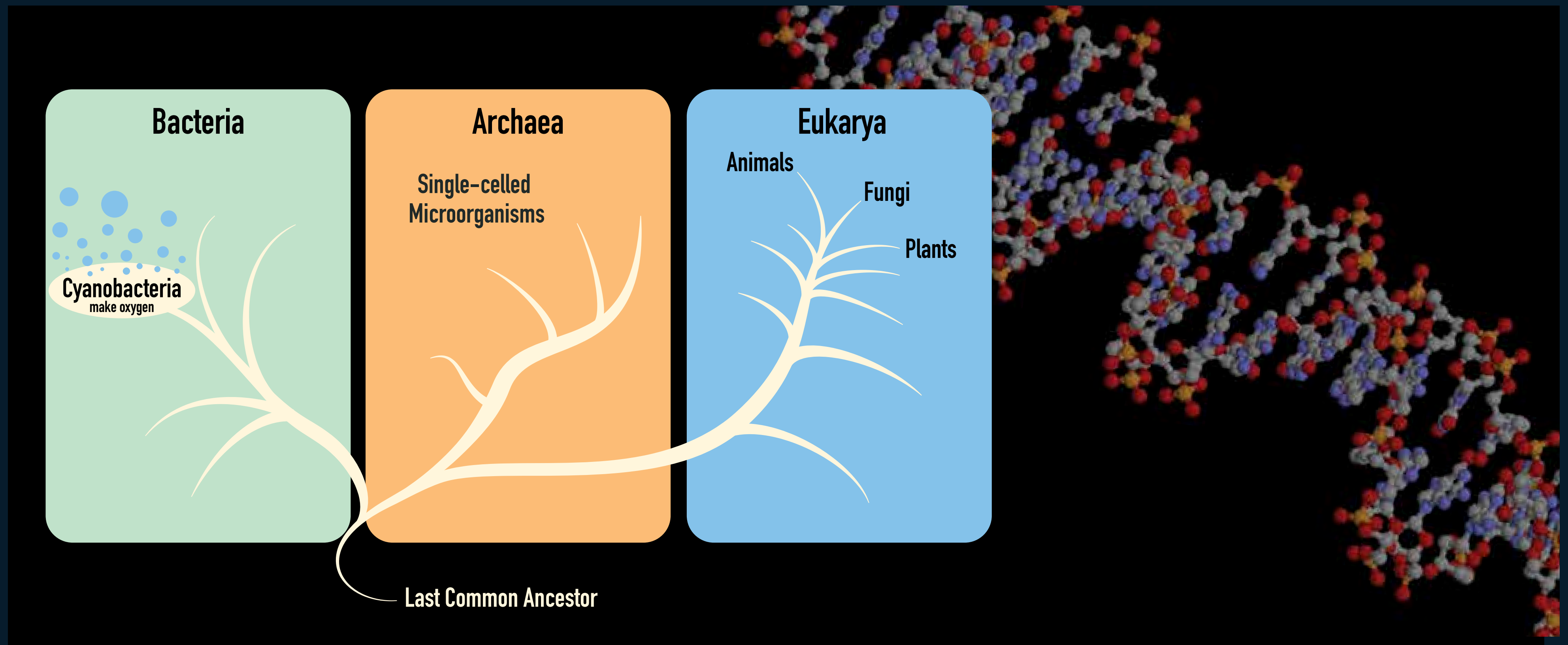
STATION 01 > Earth as a Habitat — From Origin to Present

WHY IS EARTH WET AND ALIVE? Our blue Earth is shown with its lifeless Moon. Impacts pummeled the early Earth (and Moon) before life emerged. The Moon preserves a record of those events because it lacks an atmosphere and plate tectonics. Impacts also affected Mars and other planets.

Earth is unique within our Solar System – wet and teeming with life. How did life begin here? How has the environment changed since Earth's formation? Why is Earth a life-sustaining habitat now? Can life exist elsewhere in the Solar System and in the Universe? This "walk through time" illustrates critical steps along the pathway to life today, and scientific efforts at Goddard to address them.

↑ THE SPIRAL TIMELINE
The spiral represents the timeline of Earth history from its formation about 4.6 billion years ago to the present. Each station in this exhibit describes a different epoch and has a distinctive 3D iconic object above the station and on the spiral. The number of a station (2, 3, ...) identifies the order of its appearance in this Astrobiology Walk.

Life and its Instruction Codes

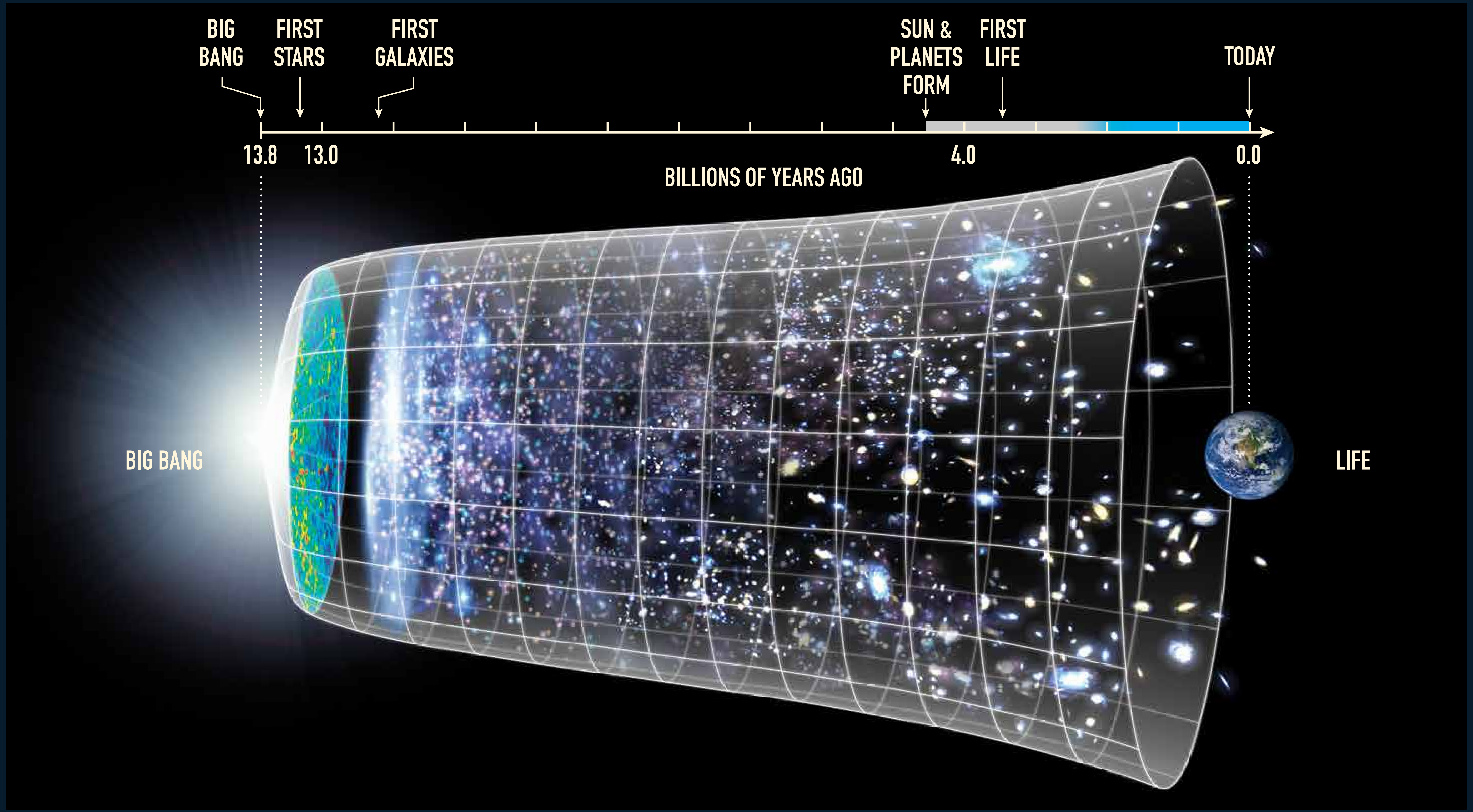


THREE DOMAINS OF LIFE: All living organisms store an instruction set (DNA, background) used in reproduction and function. The DNA molecule is made of hydrogen, oxygen, nitrogen, carbon and phosphorus.

Astrobiologists define life as cell-based organisms that can reproduce and evolve. These include single-celled organisms such as bacteria and archaea that could survive in extreme environments on early Earth and now. Scientists search for pathways that could lead from chemical mixtures to the basic building blocks of living organisms.

The Cosmic Progression Towards Life

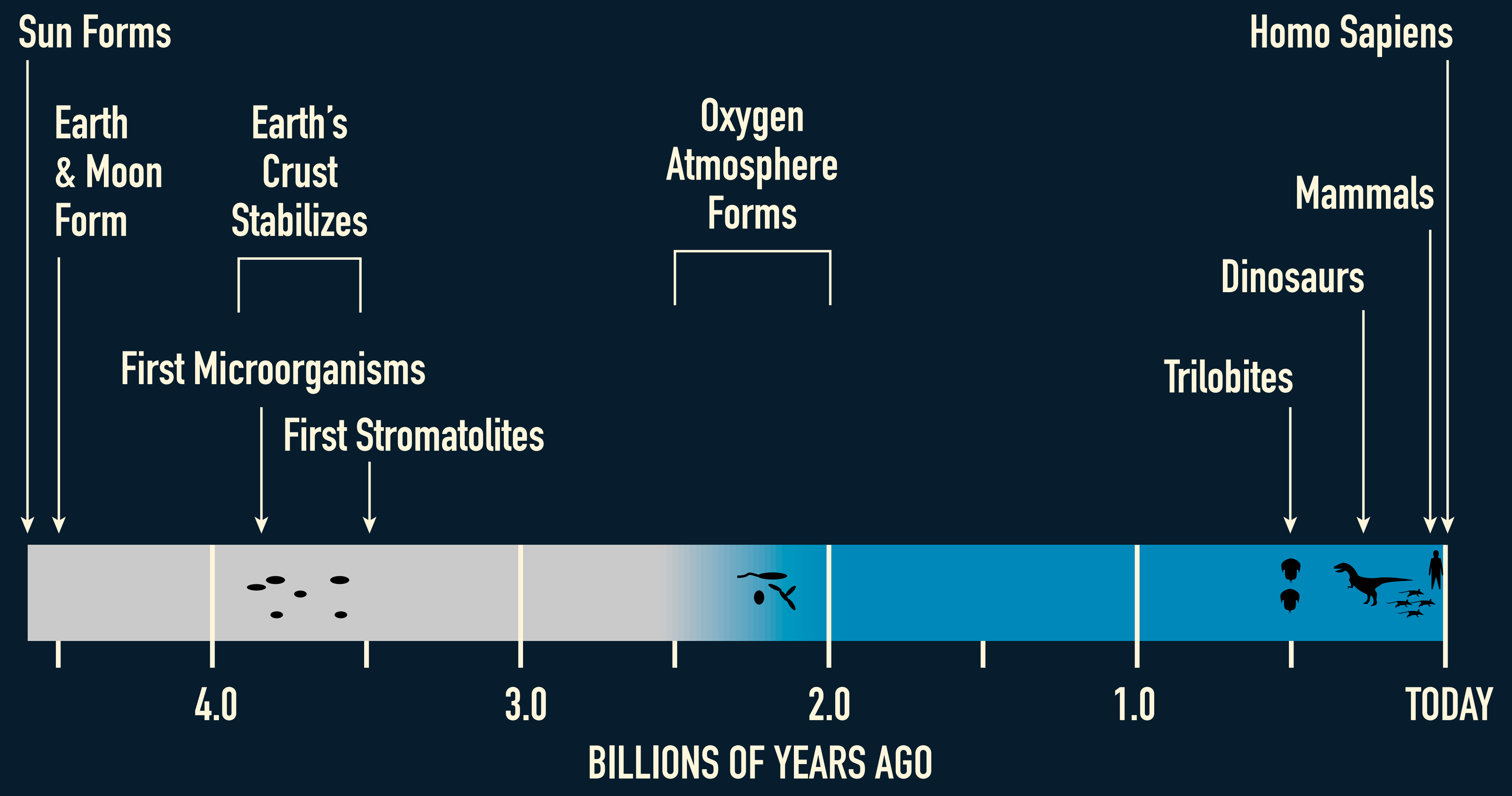
Life is the product of nearly 14 billion years of cosmic evolution. Atoms formed as the Universe cooled following the Big Bang, then stars and galaxies, planets and life. The Big Bang produced atoms of hydrogen, helium and lithium, the lightest elements. Other elements were made inside the first stars, but formation of the heavier elements required cycling through many generations of stellar birth and death. The Earth and life as we know it required this heritage – you are made of star stuff! Thus, the cosmos evolved towards greater complexity in a progression that enabled the emergence of life.



NASA/WMAP Science Team

FROM THE BIG BANG TO LIFE: This graphic illustrates the evolution of the Universe since the Big Bang. It is based in part on discoveries of the Cosmic Background Explorer and the Wilkinson Microwave Anisotropy Probe spacecraft, developed at Goddard Space Flight Center.

A Cosmic Timeline Towards Life

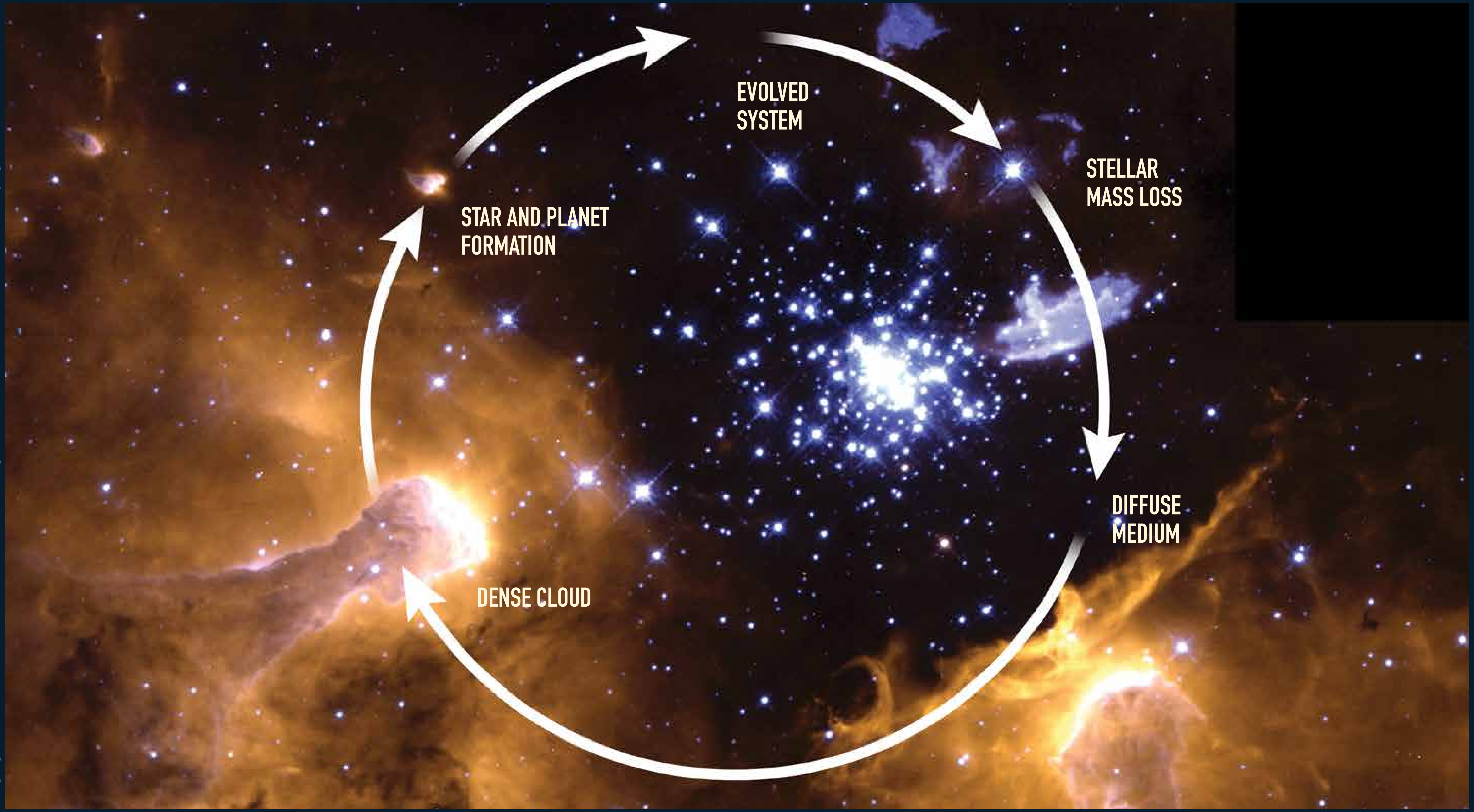


What exactly is astrobiology? Astrobiology is a multidisciplinary science that involves astronomy, biology, chemistry, geology and physics. Researchers of the Goddard Center for Astrobiology study the origin and formation of the building blocks of life in extraterrestrial environments, and examine whether the delivery of these primordial materials and water to the early Earth enabled the emergence and evolution of life. They also extend these studies to other planets and moons, and to other planetary systems.

DID YOU KNOW?

If the history of the Universe were compressed into one year with the Big Bang occurring on January 1st, Earth would be formed in mid-September, microorganisms in early October, multicellular life in early December, and Homo sapiens (humans) on December 31st.

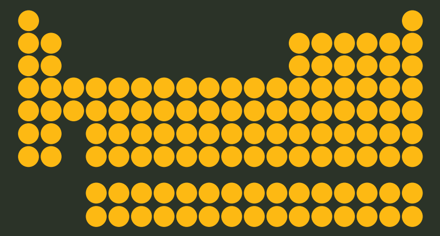
STATION 02 > The Cosmic Cycle of Matter



Wolfgang Brandner (JPL/IPAC), Eva K. Grebel (Univ. Washington), You-Hua Chu (Univ. Illinois Urbana-Champaign), and NASA

MOVEMENT OF MATTER: The bright blue objects at the top of the picture are stars and regions of hot gas. The brown-gold darker regions at the right and the bottom are cool clouds of dust and gas from which new stars are made. Atoms and molecules can move between the two regions.

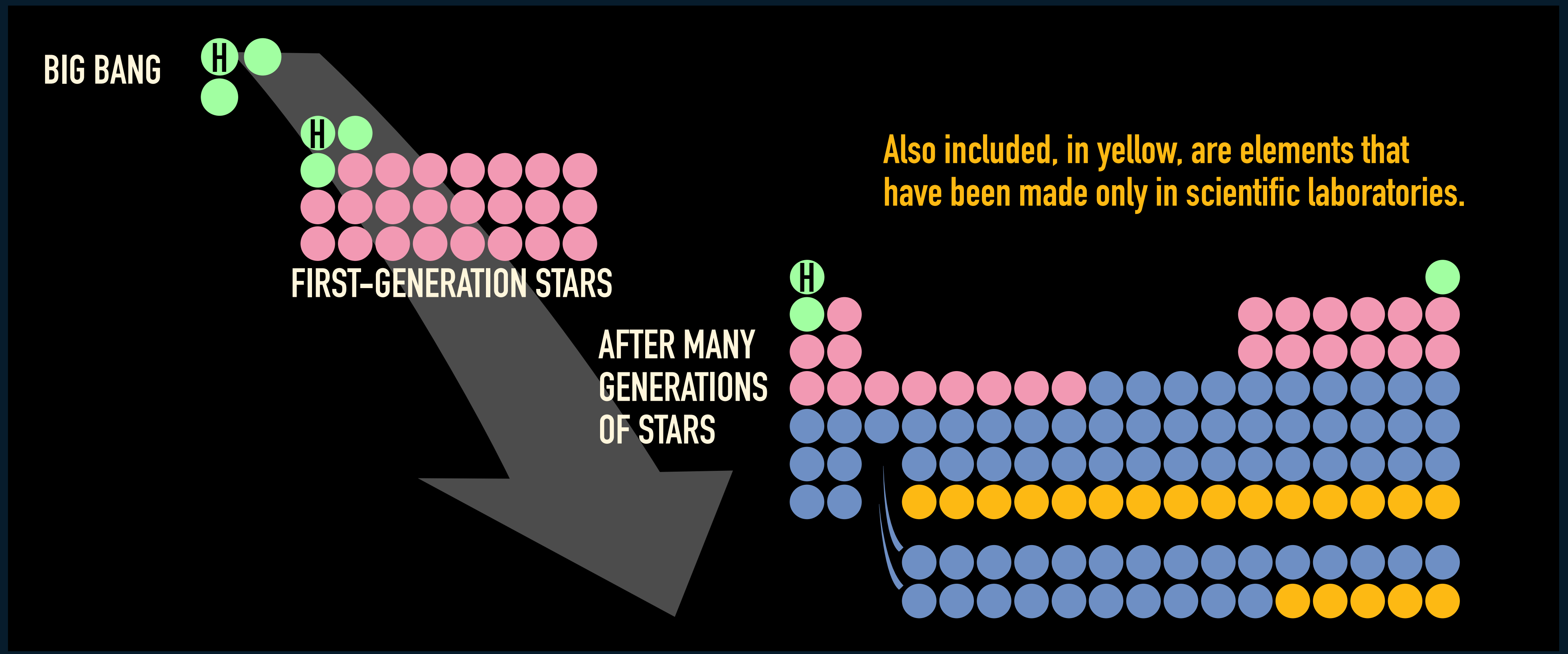
From the diffuse medium between stars, matter gathers in a dense interstellar cloud that collapses and forms new stars, which later return their substance to interstellar space. Nuclear processes within the stars change the elemental makeup from its initial composition to the legacy materials bequeathed to the Universe upon stellar death.



↑ **PERIODIC TABLE OF THE ELEMENTS**
The icon at the top of this station is known as the "periodic table," a special arrangement of all the elements found in nature, here color-coded to show the manner in which they were made. The protruding pegs highlight elements found in DNA. On the reverse side, the most abundant elements used in human biology are highlighted.

Big Bang 13.8 billion years ago — Present

Some Elements are Older than Others



BUILDING THE ELEMENTS: The elements grew in number after the Big Bang. About 100 elements occur naturally, but many are rare. Hydrogen (H) is the most common and it plays a major role in biology.

The elements on the periodic table make up all that you can see around you today, including stars and other objects in outer space. Hydrogen, carbon, oxygen, nitrogen, sulfur and phosphorus are some of the more abundant elements in biological organisms. Rarer, but biologically important, elements include iron, copper, zinc and iodine.

STATION 02 > # Goddard Initiatives

From Atoms to Molecules

Huge interstellar clouds of dust particles and gas can form between the stars. In the cold cores of dense clouds, a rich chemistry develops as atoms combine to form molecules.

Astronomers have identified more than 120 kinds of molecules in such clouds. Simple molecules can be made in space either as a gas or on dust grains, and those simple molecules evolve into even more complicated ones through processes studied by scientists of the Goddard Center for Astrobiology. Most of the atoms in your body are bound up in molecules.

T.A.Rector (NOAO/AURA/NSF) and Hubble Heritage Team (STScI/AURA/NASA)

T.A.Rector (NOAO/AURA/NSF) and Hubble Heritage Team (STScI/AURA/NASA)

TWO DENSE INTERSTELLAR CLOUDS: The dark object at left is a Bok Globule. At right is the Horsehead Nebula, a cold interstellar region of gas and dust in front of hot clouds of hydrogen atoms (red light). The horsehead is about 4 light years (38,000,000,000,000 kilometers) in size, from top to bottom.

We Study Chemistry in Space

Courtesy W.M. Keck Observatory

ESO/C. Malin

NASA

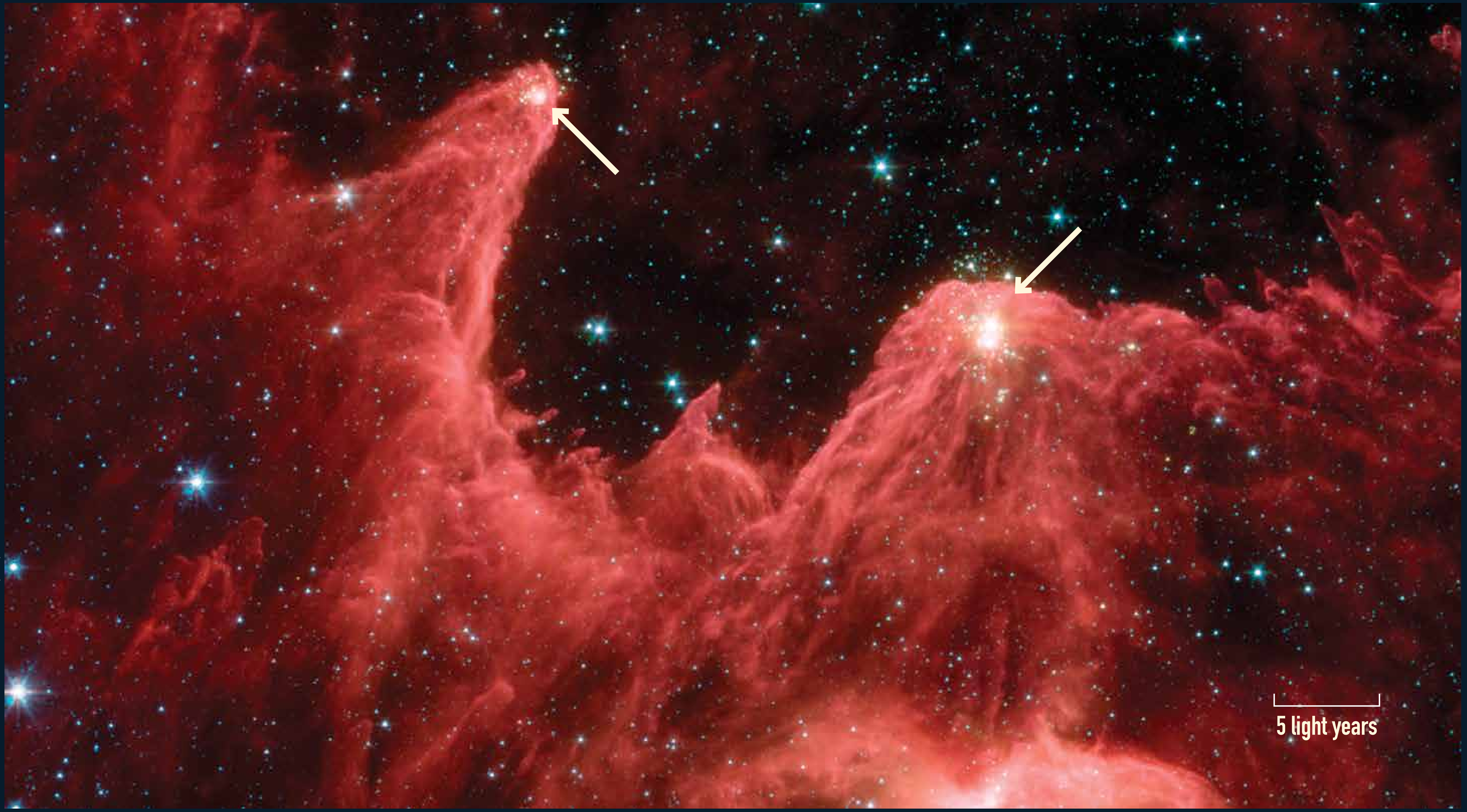
NASA

Members of the Goddard Center for Astrobiology use sophisticated equipment to study the atoms and molecules in outer space between stars, around stars, on planets and moons, and on comets and asteroids. We identify them by the light they absorb or emit at X-ray, ultraviolet, visual, infrared or radio wavelengths. Our laboratory scientists study how cosmic rays and high-energy light can both make and destroy molecules, including those with biological roles.

DID YOU KNOW?

The calcium in your bones and the iron in your blood were made in stars. Also, some of the molecules made in the cold birth cloud of our Solar System are preserved in comets and carbonaceous meteorites.

STATION 03 > Protostellar ‘Factories’ Churn Out Chemicals



NASA/JPL-Caltech/L. Allen and J. Hora (CfA)

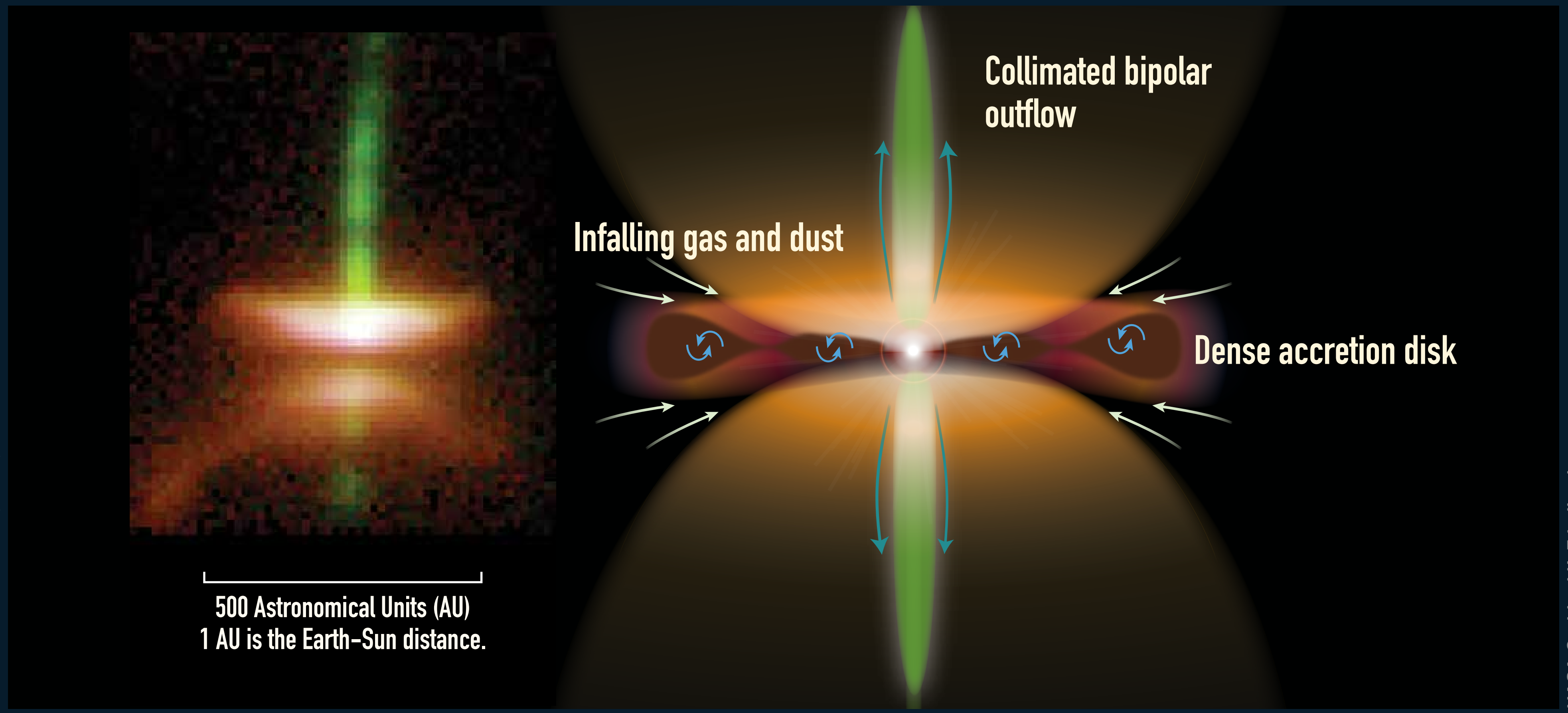
CHEMICAL ENRICHMENT CONTINUES AS A STAR FORMS: The “Mountains of Creation” (in the interstellar cloud W5) reveal collapsing cloud “cores” where complex chemicals are produced in protostellar nebulae (arrows). The Goddard-built infrared camera on Spitzer Space Telescope took this image.

The star-forming region (“core”) is a hot and turbulent place where energetic radiation abounds as X-rays and ultraviolet light. This energy fuels a rich and diverse chemistry that extends the formation of complex organic molecules begun in the interstellar cloud. The legacy chemicals found in primitive Solar System materials reveal this mixed heritage.

↑ PROTOPLANETARY DISK

After a star forms, the leftover dust and gas become the protoplanetary disk. When the conditions are right, this material will eventually condense into planets and small bodies such as comets and asteroids. This icon represents the epoch when Solar System planets began to form and large-scale chemistry in the nebula ended.

Hot and Cold Chemistry



NASA/Chris Burrows (STScI) and the WFPC2 Science Team

NASA Goddard/J. Friedlander

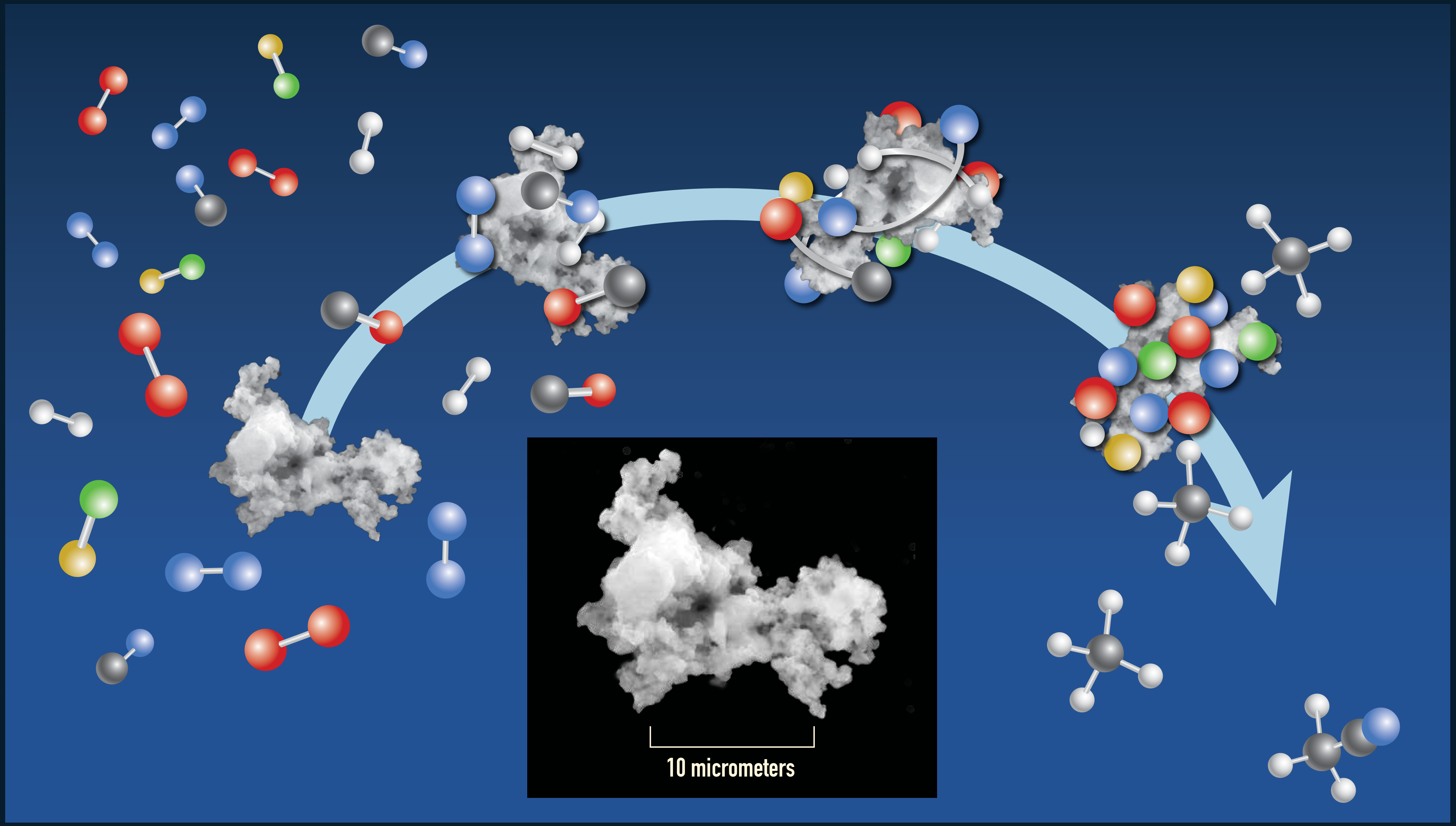
A new protostellar disk is typically flared, as seen in this image and diagram of an edge-on disk. The new star illuminates the disk from within, and jets of material escape along the polar axes above and below. In the hot inner zone, tiny dust grains convert gases into simple organic compounds. Other reactions form carbon dioxide on cold grains in the outer regions, while ionized and neutral gases form new chemicals in regions reached by X-rays and ultraviolet light. Internal forces mix material between the inner and outer disk regions.

STATION 03 >

Goddard Initiatives

The Importance of Space Dust

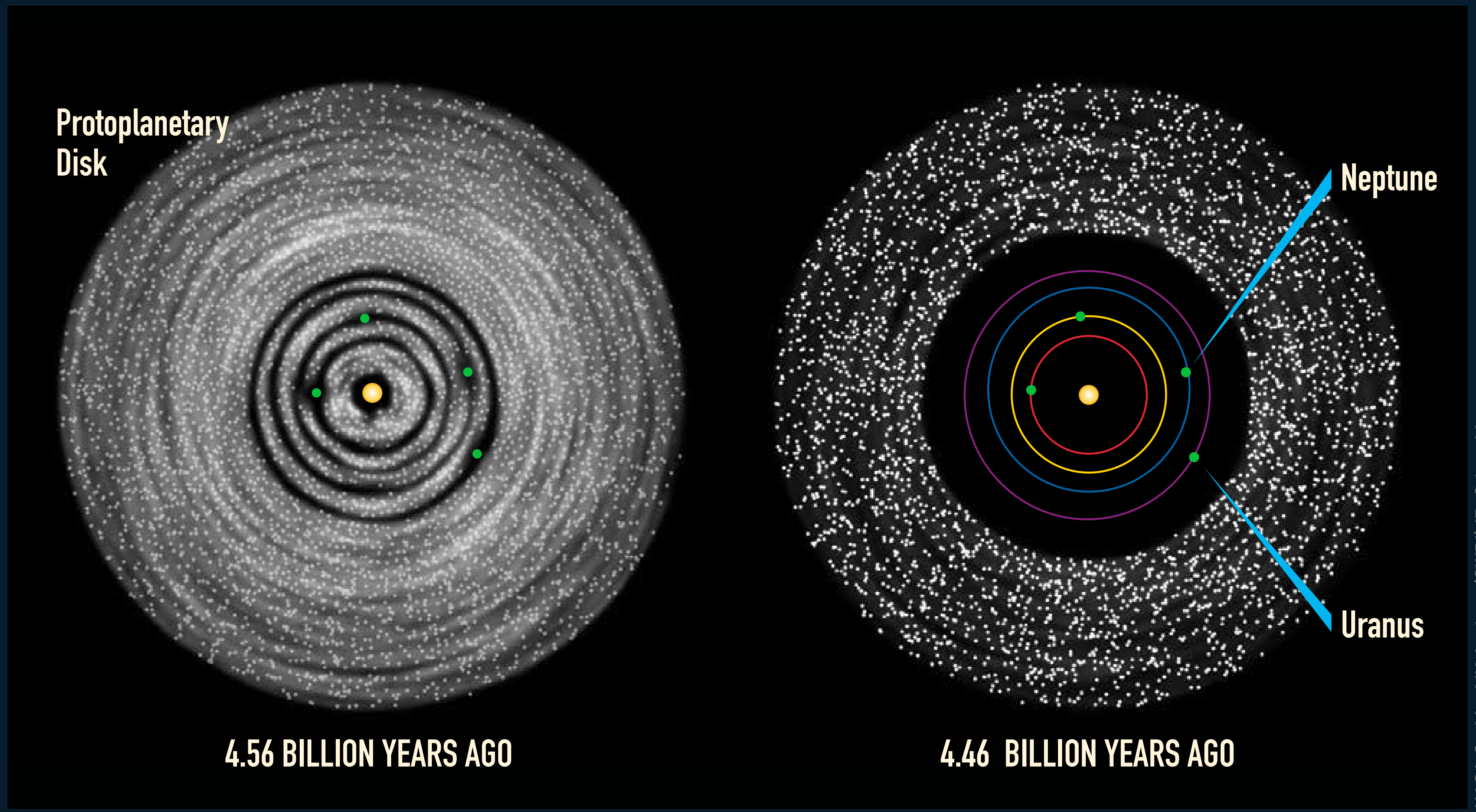
In the hot inner region of a protostellar disk, countless tiny dust grains convert gases stuck to their surfaces into simple organic, or carbon-containing, compounds. Later reactions will convert these compounds into more complex molecules, possibly including ingredients of the “prebiotic soup” that led to life on Earth. The “cosmic cycle” of this production is illustrated below.



NASA Goddard/J. Nuth, J. Friedlander

DUST GRAINS KICK-START CHEMICAL REACTIONS: Dust grains in space often serve as tiny test tubes where crucial chemical reactions take place. Goddard scientists investigate these reactions using heated grains of astrophysical “smokes”. Center: A tiny interplanetary dust grain collected in Earth’s stratosphere.

A Planetary System is Born



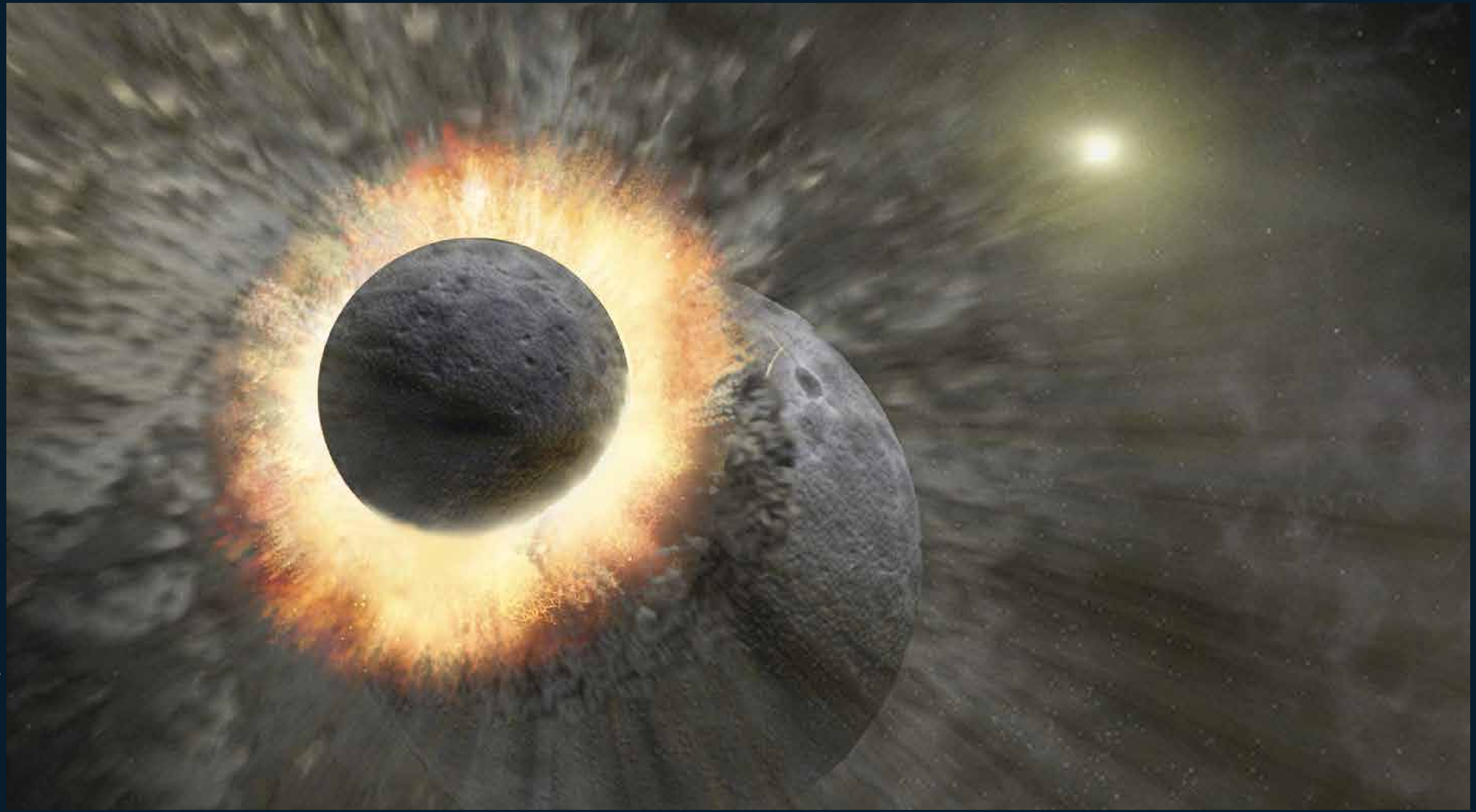
NASA Goddard/H. Levison (SWRI)/B. Griswold

DUST IS CLEARED AS PLANETS FORM: The protoplanetary disk phase ends with the formation of planets and clearing of gas from the disk. Gaps appear in the disk as the planets grow, here illustrated by the giant gas planets (left). After planetary growth ended, the Solar System could have been configured with an outer disk of icy bodies and with Uranus as the outermost giant planet (above, right). Today, Neptune is outermost.

DID YOU KNOW?

The same chemical reactions that made complex organic chemicals in the inner solar nebula can be used to convert coal into gasoline and nitrogen from the air into fertilizer here on Earth.

STATION 04 > Formation of the Earth and its Moon

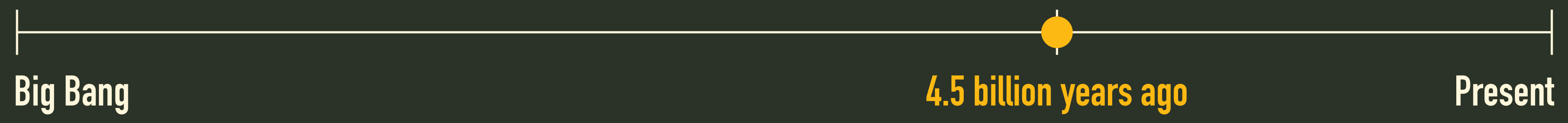


NASA/JPL-Caltech/T. Pyle

THE MOON-FORMING EVENT: The impact of a Mars-sized protoplanet vaporized proto-Earth's upper layers and ejected large amounts of solid debris that later accreted to form the Moon. This impact also caused Earth's axis to be tilted at an angle that is responsible for Earth's seasons.

The proto-Earth accreted about 4.56 billion years ago in the protoplanetary disk, and the Moon-forming event occurred about 50 million years later. Molten rock covered the fresh new Earth, but it cooled quickly. Analysis of ancient gems called zircons shows that a water ocean existed by 4.3 billion years ago.

↑ THE MOON-FORMING COLLISION
This iconic object represents a collision between the proto-Earth and a Mars-sized protoplanet. The ejected material formed an Earth-orbiting debris disk that later accreted into the Moon.



Newly Formed Earth was Hot

Courtesy Fahad Sulehria/ novacelestia.com

MOLTEN ROCK COVERED THE NEW EARTH: This image depicts Earth's magma ocean after the Moon-forming event: exposed molten rock is yellow or red, while cooler solidified lava crust is black. No life could exist then.

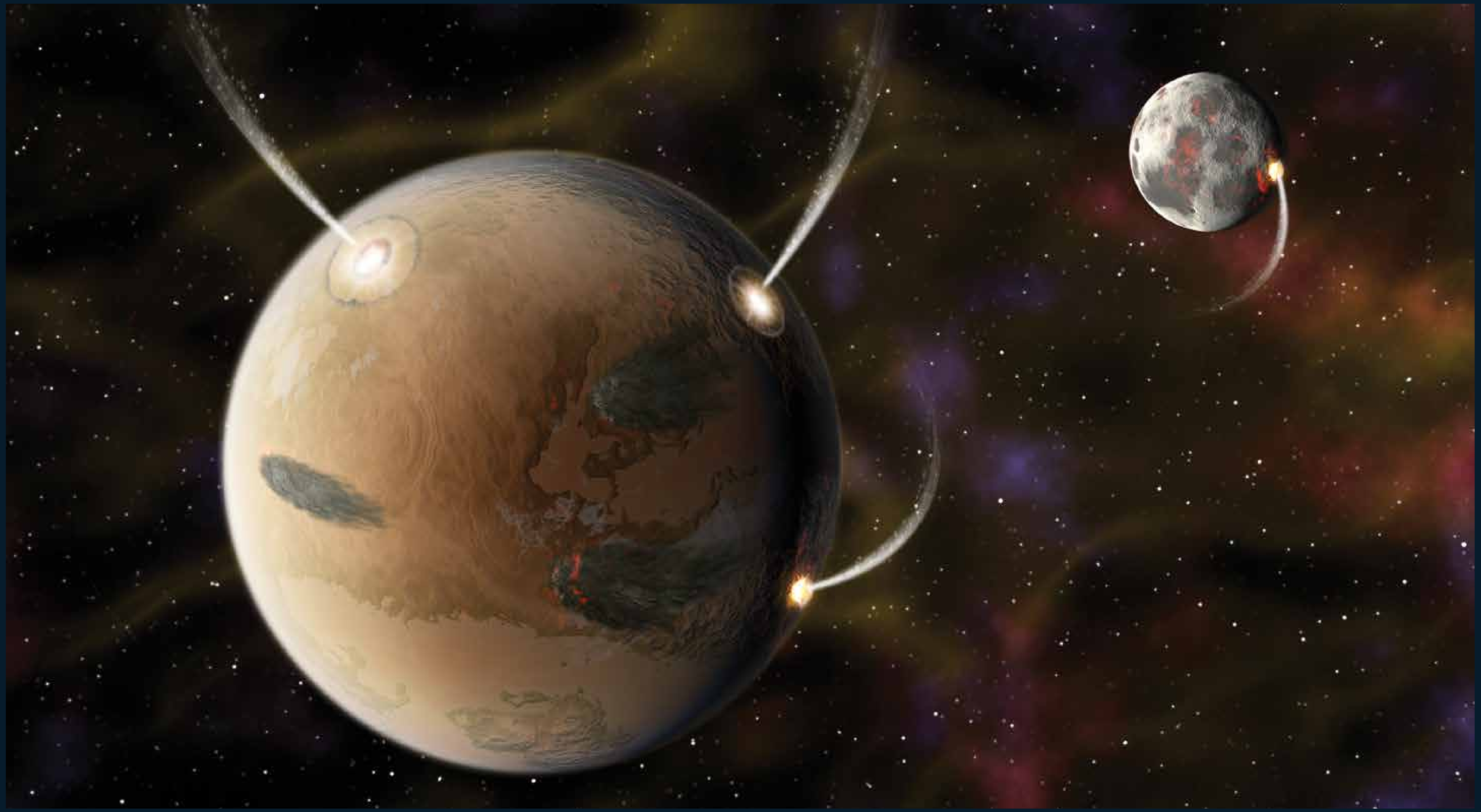
Detailed simulations suggest that much of Earth's original atmosphere was likely lost in the impact event, and more was later blown off because of the high heat.

This primordial atmosphere contained almost no oxygen and would have been toxic to humans and most modern life.

STATION 04 > Goddard Initiatives

Missing: Record of Earth's Early History

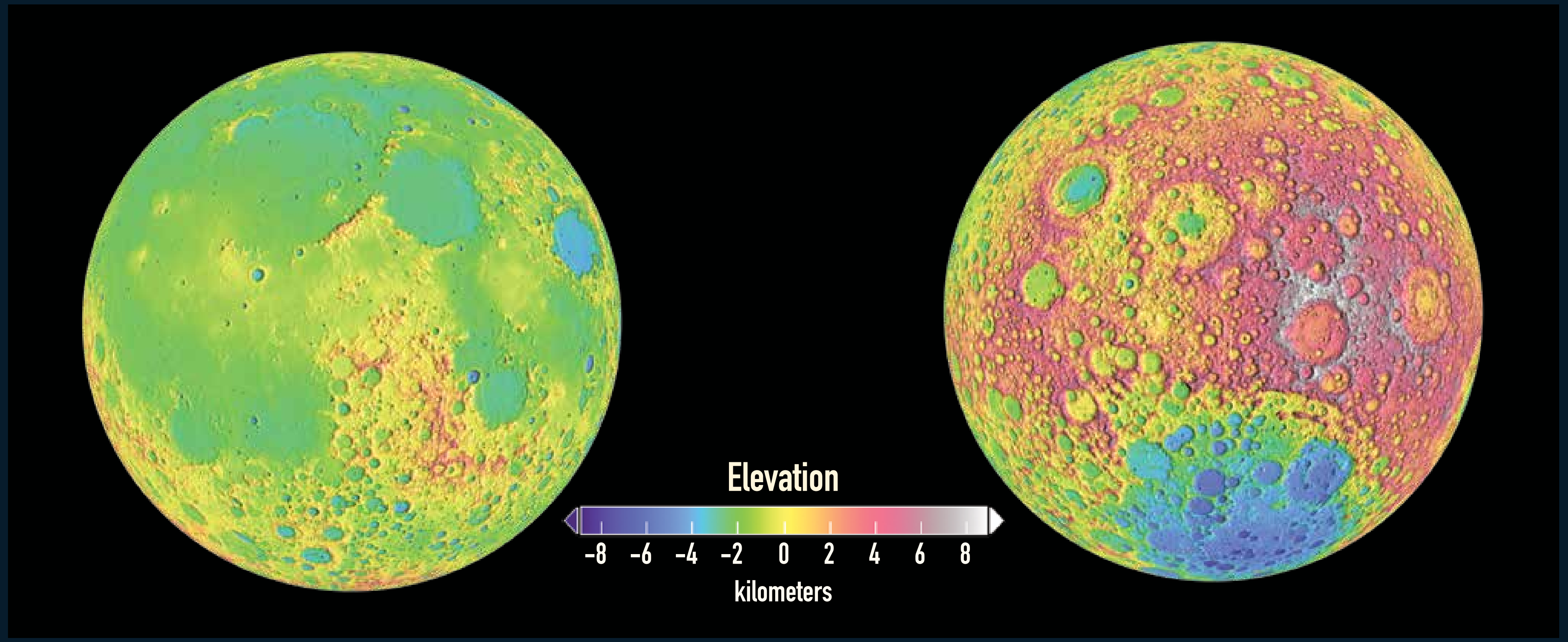
After the Moon-forming impact, bombardment continued for the next billion years. Over time, these cosmic impacts became less frequent, allowing the planet to cool and form a solid crust. However, geological activities and erosion by water and weather erased Earth's record of this early period. How do scientists learn about the events of this period? Our Moon lacks an atmosphere and plate tectonics, so it preserves a record of impacts experienced during the first one billion years and later periods. That is one reason why we explore the Moon: it holds the key to understanding early Solar System and Earth history.



NASA Goddard/B. Griswold

IMPACTS PUMMELED THE EARTH AND MOON: The record of this intense bombardment is preserved on the Moon but not on Earth. Apollo samples and lunar meteorites inform us of the ages of major impact events, while crater counting reveals the number of impacts over time.

Lunar Impact Craters



NASA/Goddard Space Flight Center Scientific Visualization Studio

OUR MANY-FACED MOON: This color-coded elevation map of the Moon's surface shows the effect of early bombardment on planetary crusts in the inner Solar System, including Earth's. Most craters on this map are over 20 kilometers in diameter. The near side (left) and far side (right) present very different cratering records, and thus appearances. These images were made using data from NASA's Lunar Reconnaissance Orbiter, built at Goddard.

DID YOU KNOW?

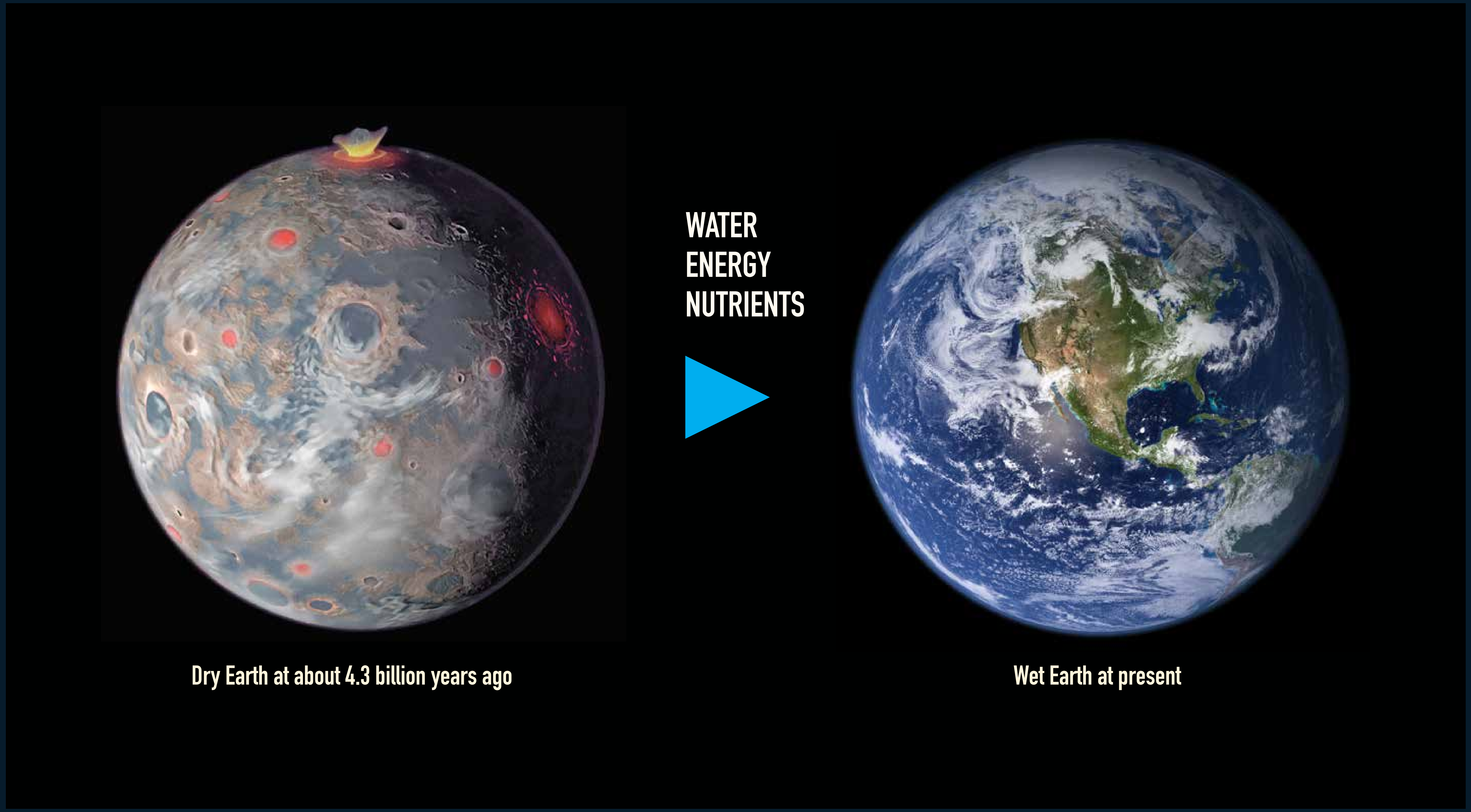
Scientists learned about Earth's early bombardment history by counting lunar craters of various sizes and measuring the ages of Moon rocks brought back by the Apollo astronauts. The Moon preserves a good record of these impacts.

NASA AS17-134-20425

RIGHT: Astronaut Harrison Schmitt collecting lunar rake samples during the Apollo 17 mission.

STATION 05 >

Building a Wet and Habitable Earth

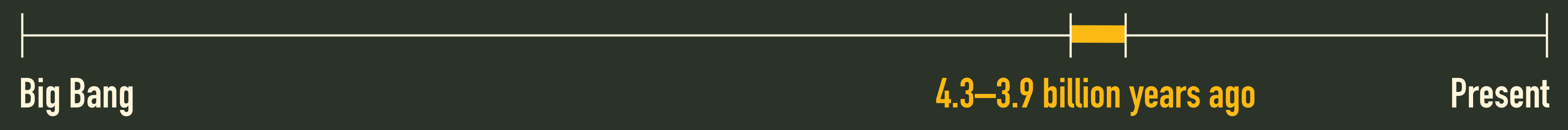


NASA

HOW DID THE OCEANS FORM? The Earth's surface cooled quickly after the Moon-forming event, forming a hot solid crust. Condensing water vapor from volcanoes, together with water and chemicals delivered by asteroids and comets, produced the first oceans, where life likely began.

Earth's oceans grew from small to global in scale in only 400 million years. Much of this water came from outer space, when migration of the giant planets scattered comets and asteroids throughout the Solar System in the Late Heavy Bombardment. These impactors brought water and organics (some of life's ingredients) to the early Earth.

↑ EARLY EARTH
The icon above represents Earth during the Hadean period about 4.3 billion years ago. During this period, Earth had early oceans and dry continents with abundant old impact basins and fresh impact basins filled with lava.



NASA Goddard/B. Griswold

THE LATE HEAVY BOMBARDMENT: During this period, impacts on Earth created over 22,000 craters larger than 20 kilometers (km) in diameter, about 40 basins larger than 1,000 km, and several continent-sized basins larger than 5,000 km.

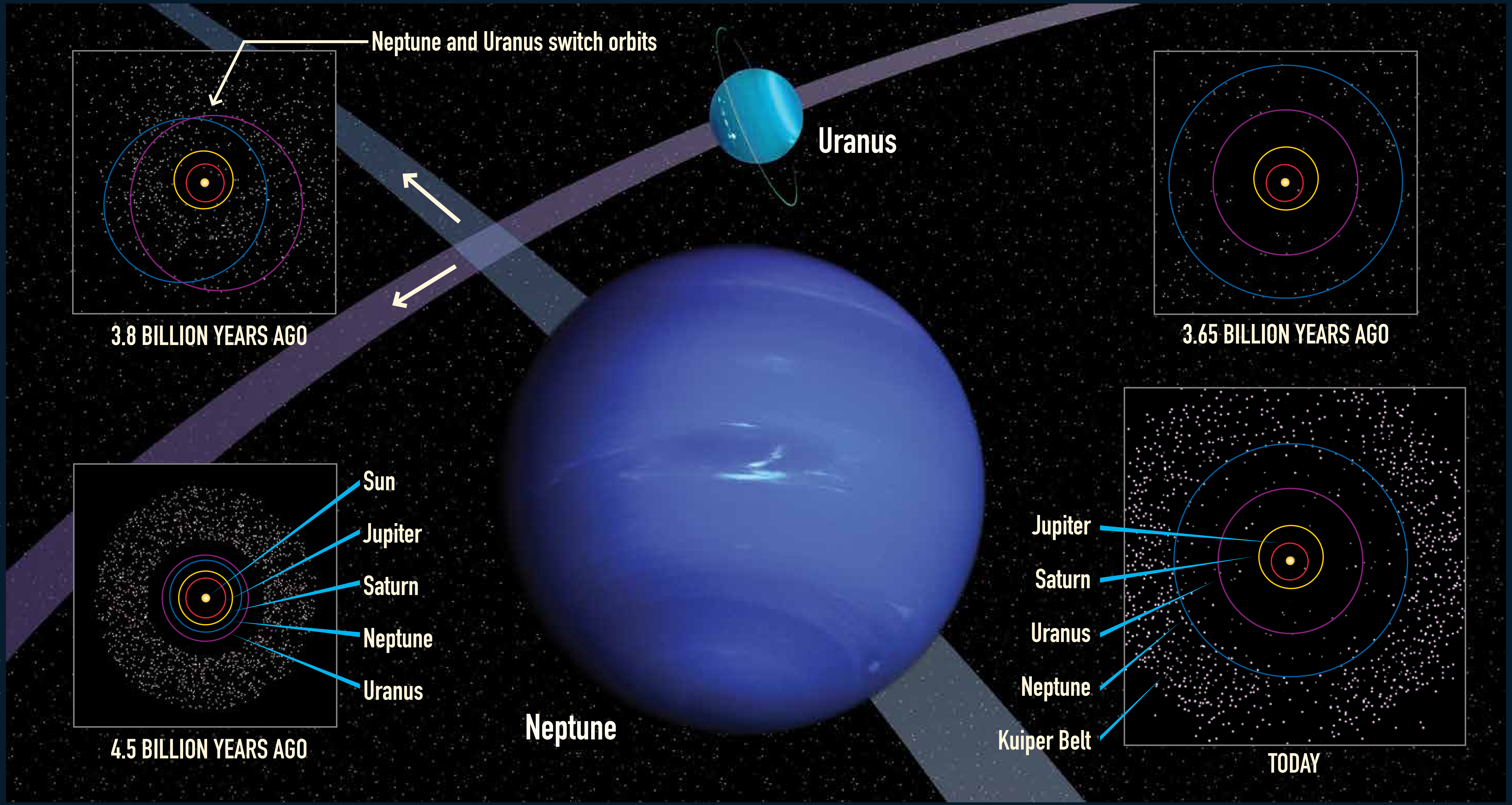
An ocean formed soon after the Moon-forming impact, but life first appeared 800 million years later (3.7 billion years ago), after the Late Heavy Bombardment.

Those impacts brought water and some of life's ingredients, and created hydrothermal systems on Earth that were excellent incubators for life.

STATION 05 > Goddard Initiatives

Rearranging our Planetary System

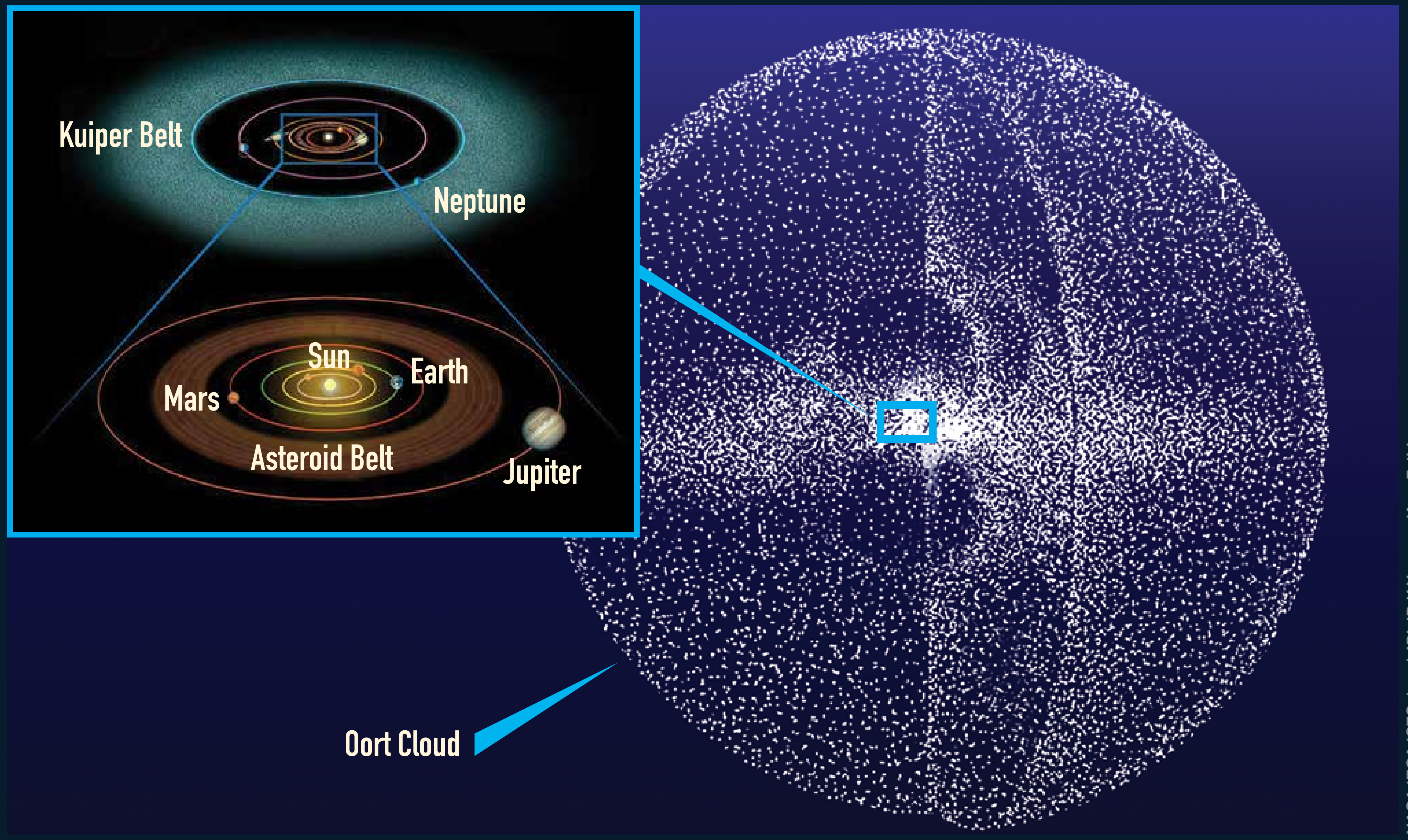
The early Solar System probably started with the four giant planets in a compact configuration closer to the Sun, and in the order Jupiter, Saturn, Neptune and Uranus. Detailed simulations of planetary interactions suggest that when the orbits of Jupiter and Saturn fell into lockstep, their combined gravitational pull caused Neptune and Uranus to switch places and move outward. This triggered the dispersal of an outer disk of icy debris and 90% of a disk of rocky bodies between Mars and Jupiter, causing the Late Heavy Bombardment of Earth and the Moon. The remaining 10% form today's asteroid belt.



NASA/H. Levison (SwRI)/Minor Planet Center (CfA)/J. Friedlander

TRADING PLACES: Shortly after their formation, the giant gas planets follow nearly circular orbits close to the Sun (lower left). About 3.8 billion years ago, Neptune and Uranus switch places and trigger major disruptions (center & top left). Then the giant planets settle into their current orbits, the Kuiper Belt and Oort Cloud comet reservoirs form, and the major bombardment ends (top right). Lower right: Detected Kuiper Belt objects.

Comet and Asteroid Reservoirs Today



NASA/ESA/STScI and JPL/D.K.Yeoman/Ann Feild

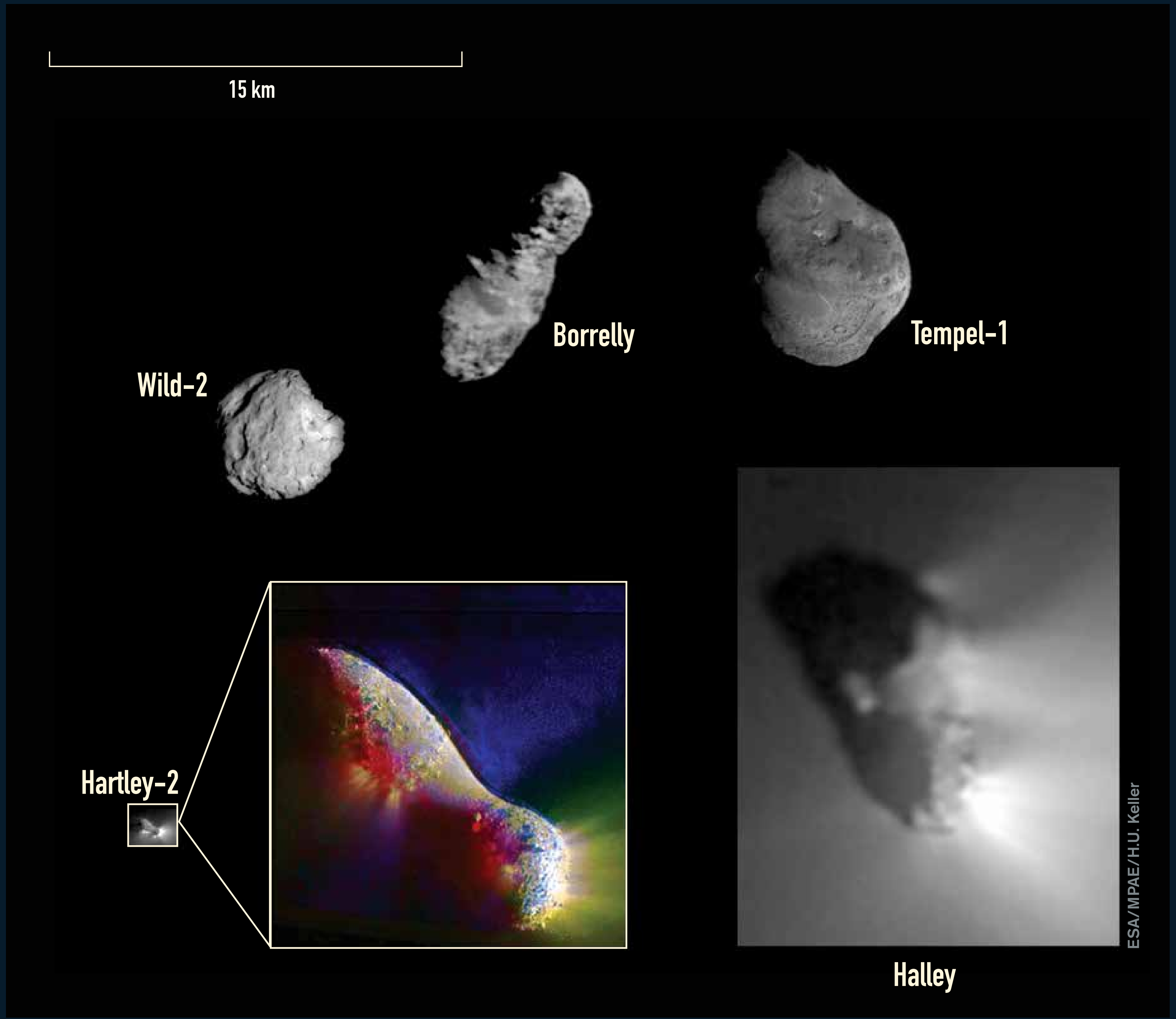
Icy bodies are ejected from the Oort Cloud by passing stars and galactic tides, and from the Kuiper Belt by planetary perturbations. Each year, some icy bodies enter the inner Solar System and become active comets. Asteroids reside much closer to the Sun, in a stable belt between Jupiter and Mars.

DID YOU KNOW?

Comets currently occupy at least two reservoirs: the Kuiper Belt, where Pluto resides, and the Oort Cloud. The Oort Cloud contains about 1,000 billion comets and extends halfway to the nearest star.

STATION 06

Messengers from the Early Solar System



FIVE COMET NUCLEI IMAGED BY SPACECRAFT: Active vents of comet Halley (lower middle) release jets of gas and dust that are seen as white streaks in reflected sunlight. The largest nucleus measured was of Hale-Bopp (70 kilometers; about 6 times larger than Halley's nucleus).

Comets and asteroids formed during collapse of the natal molecular cloud core, and their compositions depend greatly on the time and place of their formation. As remnants of the early Solar System, comets and asteroids are central to understanding its origin and formation. Many asteroids appear to be the shattered remnants of primitive rocks.

↑ **COMET NUCLEUS**
The iconic object above is a scale model of the nucleus of comet 103P/Hartley-2. Small bodies, such as comets and asteroids, have very irregular shapes due to their small masses (and thus, low gravity). Shape model courtesy of the EPOXI team and the PDS Small Bodies Node/P. Thomas & T. Farnham.

Big Bang — 4.6 billion years ago — Present

Asteroids Come in Many Sizes

LARGE ASTEROIDS ARE DWARF PLANETS: Small asteroids are rubble piles, but large asteroids like Ceres and Vesta may have a layered internal structure, or even a core. Ceres (the largest known asteroid) is 950 kilometers (km) in diameter. Vesta is 530 km across. For comparison, Earth is 12,742 km across, Mars is 6,779 km, and Pluto is 2,390 km.

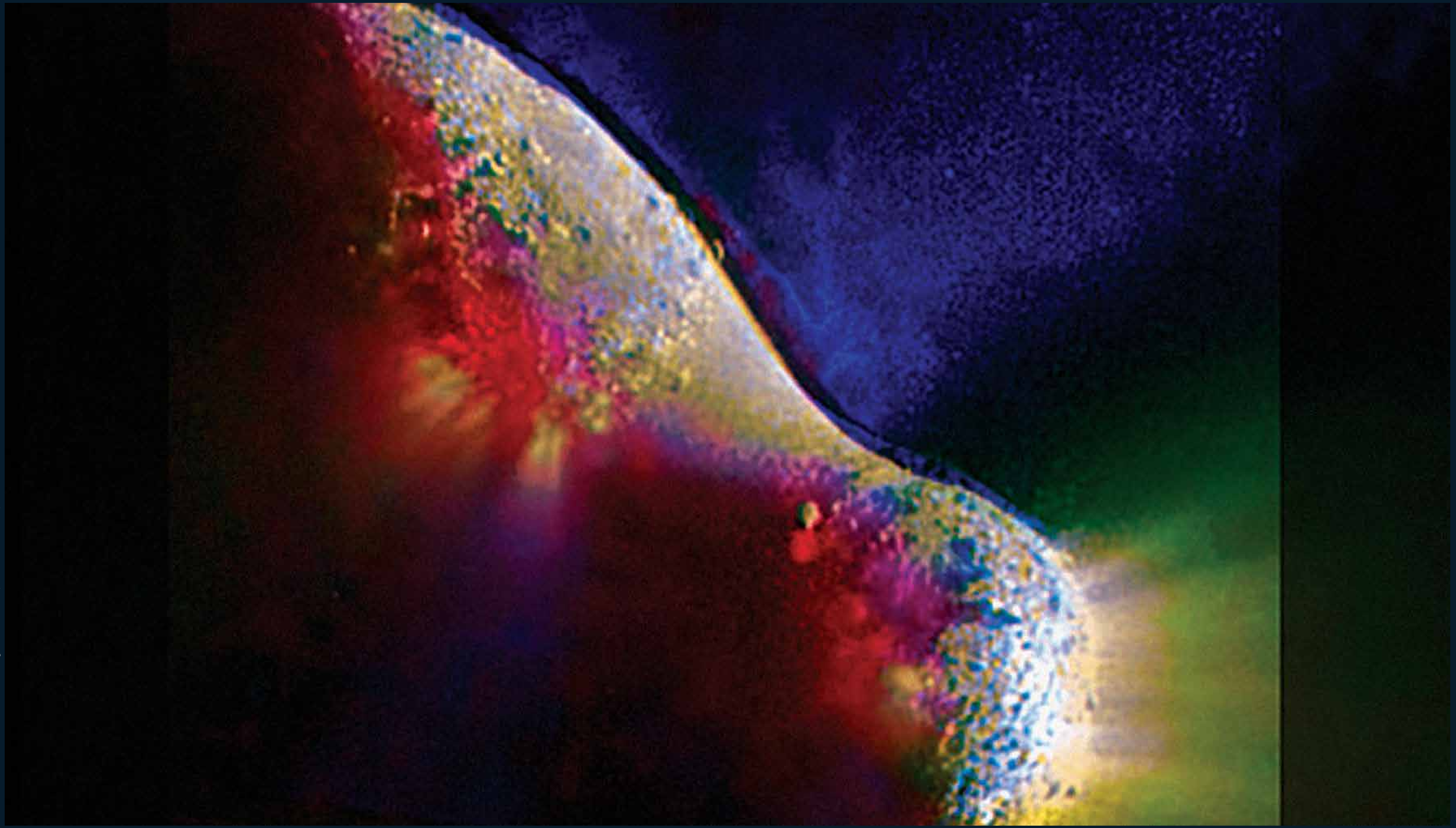
NASA spacecraft visited several comets and asteroids, and even brought material from comet Wild-2 back to Earth.

Goddard scientists found glycine, a building block of life, in samples of Wild-2 collected by the Stardust spacecraft.

STATION 06 > Goddard Initiatives

Cometary Compositions Reflect Diverse Origins

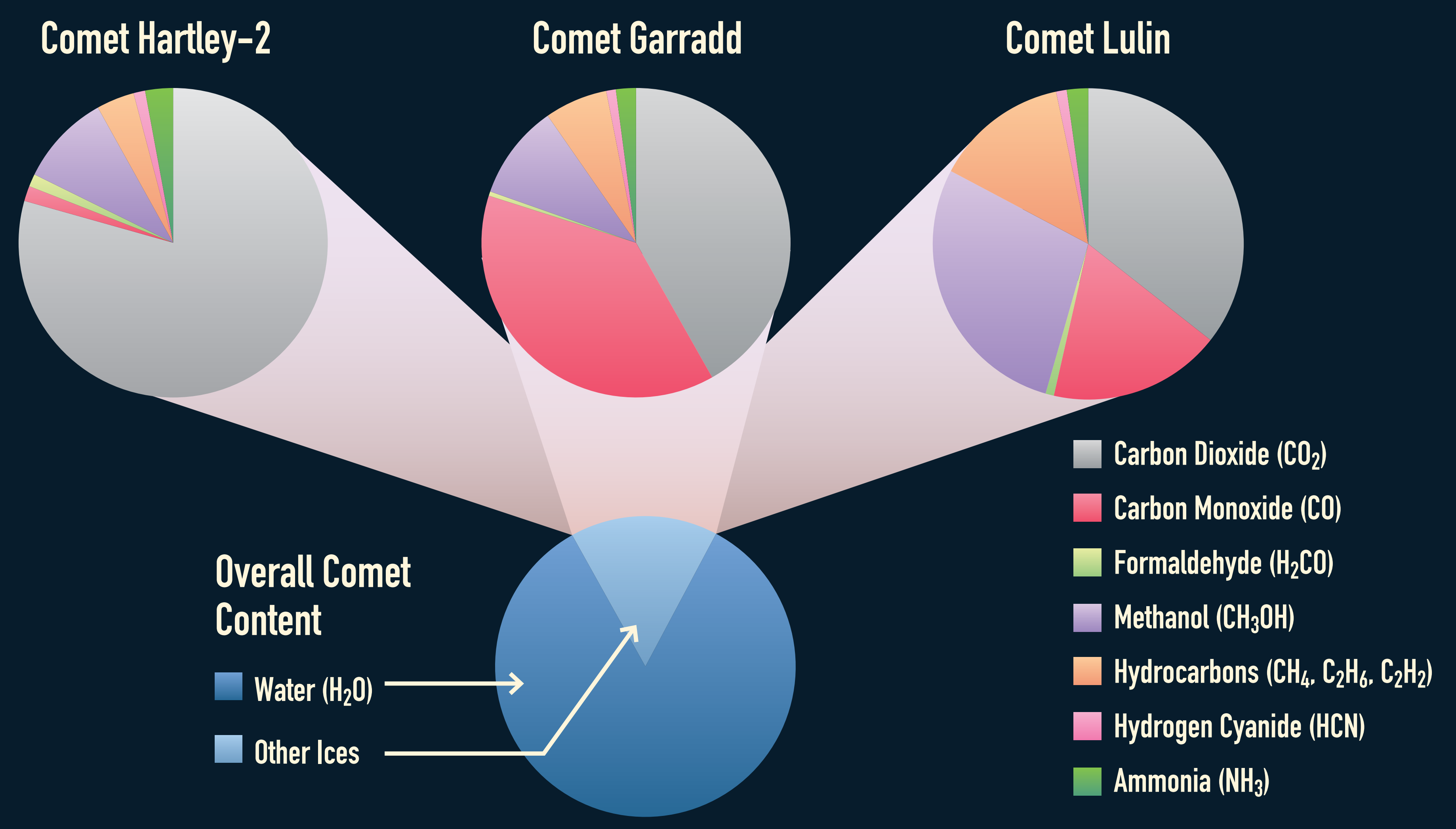
Comet nuclei are about 50-50 composed of ices (water, dry ice and others) and rocky minerals, while asteroids are richer in minerals. Goddard scientists investigate cometary ices by measuring the gases released from the nucleus. They find that comets are highly diverse in their organic (for example: methanol, ethane, methane) and nitrogen-containing ices (hydrogen cyanide, ammonia), whether the comets reside in the Oort Cloud or the Kuiper Belt.



NASA/JPL-Caltech/UMD/Lucy McFadden, J. Friedlander, B. Griswold

COMET HARTLEY-2: This false-color image of the nucleus of Hartley-2 shows jets of water vapor (blue), CO_2 (green) and dust (yellow). The ices of the measured gases are not mixed uniformly in the nucleus of this comet.

The Diversity of Cometary Ices

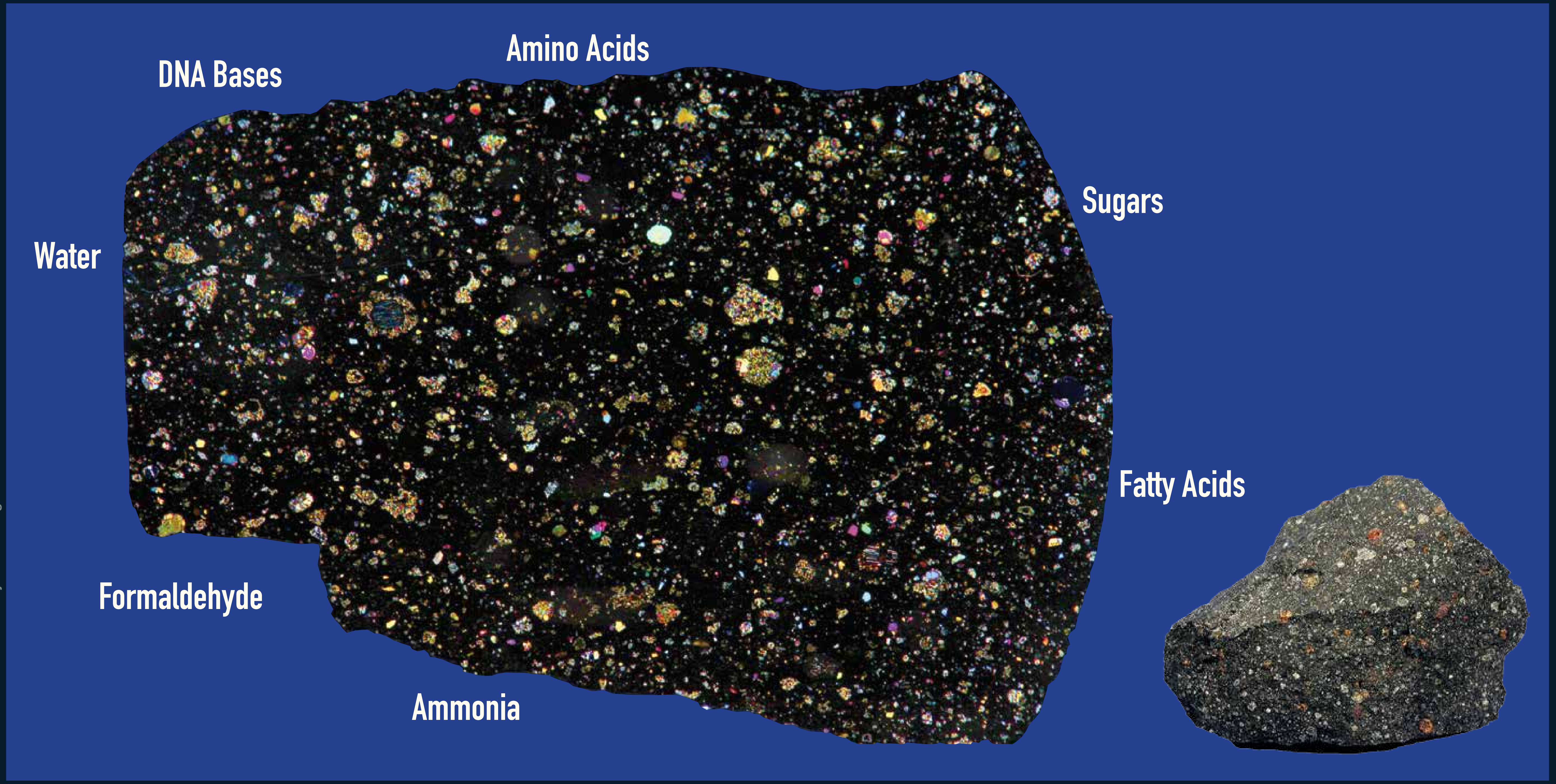


Comets and asteroids delivered much of the water, and building blocks of life, to our planet. The fraction of each delivered in this way is under intense study. Importantly, the isotopic compositions of water are the same in comet Hartley-2 and in Earth's oceans, but other comets are different. Did comets just like Hartley-2 deliver Earth's oceans?

DID YOU KNOW?

A comet nucleus could serve as a rich resource for a future space colony. A comet of 1 kilometer diameter contains about 500 million cubic meters of material, or about 250 million metric tons of ice and mineral-rich dust, enough to supply a colony with fuel, water, metals and food for a very long time.

STATION 07 > Meteorites Contain Ingredients for Life

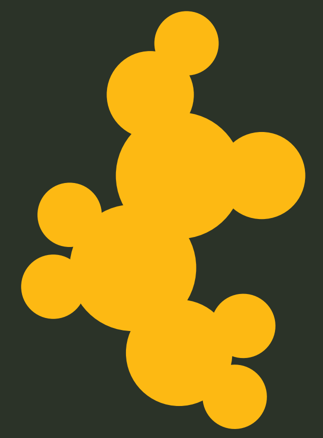


Southwest Meteorite Laboratory/ Marvin Killgore

New England Meteoritical Services/Russell Kempton/Lab photograph

CARBONACEOUS METEORITES CONTAIN MANY ORGANIC CHEMICALS: The >100-kilogram (>220-pound) Murchison meteorite landed in Australia in 1969 and has been extensively studied. It contains many types of chemicals that are used by life on Earth. A pebble-sized fragment (less than an ounce or 23 grams) is shown at lower right. Magnified 10 times and seen in polarized light, a thin slice reveals colors that indicate different minerals.

Many meteorites are pieces of asteroids and comets that land on Earth. Others are rocks from Mars or the Moon. Some contain a variety of organic (carbon-containing) chemicals. These include amino acids (the building blocks of proteins) and nucleobases that form the rungs of the DNA ladder (life's genome). Astrobiologists study these meteorites to discover their chemical content.



↑ BUILDING BLOCKS OF LIFE
The amino acid glycine, made of carbon (gray), nitrogen (blue), oxygen (red), and hydrogen (white), is one of the many chemicals essential to life on Earth that are also present in meteorites.

Finding Meteorites on Earth

NASA Ames/Scott Sanford

COLLECTING EXTRATERRESTRIAL VISITORS: The yearly Antarctic Search for Meteorites (ANSMET) expedition finds and collects meteorites for scientific study.

About 40,000 tons of meteoritic material hit Earth each year. Most of it is dust that burns up in the atmosphere, but larger pieces land all over Earth's surface. Scientists study collected meteorites, often by crushing them and placing them in hot water to dissolve certain molecules. The resulting "meteorite tea" is analyzed in the laboratory to identify the meteorite's chemical content.

STATION 07 > Goddard Initiatives

Mirror-Image Molecules: Left-Handed Life

Amino acid molecules exist in two mirror-image forms, like your hands. Chemistry usually makes these two forms in equal amounts, but life on Earth uses mostly the "left-handed" type to build proteins.

Why? This is a great mystery in science, and meteorites might hold the answer. Some meteorites have more left-handed amino acid molecules than right-handed ones. Scientists are working to understand how this happened, and whether meteorites delivered extra left-handed amino acids to the early Earth. Maybe the first life on Earth used the left-handed molecules delivered by meteorites!

NASA Goddard/B. Griswold

AMINO ACID'S HANDEDNESS: The two mirror-image forms of amino acid molecules are like your hands – they can't be rotated or flipped to line up with each other. A right hand won't fit into a left-handed glove, and right-handed amino acids don't fit into life's left-handed proteins.

Clues from Pristine Samples

NASA

MISSION TO A CARBONACEOUS ASTEROID: In 2019, OSIRIS-REx will collect pristine material from asteroid 1999 RQ36 and return it to Earth for study in terrestrial laboratories at Goddard and elsewhere.

Goddard scientists identified the amino acid glycine in samples returned from comet Wild-2 by the Stardust spacecraft.

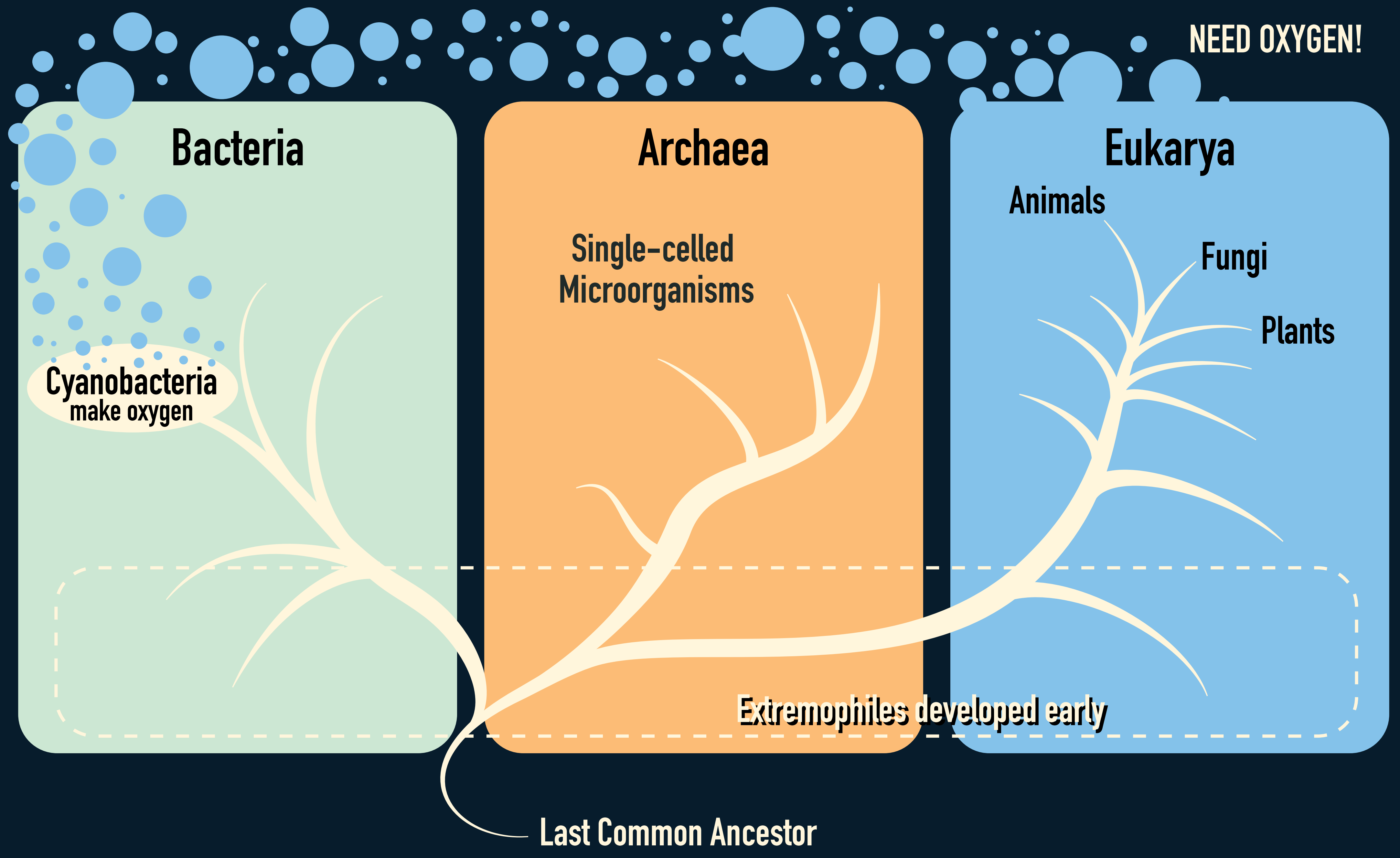
OSIRIS-REx will return samples of a carbonaceous asteroid for similar study.

DID YOU KNOW?

Sample return missions bring pieces of other Solar System bodies to Earth. This material is untouched by Earth's contaminating environment, and so preserves a true record of its history. Scientists who were not yet born when Apollo astronauts walked the Moon are now studying the lunar rocks brought back to Earth.

STATION 08 > Life Transformed Earth

Life Transformed Earth



JUST ADD OXYGEN: A phylogenetic tree of life shows that all major groups of organisms are linked to one common ancestor billions of years ago. This ancestor was probably a small single-celled organism that lived in an extreme environment. The rise of atmospheric oxygen led to the development of plants and animals (including humans). Without oxygen, life on Earth may have looked completely different.

Once life was established on the early Earth, it began to change the environment. Cyanobacteria released oxygen as a waste product of photosynthesis. The oxygen first reacted with dissolved iron in the oceans to create banded iron formations. At about 2.4 billion years ago, oxygen began to increase dramatically in the atmosphere (the Great Oxidation Event). This made multicellular life possible and created our protective ozone layer.

↑ ANCIENT STROMATOLITES BUILT BY CYANOBACTERIA, AND BANDED IRON
You can touch rocks that were formed by some of Earth's oldest life. The larger stromatolite is 2.7 billion years old, while the smaller one is 2.3 billion years old. Their ages bracket the Great Oxidation Event (GOE). On the reverse side is a banded iron sample (2.45 billion years old).

Courtesy of Mark Boyle/reproart.com.au

RECORDS OF ANCIENT LIFE: On the early Earth, microbial mats were everywhere! Some produced stromatolites, which are stubby pillars that later became fossilized. Stromatolites are not fossils of organisms but instead are the fossilized remains of layered sedimentary grains captured by the bacterial colony. This image shows modern stromatolites located in Shark Bay, Western Australia.

STATION 08 > Goddard Initiatives

Extremophiles: Some Like it COLD

Scientists of the Goddard Center for Astrobiology study life found in extreme environments on Earth such as glacier ices, hydrothermal vents and alkaline lakes. For one research project, NASA scientists traveled to Svalbard, Norway, to study life that survives in very cold temperatures and in glacier ices. But you don't always have to be a world traveler to study life under extreme conditions. Scientists can simulate some of these extreme conditions in the laboratory.

AMASE/Kjell Ove Storvik

THE COOLEST LIFE: Goddard scientists study the red and blue algae that live in glacier ice. The photo above shows samples being collected from Friedrichbreen glacier in Svalbard, Norway.

Some Like it HOT

Jim Peaco/National Park Service

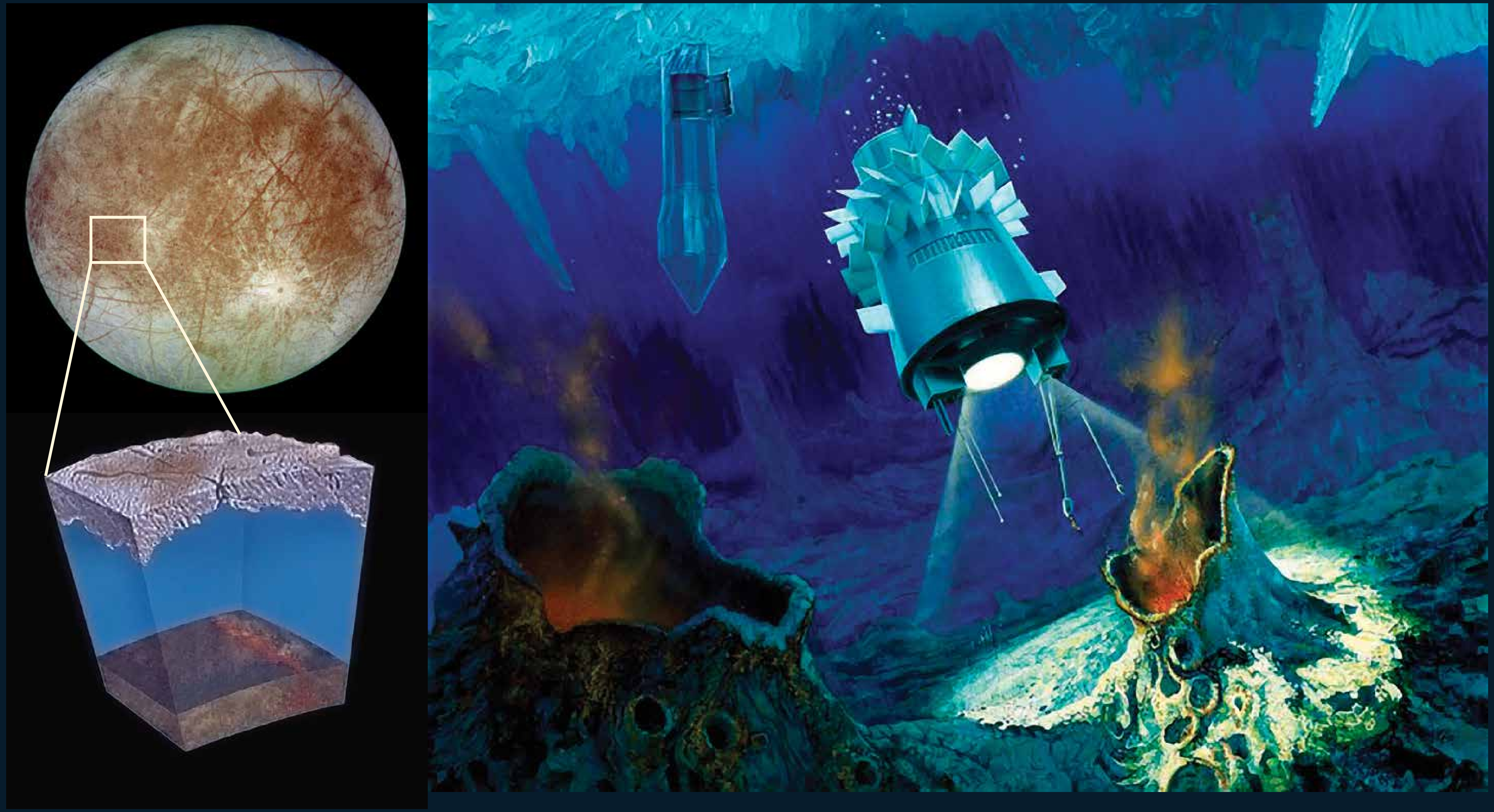
HEAT-RESISTANT BACTERIA: The vivid colors around the Grand Prismatic Spring in Yellowstone National Park result from microbial mats that grow around the edges of the water. Life can survive even at the hot temperature of 160 °F (71 °C). The boardwalk path on the lower right side indicates the size of this thermal vent.

Understanding how life survives in extreme environments informs and guides the search for life beyond Earth. The extreme environments on Earth may be analogous to those on different planets and moons. Thus, extraterrestrial life may exist even on a hot or cold planet.

DID YOU KNOW?

The rise in oxygen was not entirely beneficial for life. It actually led to the near-extinction of oxygen-intolerant organisms.

STATION 09 Search for Life in the Solar System

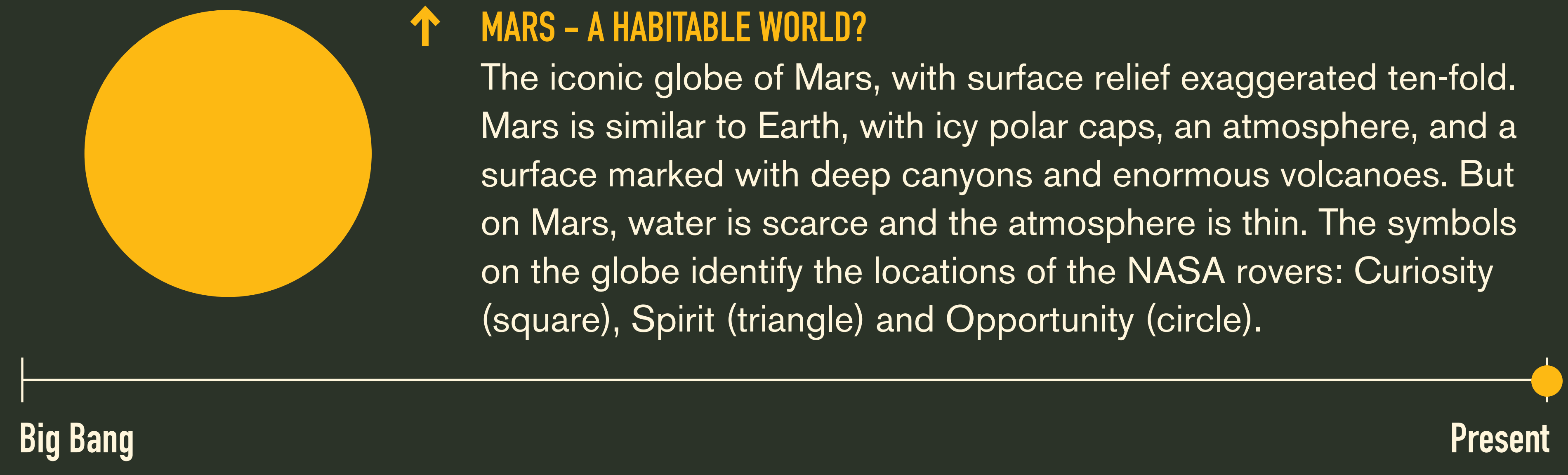


NASA/JPL-Caltech

HIDDEN OCEANS ON ICY WORLDS: The thick icy crust of Europa, a moon of Jupiter, hides a deep ocean. Scientists hope to penetrate the crust with a powerful “melt probe” and reach the subsurface ocean. Underwater, a “hydrobot” would collect information and send it to Earth.

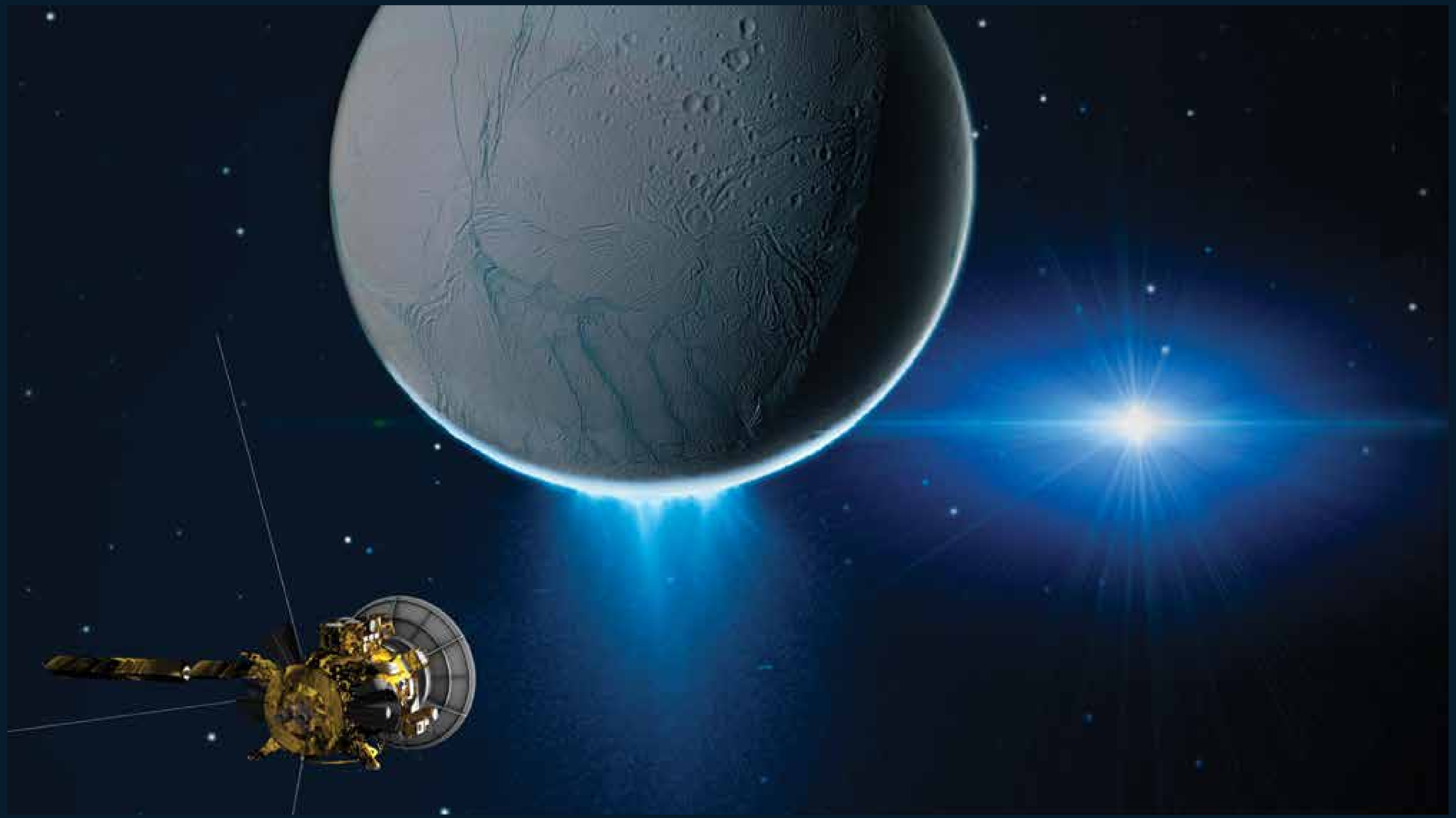
What type of life do we expect beyond our planet? Most of Earth’s life is microbial and is found in our oceans. Several moons in our Solar System contain deep oceans and have strong potential for habitability. Life could exist in these subsurface oceans, perhaps in an environment similar to Earth’s deep-ocean hydrothermal vents or the Antarctic subglacial Lake Vostok.

MARS – A HABITABLE WORLD?
The iconic globe of Mars, with surface relief exaggerated ten-fold. Mars is similar to Earth, with icy polar caps, an atmosphere, and a surface marked with deep canyons and enormous volcanoes. But on Mars, water is scarce and the atmosphere is thin. The symbols on the globe identify the locations of the NASA rovers: Curiosity (square), Spirit (triangle) and Opportunity (circle).



Mars topographic data courtesy of NASA MOLA team (D.E. Smith et al.)

A Subsurface Ocean and Water Plumes



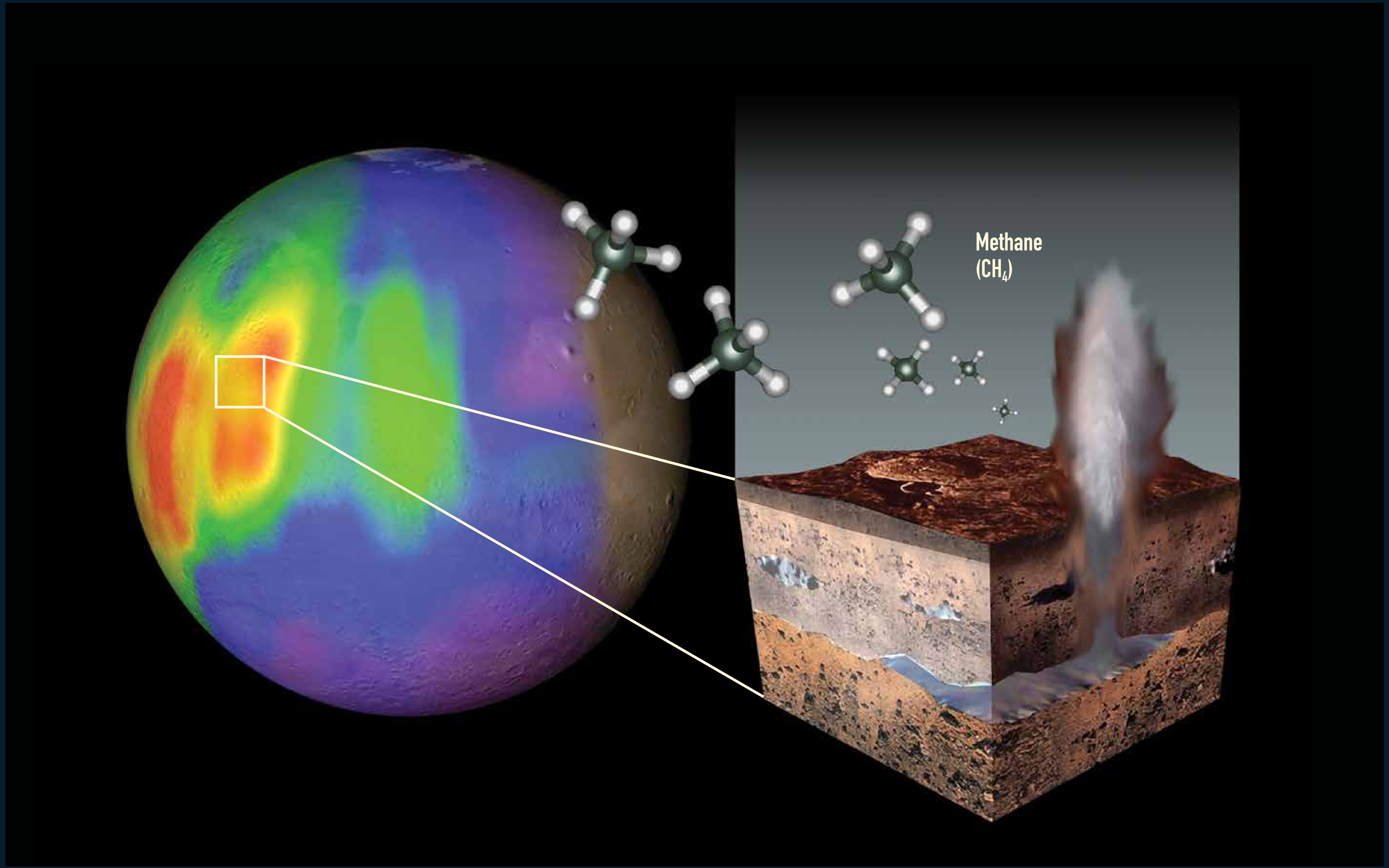
NASA/JPL-Caltech

SATURN’S MYSTERIOUS MOON, ENCELADUS: In 2005, scientists using NASA-ESA’s Cassini spacecraft detected plumes of water vapor and organic gases above Enceladus’ south pole, suggesting that a deep liquid ocean lies beneath its icy surface. The Goddard-built and -managed infrared spectrometer on Cassini discovered warm temperatures in the vents that release these plumes.

STATION 09 > Goddard Initiatives

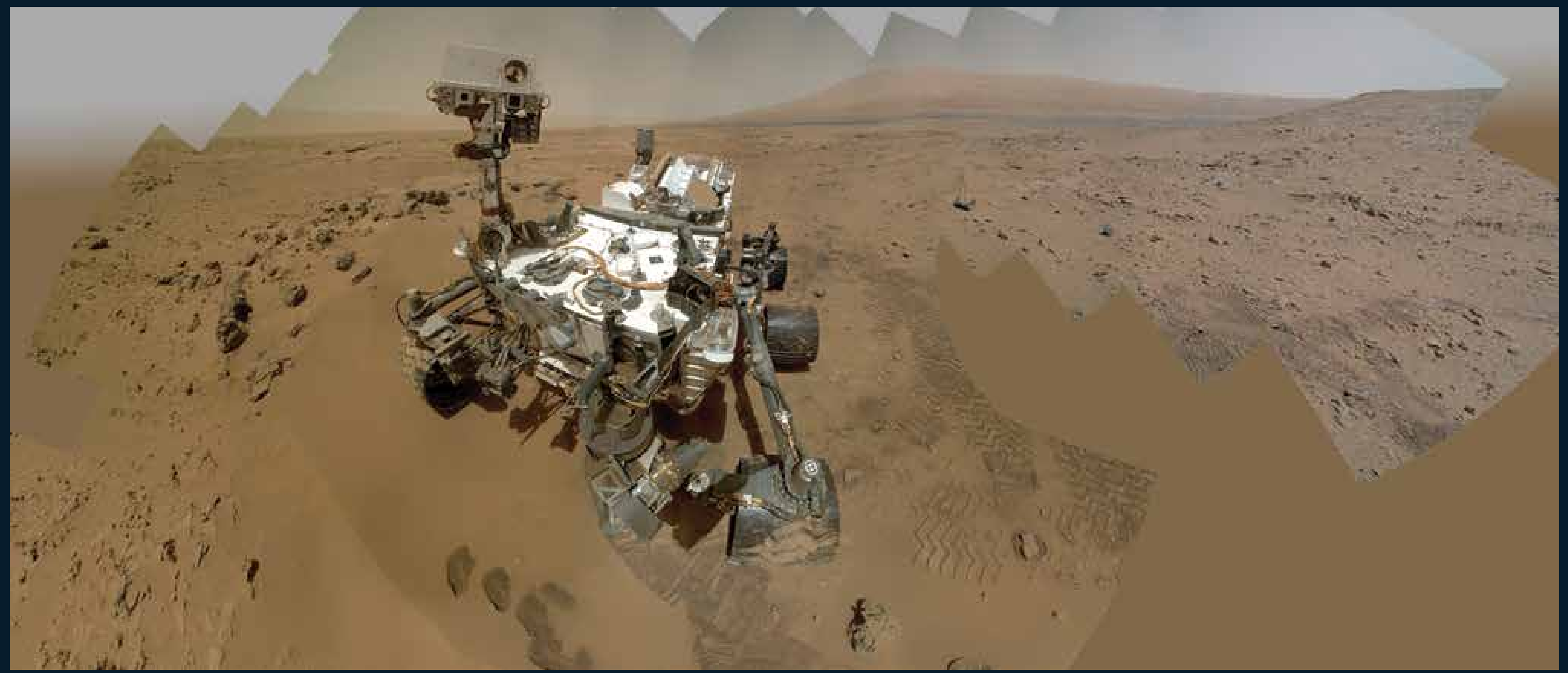
Search for Life on Mars

The search for life (existing or extinct) has been a driving theme in exploration, giving rise to several NASA missions and to sensitive searches for gases related to biology. Mars is one of a select few Solar System bodies where life might have evolved and perhaps might survive in favorable niches even today.



METHANE RELEASES ON MARS: In 2003, Goddard scientists detected methane on Mars. On Earth, methane is an indicator of biology and geology, and these observations may point to habitable regions on Mars, or active geological areas. On Mars, methane was found in large plumes (red, above).

Was Ancient Mars Habitable?



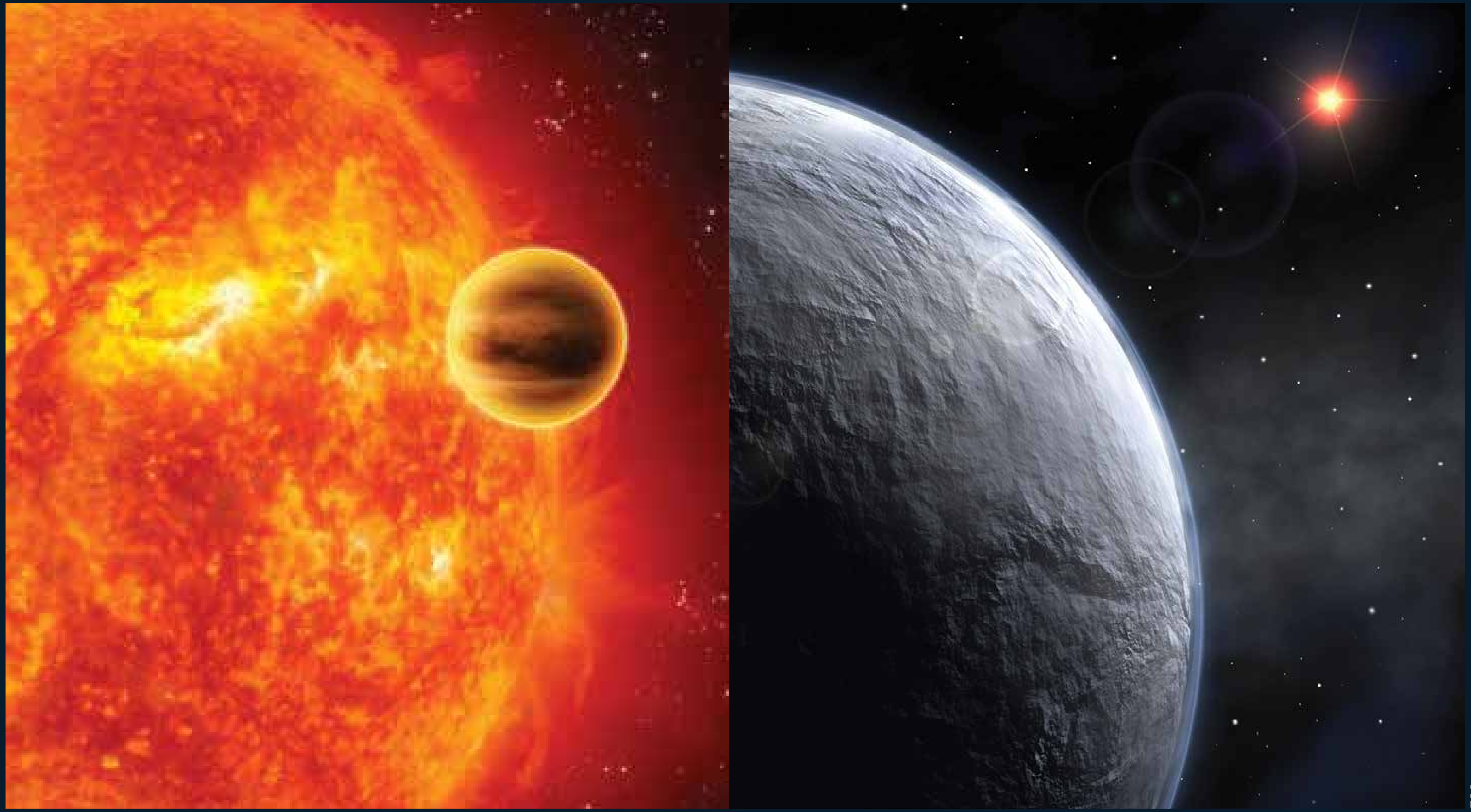
CURIOSITY SELF-PORTRAIT: Goddard scientists search for methane and other organics on Mars with the Curiosity rover, the most powerful lander ever to operate on the surface of Mars.

Mars' signature color (red) originates in a cover of rust, a deep layer of dusty iron-oxide covering much of its surface. Mars is also blanketed with many other minerals including some that formed in water, indicative of a wet past.

DID YOU KNOW?

Life controls Earth's atmosphere. Oxygen and carbon dioxide are produced by life, but so are many less abundant gases. Methane, ammonia and nitrous oxide are produced mainly by biological processes. Without life, our atmosphere would have a very different composition. That is why scientists seek "biomarker" gases on Mars and exoplanets.

STATION 10 > A Galaxy Full of Diverse Exoplanets



ESA - C.Carreau

ESO

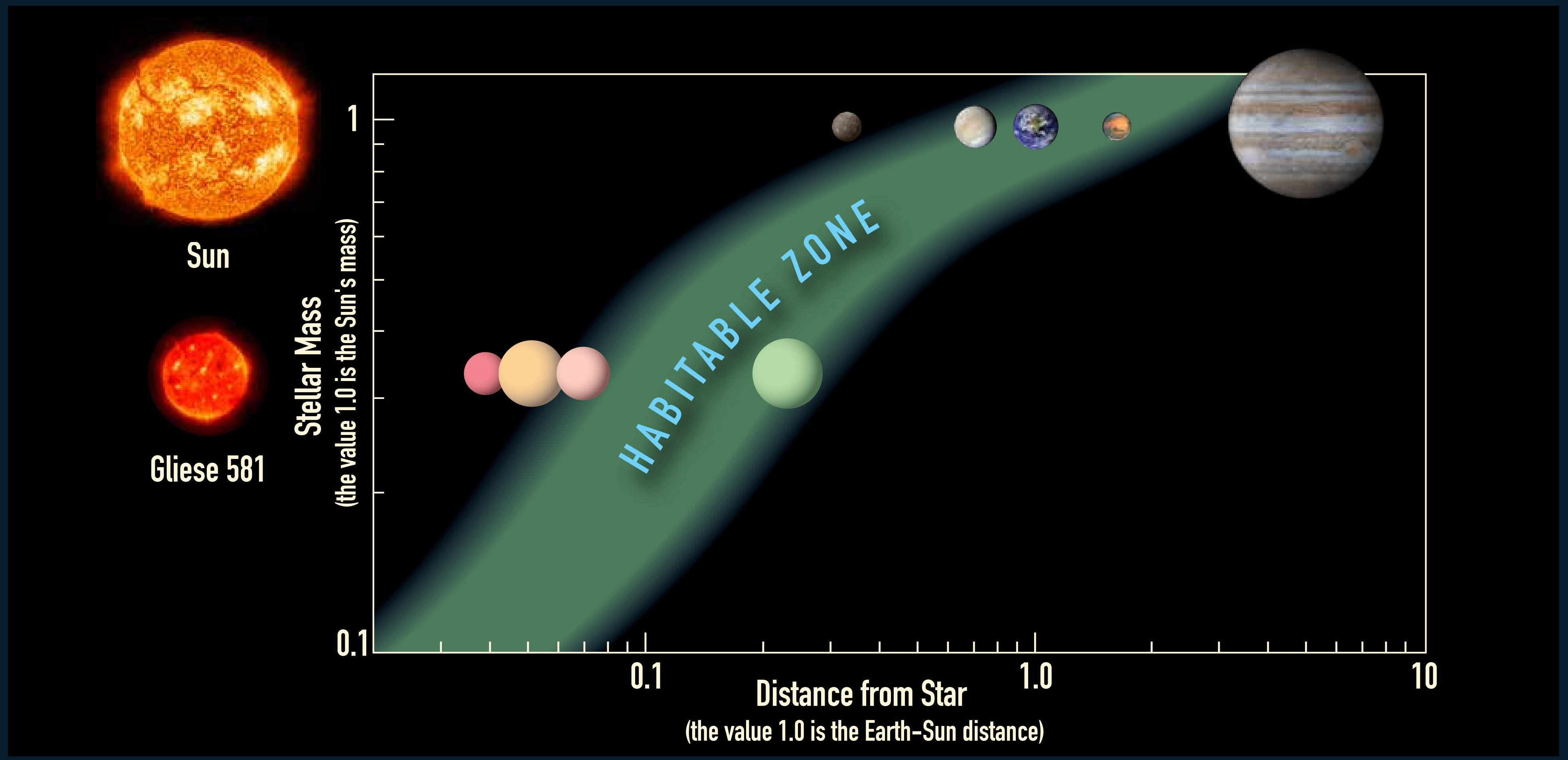
OTHER WORLDS: Notional representations of a "hot Jupiter" orbiting very close to its host star (above, left) and an icy "super Earth" a few times larger than the Earth (above, right). These types of planets have been found around other stars but are not present in the Solar System.

Astronomers have found many planets around other stars both near and far. Some of these "exoplanets" resemble planets in the Solar System, but others are very different. Up to 160 billion planets might exist just in our own galaxy, the Milky Way. We have even found a small hot exoplanet orbiting Alpha Centauri B, the star system nearest to the Sun (four light years away).

↑ THREE PLANETARY SYSTEMS
Diagrams of two exoplanet systems found by NASA's Kepler mission are compared to the Solar System (middle). All three systems have planets in their habitable zones, which are marked by the patterned region. However, these Kepler planets are much more massive than Earth.

Big Bang — Present

What Makes a Planet 'Habitable'?



ESO

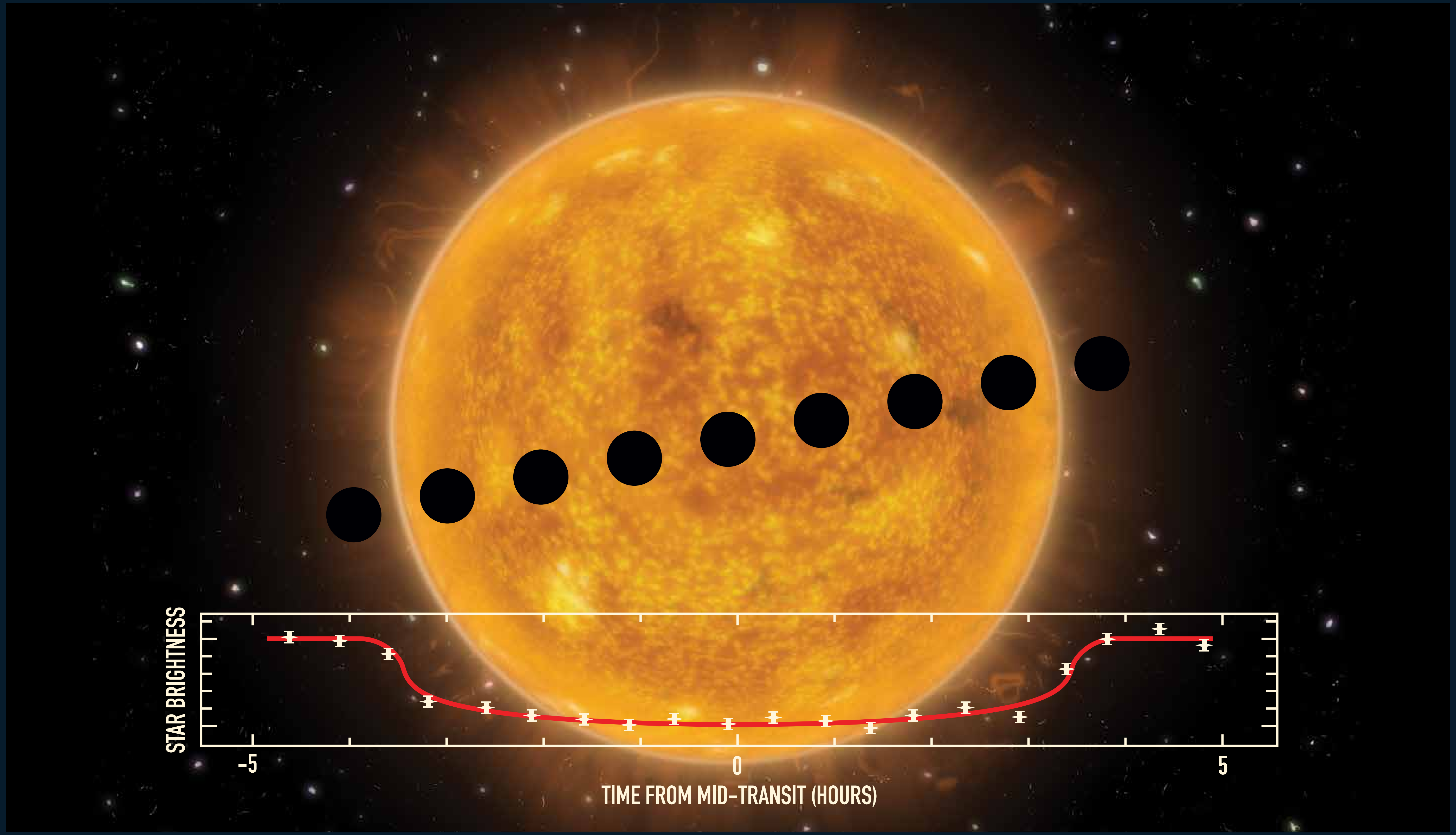
HABITABLE ZONES: The Solar System's habitable zone stretches from near Venus to slightly beyond Mars (top). The habitable zone of a smaller, cooler star like Gliese 581 is closer to the star (middle).

The habitable zone is the "Goldilocks region" around a star, where the surface of an Earth-like planet receives the amount of light needed to bring its temperature into the range where water is liquid (0 to 100 °C).

STATION 10 > Goddard Initiatives

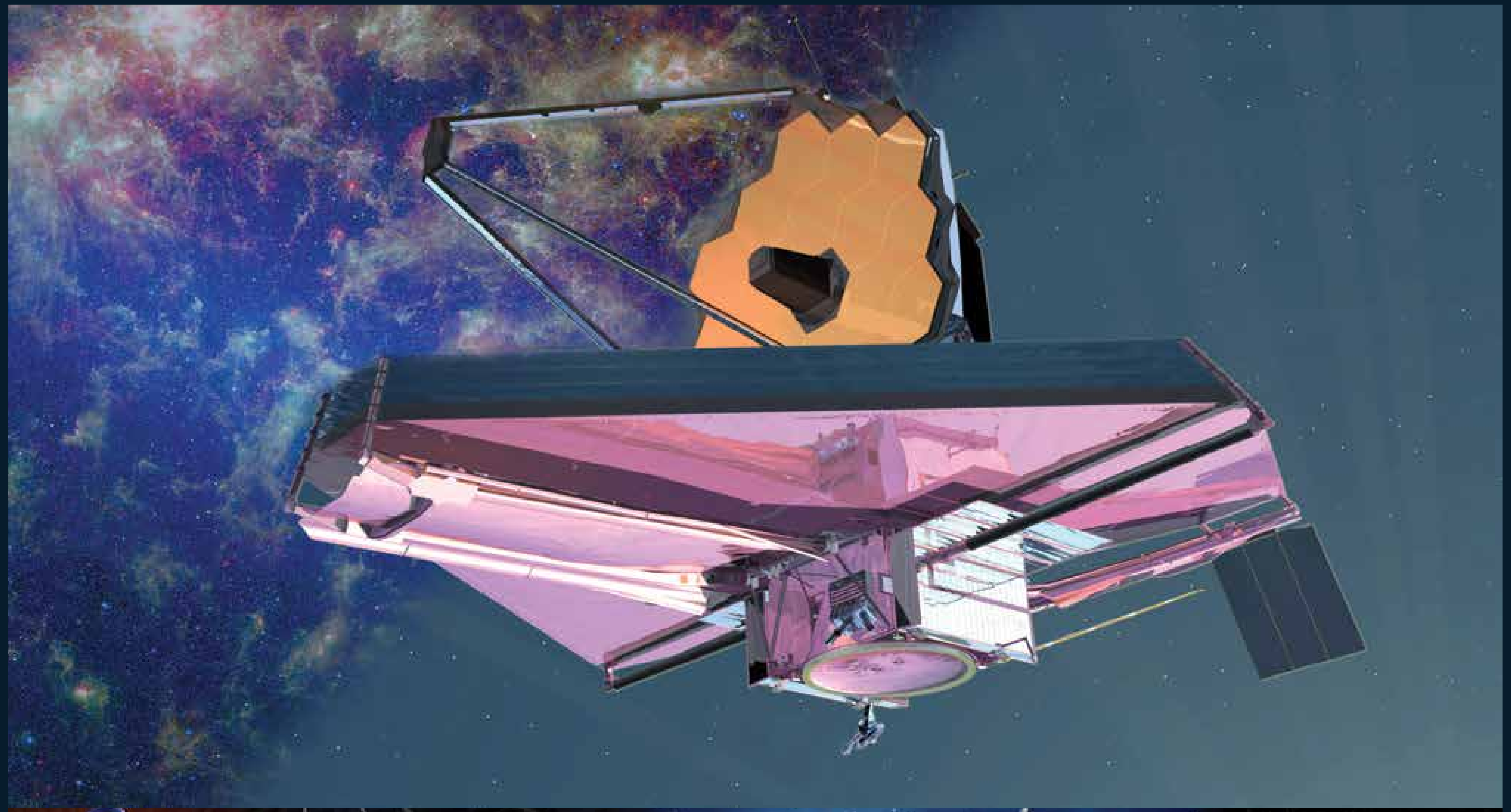
Exploring Exoplanet Atmospheres

The transit method is a highly productive strategy for discovering and characterizing exoplanets. When an exoplanet "transits," or passes in front of its star, it blocks a fraction of the star's light and causes a dip in brightness. Since larger planets block more light, the size of the dip gives the size of the planet. Transits can also be used to probe planetary atmospheres by searching for evidence of gases such as water and methane. Scientists at Goddard are using transits to determine the size, structure and composition of these distant worlds.



NASA Goddard/B. Griswold

PLANETARY TRANSITS: The red curve shows a dip in a star's brightness as a planet passes in front during transit. The amount of light blocked reveals the size of the planet. Other studies reveal its mass, density and temperature, for comparison with planets in our Solar System.



NASA Goddard/JWST

NASA Goddard/M. Hrybyk-Keith

FUTURE EXOPLANET MISSIONS: Goddard scientists and engineers develop telescopes for exoplanet science. Top: NASA's James Webb Space Telescope, now being built. Bottom: Notional telescope and starshade for imaging Earth-sized planets in the habitable zones of nearby stars.

DID YOU KNOW?

Most exoplanets are too distant to see in pictures taken with present telescopes, but scientists study their sizes, compositions and atmospheres using other methods.