chemical factory, transmuting simple elements into heavier, more complex ones; and life is a collection of some of these complex molecules. Visible matter comes in a wonderful variety of galaxy forms, characterized by their distributions of stars and glowing or dark

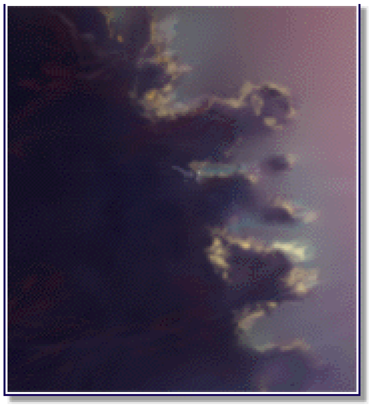
Distant Galaxies and the Hubble Deep Field

The Hubble Deep Field is our deepest and most detailed look at the horizon of the visible universe. This dark patch of sky was selected by astronomers to be as empty as possible of foreground stars and known clusters of galaxies. This image was constructed from 342 separate Wide-Field Planetary Camera-2 (WFPC2) exposures taken in ultraviolet, blue, red, and infrared light during ten consecutive days of observing in December 1995 by the Hubble Space Telescope (HST). The Hubble Deep Field is located near the handle of the Big Dipper, and its size in the sky would appear to the naked eye about equal to the size of a grain of sand held at arm's length.

The Hubble Deep Field shows over 3000 galaxies at various distances and stages of evolution. There are only four obvious stars visible in the image (they appear as point-like objects with diffraction spikes, can you find them?). The small number of stars is a consequence both of the tiny field of view and of the fact that we are looking up out of the plane of the Milky Way Galaxy. Many different types of galaxies are visible, including spirals like our own, almost featureless ellipticals, and many disturbed-looking "oddballs." Some of these oddball galaxies may be in the midst of titanic collisions with other galaxies, while others are still in the star-forming exuberance of youth.

Astronomers are using the largest telescopes in the world to determine which of the galaxies in the image are relatively nearby and faint, and which are truly at the edge of the visible universe. The light from these farthest galaxies took many billions of years to cross the vast expanse of the universe, and so we are seeing them as they appeared very shortly after they and the universe were born. The Hubble Deep Field therefore promises to become the Rosetta Stone of cosmology, allowing astronomers to answer fundamental questions about the age, size, and composition of the universe. Whatever the answers, the Hubble Deep Field will rank among the greatest scientific treasures of the twentieth century.

Image Credits: Robert Williams (Space Telescope Science Institute), the Hubble Deep Field Team, and NASA.



Giant Molecular Clouds

The largest inhabitants of galaxies are giant clouds of molecules that contain the raw material for stars and planets. A cloud with a diameter of 300 light years (1 light year is equal to about 10 trillion kilometers) contains enough mass to manufacture 10,000 to a million stars, each with the mass of our Sun. However, only about 10 percent of the cloud will be in clumps dense enough for stars to form -- enough to produce a few hundred to a few thousand new stars. Giant molecular clouds last for 10 to 100 million years before they dissipate.

Element Formation in Stars

Star birth in Eagle Nebula.

Clouds and Star Birth

Gravity acts on individual particles to form collections that attract still more particles. Under the right conditions, gravity can overcome the disruptive forces of heat and turbulence to create spheres of gas that are hot enough and dense enough at their centers so that hydrogen can fuse into helium -- creating a star. But this new star will probably not yet be apparent in visible light. The young star is surrounded by a dense, opaque shroud of dust. As the star heats the dust, the star becomes detectable by infrared telescopes as a "hot spot" within a large, dense molecular cloud. Winds from the star will eventually blow away residual gas and dust and the star will become visible in optical telescopes.
Star Birth in the Eagle Nebula

These magnificent, pillar-like structures are vast columns of gas and dust in the Eagle Nebula, within which new stars have recently formed. The pillars protrude from the interior wall of a dark molecular cloud like stalagmites from the floor of a cavern. The tallest of the pillars (at left) is about one light year in length from base to tip. The Eagle Nebula is a star-forming region 7000 light years away in the constellation Serpens.

The pillars are in some ways akin to buttes in the desert, where basalt and other dense rock have protected a region from erosion while the surrounding landscape has been worn away. In this celestial setting, especially dense clouds of dust and gas have survived longer than their surroundings as they are flooded by intense ultraviolet light from nearby hot, massive, newborn stars in an erosive process called photoevaporation. The ultraviolet light is also responsible for illuminating the convoluted surfaces of the pillars and the ghostly streamers of gas boiling away from their surfaces.

As the pillars are slowly eroded by the ultraviolet light, small globules of even denser gas and dust buried within the pillars are uncovered. These globules have been named evaporating gaseous globules (EGGs). The term describes their nature, for forming inside some of the EGGs are embryonic stars, which abruptly stop growing when the EGGs are uncovered and separated from the larger reservoir of gas and dust from which they were drawing mass. Eventually, the new-born stars emerge as the EGGs themselves succumb to photoevaporation.

This color picture has been constructed from three separate WFPC2 exposures taken in the light of emissions from different atomic constituents: red shows emission from singly ionized sulfur atoms, green is emission from atomic hydrogen, and blue shows emission from doubly ionized oxygen atoms.

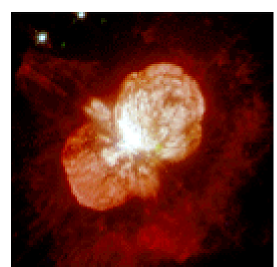
Image credits: J. Hester and P. Scowen (Arizona State University), and NASA.

Mature Stars and Nucleosysthesis

Young stars grow and shrink as they try to strike an evolving balance between gravity, which tries to compress the star, and the pressure from the fusion reactions that try to make the star expand. **Mature stars** have achieved that delicate balance and spend almost their entire lives that way.

A star's size, color, brightness, and lifespan are the consequence of the total amount of its mass. Stars with only small amounts of material (a few tenths the mass of our Sun) become cool "red dwarfs" that live for many billions of years. Stars with the mass of our Sun last for about 10 billion years. Giant stars, with a few tens of the mass of our Sun, consume their fuel furiously and burn, white-hot, for only a few million years.

Over its entire lifetime, a star's hydrogen is being fused into helium. Late in the star's life, its helium mass becomes great enough to reach the necessary pressure and temperature, and the helium begins to fuse into still heavier elements. Shells of fusion, each requiring higher and higher pressures and temperatures, form from the ashes of the previous reaction and create new elements in the process known as **nucleosynthesis**. The additional heat produced in the core causes the star to swell.



Death of star Eta Carinae.

The New Star

Eventually, all stars run out of fuel in their cores. They lose their equilibrium as the force of gravity comes to dominate. Different-mass stars end their lives differently. Low-mass stars die quietly as their nuclear fires dwindle. The core in a Sun-like star collapses rapidly into an Earth-size white dwarf. The star's outer layers, containing atoms formed in the fusion process, are left as expanding bubbles or jets of material that expand out into the universe. A massive star's core collapses almost instantaneously. It rebounds outward and strikes other material falling inward. This collision occurs with so much energy that it creates all of the naturally occurring elements and blows the star apart. This explosion, a **supernova**, is the source of all the heavy elements that are found in nebulae, stars, planets, and interstellar space.

Deep in cold, interstellar space, elements such as carbon, oxygen, and nitrogen can combine with primordial hydrogen to form complex molecules, particularly in dense condensations of gas called molecular clouds, where collisions between gas atoms and dust grains are possible. A large number of complex molecules, particularly those involving carbon atoms, have been detected in interstellar space.

PHOTO CAPTION (JPL P-43398 C)

Death of Star Eta Carinae

An "almost true color" image of the material surrounding the star Eta Carinae. The picture was obtained with the second generation Wide-Field and Planetary Camera-2, designed and built at the Jet Propulsion Laboratory in Pasadena, Calif. The new camera was installed during the Hubble Space Telescope servicing mission, STS-61, in December 1993. WFPC-2 incorporates optics that correct for the aberration of the telescope's primary mirror, restoring the optical quality of images obtained with the telescope to the level that the telescope was originally designed to provide.

Eta Carinae is one of the best studied and most fascinating objects in the sky. The star has a mass of approximately 150 times that of the sun, and is about 4 million times brighter than our local star, making it one of the most massive and most luminous stars known.Unlike the benevolent and quiescent center of our solar system, Eta Carinae is highly unstable and prone to violent outbursts. The last of these occurred in 1841, when despite its distance (more than 10,000 light years away), Eta Carinae briefly became the second brightest star in the sky. Since that time the star has grown over 600 times fainter in visible light, so that today, Eta Carinae is only barely visible to the naked eye. The rapidly expanding shell of material ejected during the last century's outburst (named the "homunculus" or the "little man" in 1950 by the Italian astronomer Gaviola) was the target of pre- servicing mission Hubble Space Telescope observations taken with JPL's original Wide-Field and Planetary Camera-1. This observation demonstrated the potential for discovery which has always been one of the strongest motivations for a mission such as HST. However, the WFPC-1 image of Eta Carinae suffered from the effects of HST's spherical aberration. In particular, the structure of the material very near Eta Carinae itself a question of great scientific interest was totally obscured in the original images by the spherical aberration "skirt" around the bright star. Now the clear view of Eta Carinae provided by WFPC-2 dramatically demonstrates the ability of HST to reliably study faint structure near bright objects a demonstration of the capability that will allow the HST to carry out many of the high priority scientific programs (e.g. imaging of disk systems surrounding stars) which were most hampered by spherical aberration. \On the other hand, the observations of Eta Carinae also demonstrate how pre-servicing mission HST science complements work to be done with the restored capabilities of the telescope. By comparing the WFPC-1 and WFPC-2 images, astronomers are watching the nebula grow and change with time.

The picture shown is actually a combination of three different images taken in red, green and blue light. The ghostly red outer glow surrounding the star is composed of the very fastest moving of the material which was ejected during the last century's outburst. This material, much of which is moving in excess of 2 million miles per hour, is largely composed of nitrogen and other elements formed in the interior of the massive star, and subsequently ejected into interstellar space. Massive stars convert the hydrogen and helium which were present in the early universe into heavier elements, then disperse this enriched material into space, where it can be incorporated into other stars and solar systems (and eventually people). Thus, by looking at Eta Carinae, we are looking at one way that the universe conspired to make our own existence possible. The bright blue/white nebulosity closer in to the star also consists of ejected stellar material. Unlike the outer nebulosity, this material is very dusty and is seen in reflected starlight. The new data show that this structure consists of two lobes of material, one of which (lower left) is moving toward us and the other of which (upper right) is moving away. This is called a "bipolar flow." The knots of ejected material have sizes comparable to that of our solar system. Astronomers study bipolar flows in a number of contexts; the principal feature of most models of bipolar flows is a dense disk surrounding the star which funnels the ejected material out of the poles of the system. Such disks are used to explain almost all directional outflows from stars, and are also thought to be linked to the formation of solar systems. In Eta Carinae, however, high velocity material is seen to be spraying out in the same plane as the disk which is supposed to be channeling the flow. This is quite unexpected: bullets don't normally shoot out of the sides of a gun. How can it be that the same disk that keeps material from the star flowing into the two lobes also lets other material through, actually concentrating it in the very direction which should be hardest for it to go? Does the disk exist at all, or is there something fundamentally wrong with our understanding of how bipolar flows are formed? As with all good scientific experiments, the WFPC-II observations of Eta Carinae raise as many questions as they answer.

Source: PUBLIC INFORMATION OFFICE
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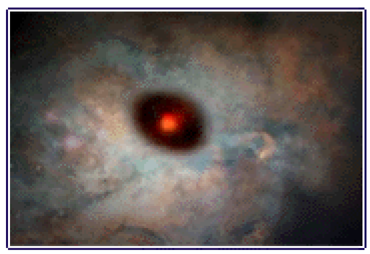
Planetary System Formation

Protoplanetary Disks



Forming planetary systems may appear as dark or luminous disks silhouetted against a glowing nebula. Others, deeply embedded in their natal clouds, can be seen only in infrared light. Still others show knots of material with long, comet-like streamers formed as an interstellar wind blows the area clear.

These protoplanetary regions are up to 20 times the diameters of our solar system. All the material in a protoplanetary disk spins in the same direction around the star. The disk includes the complex molecules found in the original nebula, plus others that may form as the density and temperature change in the dense regions of the nebula surrounding the star.

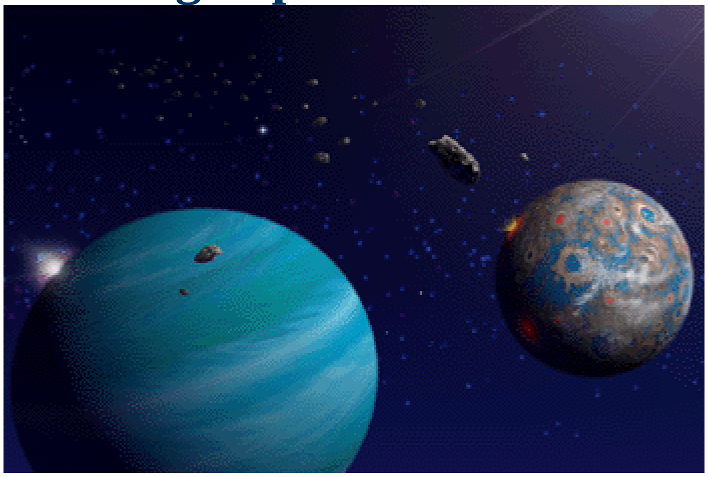
Planetesimals Form and Protoplanets Condense

Artist's conception of the formation of planetesimals within a protoplanetary disk.
Image Credit: Pat Rawlings, for the Jet Propulsion Laboratory.

Within the spinning protoplanetary disk, gravity allows clumps to form and grow -- creating objects called planetesimals. Heavy metals and silicates can survive the winds and high temperatures found close to the star, but lighter, volatile materials such as water and hydrogen gas survive only in the outer parts of the disks.

Clumps of solid material begin to solidify as they accumulate enough mass; growing larger as the result of collisions. Eventually, a few large objects -- protoplanets -- will begin to dominate the nebula, accreting more and more of the nebular material as the amount of free dust and gas is steadily reduced.

Forming Jupiter and Earthlike Planets

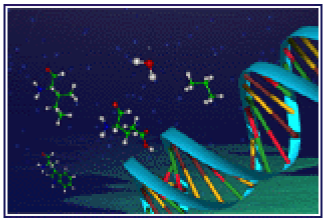


Very subtle differences in the way mass is distributed in the protoplanetary disk will determine where planets will form and how big they will be.

The rocky and metallic planetesimals in the inner solar system form into Earth-like planets with molten interiors. As these Earth-like planets radiate the heat of compression into space, they form hard crusts. Over long periods of time, they may become solid all the way through. Bombardment by rocky and icy planetesimals disrupts the surface but also delivers elements and molecules, including -- most critically from the standpoint of the evolution of life -- water.

Predominantly icy objects in the outer solar system form Jupiter-like planets. With or without a rock and metal core, these planets are mostly liquid surrounded by thick gaseous layers; the composition of a Jupiter-like planet is similar to that of its star. These planets, too, are subject to frequent impact by icy and rocky objects.

Chemistry of Life



Found in interstellar space, and therefore in planet-forming nebulae, are complex carbon molecules and amino acids -- the building blocks of life. The universe appears to be very well populated with the raw materials to manufacture the deoxyribonucleic (DNA) molecule, the blueprint of all life on Earth. However, the method for ensuring that all of the right components find each other in the right quantities and under the right circumstances has yet to be identified. The fact that it happened once, and with such prolific consequences, suggests that in the chain of events described here, the opportunity exists for repeated occurrences of life elsewhere in the universe.