

# Earth's Formation - Tutorial Script

Humans are made up 70% of water: H-2-O. Where does the hydrogen come from? The oxygen? Carbon? How about the gold, platinum, and titanium? In this video, we'll review the age and formation of Planet Earth and the important events that cooked up the ingredients that make us and our planet what we are today.

This scaled timeline highlights key events that have happened since the formation of our universe 13.7 billion years ago. Note the 4.6 billion-year-age of Earth's formation means it happened a LONG time after the universe formed. The dot here at the bottom represents today. What has been happening in our universe over all this time? And where are the dates and details of our timeline coming from? We learn about the history of our universe through centuries of study by scientists of objects in our solar system and beyond. We gather data from sky observatories, shuttle missions, satellites, ocean research vessels, and fleets of field and lab scientists like geologists, oceanographers, and geographers exploring the earth inside and out. Every day new data are collected. And every day our understanding evolves. We test our hypotheses. We turn them into theories that underpin our understanding of natural phenomena like gravity and light. Scientists will rarely say they "know" something because scientific knowledge is not static. It grows richer and more refined as we gather new data. So here's a good basic mantra to take us through our explorations of Earth: act like a scientist and question everything!

*13.7 billion years ago, the Universe exploded forth in an instant in time, from an infinitesimally small point, and has been expanding outwards ever since.*

**How do we know?** Astronomers observe that galaxies surrounding our galaxy are moving away from us. Space itself is stretching, pulling all galaxies, including ours, with it. It's like being in an expanding balloon. All objects move away from the center AND from each other.

If we imagine running a movie of the expanding Universe backwards, we move back in time to when galaxies were much closer together. If we continue running time backwards, we eventually come to a time when everything seemed to have existed in the same place at the same time.. The time it took to rewind was 13.7 billion years. At that point and time, astronomers hypothesize that there was a big explosion of energy, which over time expanded, cooled, and eventually led to the formation of all the known objects in the Universe. We call that initial energy explosion the **Big Bang**.

In the first few seconds and minutes after the initial explosion, some of the energy transformed into subatomic particles, like protons and electrons. The first atoms formed, and by 3 minutes after the Big Bang, the universe contained by mass 75% hydrogen atoms (identified by having just 1 proton in the nucleus) and 25% helium atoms (identified as having just 2 protons in the nucleus).

Now let's jump ahead to 1 billion years after the Big Bang, when we see our oldest evidence of stars forming. How? Perturbations in clouds of hydrogen and helium gas cause collisions and accretion (where gas atoms stick to each other, much like dust particles sticking to each other under furniture). These small collections grow larger as they continue to collide and accrete with each other. As they become more massive they produce a large gravitational field that compacts them into hot dense balls and attracts and pulls in even more gas. The contraction also causes spin, and gas clouds become rotating disks. The center of the disk usually contains the largest concentration of gas, and eventually those balls of gas can become so dense and hot that nuclear fusion can occur in their cores.

Nuclear fusion is a process by which atomic nuclei fuse together to create new atoms. For example, when one hydrogen (1 proton in the nucleus) fuses with another hydrogen (1 proton in the nucleus), we get Helium (2 protons in the nucleus). During the fusion process, energy is released and shines outward from the center or core of this ball of gas. These giant balls of shining gas are called **stars**.

Back to the rotating disk: gas that is not part of the center star can go through similar collisions and accretion and create smaller non-shining balls of gas that orbit the larger center star. These smaller balls with no nuclear fusion are called gaseous planets. The combination of a star and its orbiting planets is called a **solar system**.

Now imagine you have billions of these solar systems developing from the massive amounts of gas in the early universe. Each system will feel gravitational attraction to the other systems around it, and they will clump together in collections of solar systems called star **clusters** or **galaxies**, depending on the number of stars and shape of the collections.

So now that we have stars, solar systems, and galaxies, what about rocky planets? And what about the atoms other than hydrogen and oxygen? Where did they come from? Let's return to the nuclear fusion going on inside a star's core. At first the major fuel is hydrogen, which fuses to become helium. But if the star is large enough and hot enough, eventually the hydrogen and helium fuse to produce lithium (3 protons in the nucleus). Lithium fuses with hydrogen to produce beryllium (4 protons in the nucleus). As more fusion occurs, more energy is produced. As more energy is produced, heavier elements are formed. By the time fusion produces iron (26 protons), so much energy is produced within the center of a star that it can no longer be contained, and the star explodes in a **SUPERNOVA**. These pictures here show two supernova remnants – gas and debris left over from a star's explosion. *These supernovas exploded outward at speeds greater than 6,000 km/s and collided with surrounding gas producing two shock waves. One travels outward (shown in red and high in iron); the other rebounds back into the material ejected by the explosion (shown in blue and high in oxygen and neon). Dense clumps of oxygen that have cooled to about 30,000 °C are shown in green.*

So how do we form elements heavier than iron? The shock wave of the supernova produces nuclear fusion and all the other elements currently found on the periodic table.

Now what? We have a cloud of debris peppered with some heavy elements, but still mostly hydrogen and helium gas. How do we form a rocky planet? These HUGE clouds or supernova remnants of mostly gas debris from supernova explosions will eventually undergo the same collision and accretion processes that created the first stars. Only now the new stars will be smaller and contain some of the heavier elements in their orbits.

Turns out that to create rocky planets the size of Mercury, Venus, Earth, Mars, and some of the rocky moons in our solar system, MULTIPLE episodes of STAR deaths (supernovas) and subsequent births from the remnants were necessary to cook up enough of the required heavy elements. Astronomers believe that our Sun is likely a third or fourth-generation star.

Our solar system coalesced from a former supernova remnant 5 billion years ago. We call our central star, the **Sun**. In the space immediately around the Sun, during its formation, temperatures would have been hottest and solar winds fiercest (solar winds are very hot, charged particles that escape off the sun's surface at high speeds). Uncompacted gases and low-density elements, including molecules like water, would have been blown outward to the outer solar system where they accreted there to form the gaseous planets and leftover icy bits of debris, called **comets**. In the inner solar system, the denser elements unaffected by the solar winds clumped and accreted to form the rocky planets and smaller objects leftover from this process called **asteroids**.

Eventually the planets swept up all the debris within their orbits and the nearby debris that would have been attracted to their gravity. And the solar system we're familiar with today formed. How do we know? Because we study the leftover, unaccreted remnants of the solar system's formation – the asteroids and comets. And they tell us the age of the process and the relative abundances of elements within our solar system. How do we study them?

Although comets collide with our planet regularly, because of their composition, they burn up and are absorbed by our atmosphere. To study the whole comet, we send spacecraft through the tails of comets whose orbits bring them close to Earth. Based on these exploratory missions, here is a NASA visual of what makes up "comet soup." Ingredients pictured include a cup of ice and a cup of dry ice (carbon dioxide); olivine, smectite clay, polycyclic

aromatic hydrocarbons, spinel, metallic iron; the silicate enstatite, the carbonate dolomite, and the iron sulfide marcasite.

We study asteroids when they collide with Earth's orbit. If they're too small, they burn up completely as they travel through the atmosphere, but if bigger, what doesn't burn up will land on the surface, and now we call them **meteorites**. And when we study and radiometrically date these meteorites, we discover that almost all of them are the same age - 4.6 billion years old - the time when rocky debris collided and accreted to form rocky planets and asteroids. Some younger meteorites are pieces of the crust of the Moon or Mars. We can distinguish those meteorites from the ones that are remnants of the formation of our solar system by their composition and younger age.

Gathering up and studying meteorites also teaches us about the material that makes up the Earth.

Pause now.

For more information and more detail, continue on to the next video in this series.

[end credits]

Earth Formation Series:

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Part II: Radiometric Dating

Part III: Density

Part IV: Early Earth

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Earth Formation

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