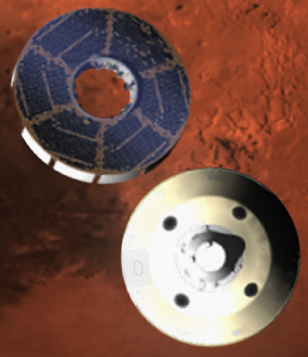
MARS



SETI INSTITUTE

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Cover Image: Perseverance Rover's cruise stage separation
Credit: NASA/JPL-Caltech

Twin Mars Cube One (MarCO) spacecraft flying over Mars
Credit: NASA/JPL-Caltech

THE WANDERING STAR

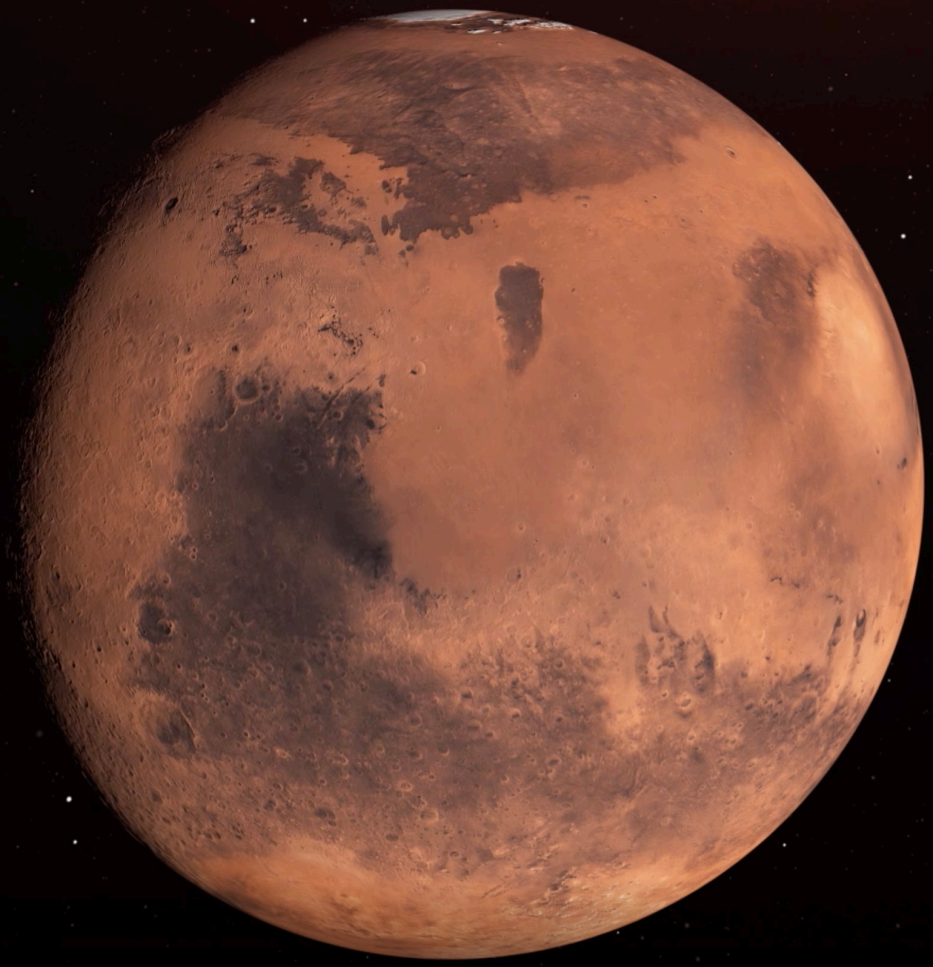
Mars. The red planet. The fourth rocky world from the sun. A planet flanked by Earth and the asteroid belt.

Mars has captivated humanity's imagination for centuries. Because of its red color, many early cultures spotted it shining in the night sky. The planet is mentioned in Ancient Egyptian writings, and the Romans named it after their God of War—a name that stuck.

In 1610, Galileo Galilei used the telescope he invented to make the first observations of Mars, and as telescope technology improved, so did astronomers' observations. In 1877, Giovanni Schiaparelli drew the shapes and shadows he saw on the planet's surface, naming the dark features he spotted canali, the Italian word for water trough. When the map was translated to English, *"canali"* became canals, a word which brings to mind artificial construction. Starting in the 1890s, Percival Lowell—a businessman who became interested in astronomy—published many writings and drawings of so-called "non-natural features" he thought he could see on the Martian surface.

Word of canals and artificial features on Mars spread across the English-speaking world like wildfire, leaving many with the idea that intelligent life wandered the planet's surface. H.G. Wells penned his famous novel "War of the Worlds" in 1897, and a slew of novels about advanced Martians followed. Mariner 4 sent back the first grainy pictures of the surface in 1965, showing Mars as a desolate planet, and this was confirmed again when we received images from Mariner 9 in 1969. Though Mars was desolate, it was also uniquely diverse with canyons, dry rivers, ancient volcanoes, dune fields, and much more.

Mars was not always the desolate world it is today. It may once have had conditions similar to those that saw the emergence of life on Earth. This possibility continues to intrigue us to this day.



MARS QUICK FACTS

ORBIT LENGTH: 687 days (1.88 Earth years)

AVERAGE DISTANCE FROM THE SUN: 225 million km (140 million miles)

DAY (AKA SOL): 24 hours and 37 minutes

RELATIVE SIZE: About half the Earth

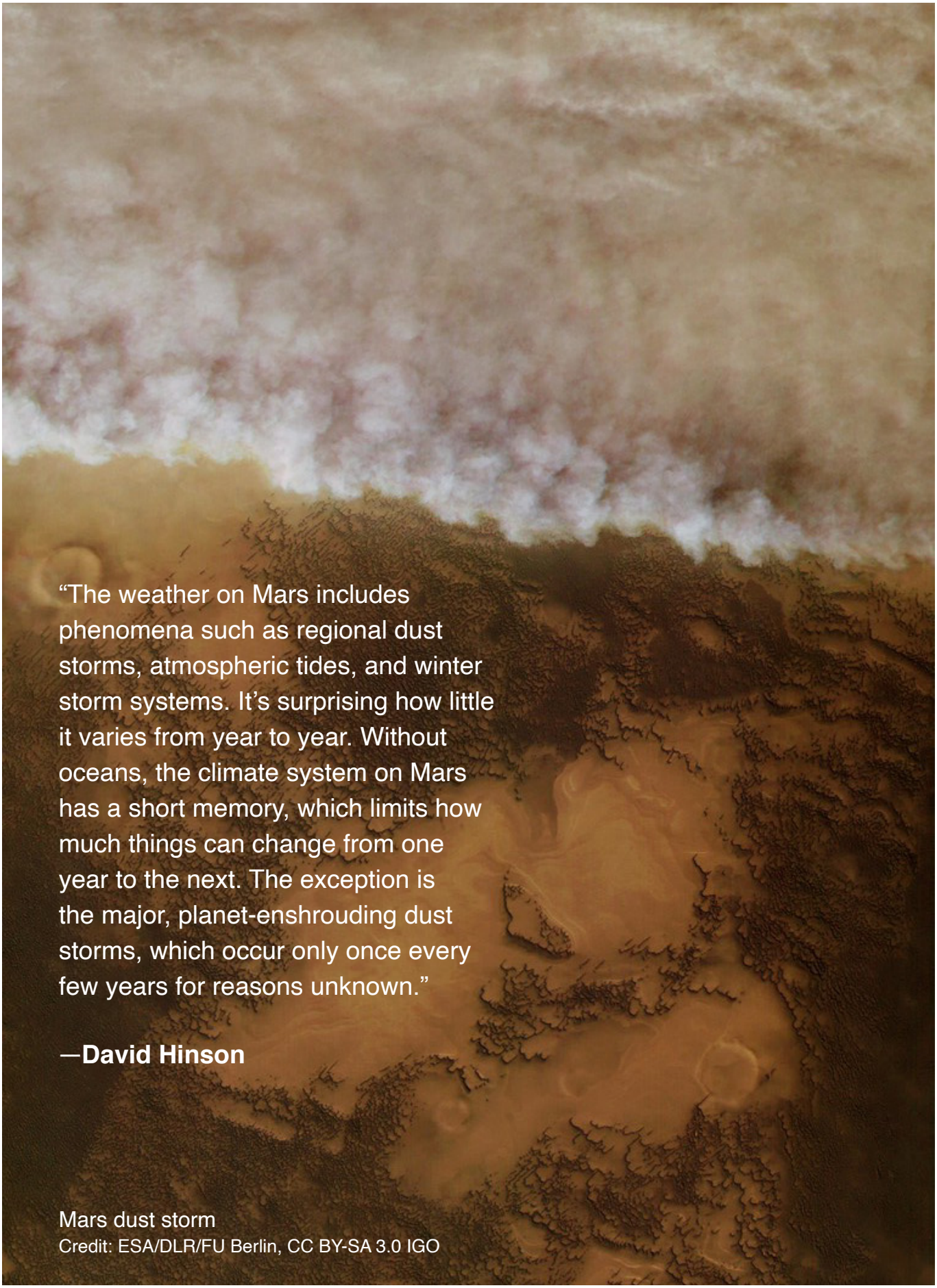
MASS: About 15 percent of Earth

GRAVITY ON MARS: 0.375 that of Earth

AVERAGE SURFACE TEMPERATURE: -60° Celsius (-80° F)

NUMBER OF MOONS: 2

Credit: NASA/JPL-Caltech



“The weather on Mars includes phenomena such as regional dust storms, atmospheric tides, and winter storm systems. It’s surprising how little it varies from year to year. Without oceans, the climate system on Mars has a short memory, which limits how much things can change from one year to the next. The exception is the major, planet-enshrouding dust storms, which occur only once every few years for reasons unknown.”

—David Hinson

Mars dust storm
Credit: ESA/DLR/FU Berlin, CC BY-SA 3.0 IGO

FORMATION TO DEVASTATION

About 4.5 billion years ago, our sun formed from a disk of gas. The remaining material began to spin around the newborn star and smashed together to form the planets, including Mars.

Shortly after the formation of the planets, Neptune and Uranus disturbed a field of asteroids and comets on the outskirts of the solar system called the Kuiper belt. These objects rained down on the inner planets, leaving craters we can still see today on Mars. This period was called the late heavy bombardment. But it might not have been all doom and gloom. The same objects from the Kuiper belt may have delivered water to Mars that formed rivers, oceans, and lakes dotting the planet's surface. At the same time, the red planet developed an atmosphere, which helped it retain the liquid water on its surface.

Mars could have looked a lot like Earth—albeit colder given its distance from the sun.

But it wasn't meant to be. The planet's magnetic field began to weaken as the planet rapidly cooled down, and eventually, solar winds eroded the atmosphere, which escaped into space. If life did exist on the surface of Mars, it likely had to migrate underground or it perished.

The planet is now desolate but beautiful. Dust and sandstorms race across the surface and its polar ice caps shrink and grow with the seasons. Mars is home to many amazing features that feel at once familiar and alien.

"In the far distant past, we think Mars was warmer and wetter, because we see dried-up river channels and flood channels. Sometime around 3.7 billion years ago, Mars started to dry up. We think it's related to loss of atmosphere, so Mars doesn't have a gas blanket to keep it warm (sort of like a reverse Greenhouse Effect)."

—Lori Fenton

The Zöe rover in the Atacama desert
Credit: David Wettergreen, Carnegie Mellon University

POTENTIAL FOR LIFE

While an advanced alien civilization hasn't built canals on Mars, the planet could have once supported simple life. When it was young, the planet was likely warmer, more active, and covered in liquid water—a good recipe for biology.

Adding to the possibility for ancient microbial life on Mars, astrobiologists have recently discovered myriad life forms here on Earth that exist in environments once believed uninhabitable. These so-called "extremophiles" live in acidic springs, superheated rocks, areas with high radiation, and in frigid temperatures (below 20 degrees Celsius). Perhaps there were extremophiles on Mars that lived through some of the more chaotic and inhospitable climates.

Previous missions to Mars have characterized the planet's present and past habitability, and the Perseverance Rover, which landed on the red planet on February 18, 2021, will be the first biosignature-focused mission. The rover will scour the surface for the most promising samples, take initial measurements for biosignatures, and store samples for a future return to Earth where scientists can take a closer look.

THE IMPORTANCE OF ANALOG ENVIRONMENTS

"In my fieldwork, I can't get to the exact conditions as Mars, so I get as close as possible here on Earth, like the Atacama Desert. By studying these analogs, I can begin to understand the limits of life in that environment. In the driest places on Earth, to the naked eye it looks like there's nothing alive, but there is something alive and it's hiding to stay out of the extreme conditions."

—Kim Warren-Rhodes

Perseverance Rover guides itself towards the Martian surface
Credit: NASA/JPL-Caltech

PAST AND CURRENT SURFACE MISSIONS ON MARS

Each mission to Mars chips away at the planet's past and present secrets. We've learned much from orbiters, landers, and rovers that have made it to the red planet. Below is a look at the amazing insights brought to us by the landers and rovers that have made it to the surface.

VIKING MISSIONS (LANDER): When the twin Viking I and II landers touched down on Mars in 1976, little was known about the Martian environment. The landers conducted life detection experiments that had intriguing and conflicting results. While some continue to believe Viking found evidence of biological reactions, most of the scientific community thinks non-biological elements can explain the results. Viking I landed on July 20, 1976, in Chryse Planitia and Viking II on September 3, 1976, in Utopia Planitia.

PATHFINDER (LANDER AND ROVER): The Pathfinder mission had both a landing platform and a shoe-size rover named Sojourner-Truth. The mission was mainly a technology demonstration for landing with airbags, a technology that would be successfully used for the Mars Exploration Rover mission that landed twin rovers Spirit and Opportunity in January 2004. Pathfinder landed on July 4, 1997, in Chryse Planitia, the outlet of a large outflow providing diverse rocks to study. It covered 100 m (330 ft) over 91 Martian days.

SPIRIT (ROVER): Spirit landed in Gusev Crater on January 4, 2004. The goal of the mission was to understand whether early Mars was habitable for life as we know it. The rover worked until 2010, covering 7.73 km (4.8 miles) in total. During this time, she discovered the first evidence of carbonates from the ground, signs of a wetter past, and evidence of volcanic/water interaction, with fumarole deposits and hot springs. Importantly, Spirit demonstrated that all the ingredients for life were once present at the same time at Gusev.

OPPORTUNITY (ROVER): The twin sister of Spirit landed in Meridiani Planum on January 25, 2004. She would go on to set countless records and make many key discoveries. This includes the discovery of hematite spherules, the famous blueberries that were the first evidence of early water on Mars. She discovered acidic and neutral environments, gypsum, and clays. She worked for 14 years, traversed 45.16 km (28.06 miles), and exceeded 55 times her designed lifespan. She stopped communicating on June 10, 2018.

PHOENIX (LANDER): The mission landed in Vastitas Borealis in the high northern latitudes of Mars on May 25, 2008, and operated until November 2 of the same year. Its goal was to characterize the history of water on Mars and understand its habitability potential. One of the surprises of the mission was she captured the first Martian snow falling from cirrus clouds. The lander also brought a wealth of new data regarding the Martian weather, climate cycles, and surface chemistry.

"There are two major challenges to exploring Mars with rovers. First is that valuable scientific targets may be in areas that are too hard to access for a rover. Second, rovers are slow—Perseverance's top speed is capped at about 0.1 mph. To avoid these pitfalls, future missions will use free-flying systems to support rover operations, improving safety by preventing the need for rovers to enter hazardous or dangerous environments, and collecting science data orders of magnitude faster. Surveying and even sampling a 10×10 km region would no longer be a matter of years but weeks."

—Pablo Sobron

CURIOSITY (ROVER): In April 2023, engineers installed a significant software update on Curiosity to enable it to drive faster, and to reduce wear and tear on its wheels. Now, Curiosity can do more of what the team calls “thinking while driving.” The new software will also enable the engineers to plan the motions of Curiosity’s robotic arm more efficiently and point its “head” atop the mast more accurately.

INSIGHT (LANDER): For four years, the InSight Lander monitored “marsquakes,” providing details on Mars’ interior, formation, and activity such as meteor impacts. The mission ended on Dec. 21, 2022, after the solar-powered spacecraft ran out of energy. InSight is characterized by 1) bringing the first seismometer to Mars and 2) recording "sounds" of Martian winds on the Red Planet for the first time. InSight was the first robotic explorer to study Mars’ crust, mantle, and core. Its mission was to uncover how a rocky body forms and evolves to become a planet.

PERSERVERANCE (ROVER): Active since 2020, the Perseverance rover has been looking for signs of ancient life on Mars at the Jezero Crater. Jezero formed from an asteroid impact almost 4 billion years ago. At over 1,000 days on Mars and 23 samples collected, the mission team discovered sandstone and mudstone, signaling evidence of a history of water in the crater. Beyond Perserverance’s key objective of searching for signs of ancient microbial life on Mars and being the first mission to collect and cache Martian rock, it also deployed its aerial sidekick, Ingenuity, which became the first powered flight on the red planet.

INGENUITY (HELICOPTER): Ingenuity, ‘the little helicopter that could,’ as NASA administrator Bill Nelson refers to it, has finally taken its last flight. It made history as the first aircraft to make a power-controlled flight on another planet. What started as a technology demonstration to perform up to five experimental flights in 30 days, Ingenuity completed an astonishing 72 flights covering the Martian surface for almost three years! Acting as a scout for the Perseverance Rover and helping search for life on Mars, Ingenuity paved the way for future flight in our solar system.

Mars 2020 Perseverance Launch
Credit: NASA/Joel Kowsky

INTRIGUING PROCESSES

From towering volcanoes to frosty sand dunes, the red planet's landscape is magnificent to behold, and there are many processes on Mars that we don't yet fully understand.

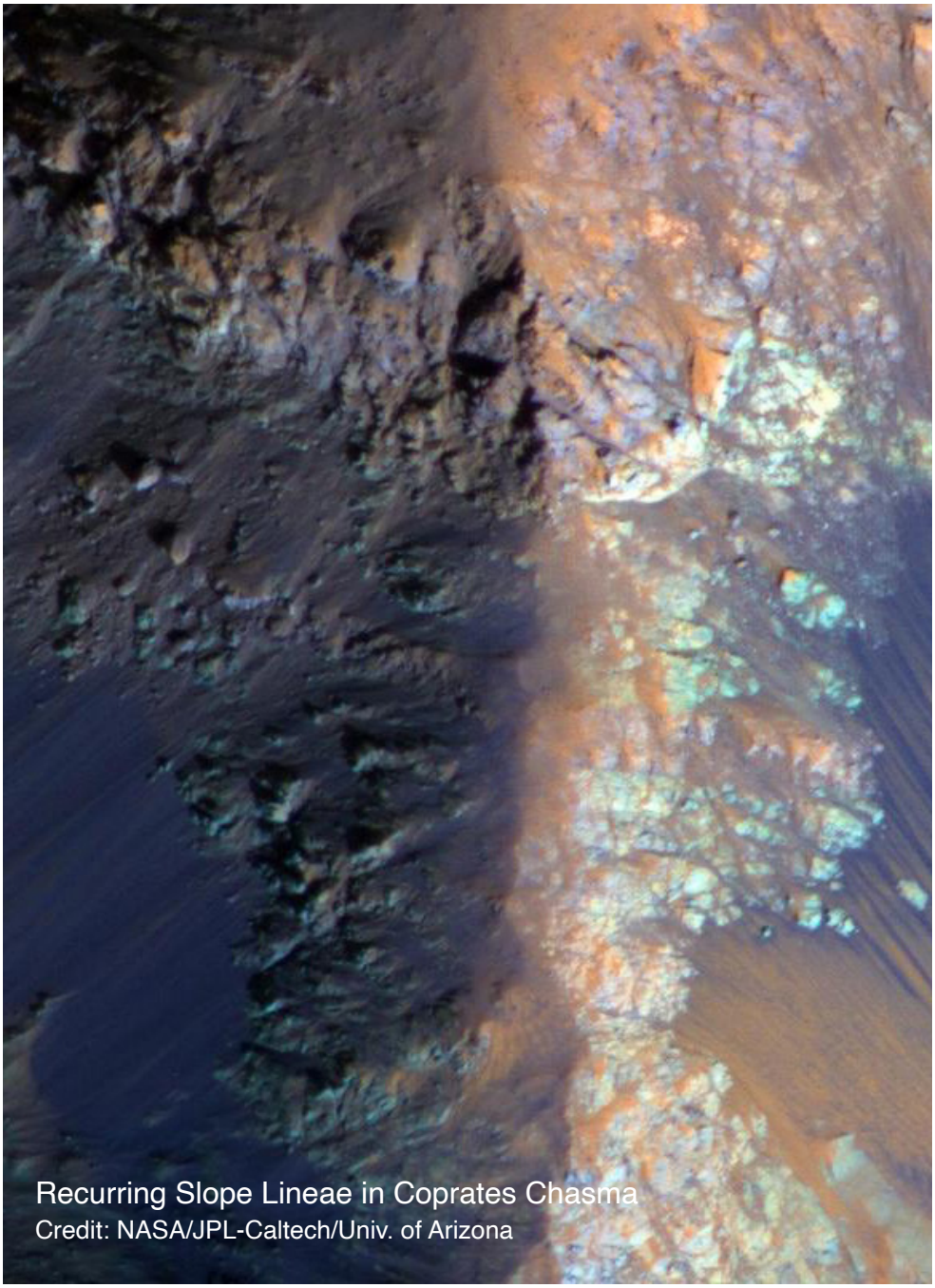
GULLY FLOW: The Mars Reconnaissance Orbiter (MRO) spotted interesting formations on the planet's surface that looked like gullies. On Earth, flowing water creates gullies, but scientists, using spectroscopic measurements from the MRO, have found no conclusive evidence that liquid water is causing these features on the Martian surface. Currently, scientists think evaporating water or carbon dioxide frost could be the cause, but the process remains a mystery.

RECURRING SLOPE LINEAE: Mars experiences seasonal landslides—called Recurring Slope Lineae or RSL for short—that have intrigued scientists for years. A recent study, led by Janice Bishop, suggests that the action of tiny amounts of salty, liquid water beneath the surface over time is the culprit. Although the MRO has captured landslides on Mars with its HiRISE camera, we have no in situ data since no rover has witnessed a landslide. Therefore, Janice and her team used analog environments on Earth and lab experiments to understand how the salty, subsurface permafrost with microscale briny water could play a role in the destabilization of slopes on Mars.

VOLCANISM THROUGH ICE: The Sisyphi Montes area of Mars is home to clusters of flat-topped volcanoes. Using spectroscopic instruments on the MRO, scientists have found evidence that the volcanoes had to punch through a layer of ice in this area of Mars billions of years ago. This activity could have created conditions and habitats ideal for microbial life.

SUBSURFACE LAKES: In 2018, the Mars Express Orbiter found evidence of several subsurface saltwater lakes beneath the planet's south pole. Some scientists are skeptical of the findings, but if there are deposits of liquid water beneath the surface, one possibility is that it originated from polar basal melting, the friction of the ice cap with the rocky basement. It has also been suggested that water could be maintained in the liquid state in this region by active volcanism. More data is needed to verify or falsify those hypotheses.

RELICT GLACIER: In March 2023, scientists revealed the discovery of a relict glacier near Mars' equator. This finding indicates that Mars may have had a more watery recent history than previously believed, potentially influencing our understanding of the red planet's habitability. SETI Institute and Mars Institute Planetary scientist Dr. Pascal Lee explains the significance of this finding: “We’ve known about glacial activity on Mars at many locations, including near the equator in the more distant past. And we’ve known about recent glacial activity on Mars, but so far, only at higher latitudes. A relatively young relict glacier in this location tells us that Mars experienced surface ice in recent times, even near the equator, which is new,” said Lee.



Recurring Slope Lineae in Coprates Chasma
Credit: NASA/JPL-Caltech/Univ. of Arizona

SETI INSTITUTE SCIENTISTS WHO STUDY MARS

NATHALIE CABROL

EXPERTISE: Astrobiology

Nathalie is an astrobiologist and the Director of SETI Institute Carl Sagan Center for Research, where she spearheads a new multidisciplinary roadmap to bridge astrobiology and SETI. Her research focuses on the exploration of habitability and life beyond Earth. She heads projects in planetary science and astrobiology, develops science exploration strategies for Mars, and designs robotic field experiments.

JANICE BISHOP

EXPERTISE: Spectroscopy, Mineralogy, Chemistry, Planetary Sciences, Remote Sensing

Dr. Janice Bishop is a chemist and planetary scientist who explores the planet Mars using spectroscopy. Her investigations of CRISM data of Mars are revealing clays and sulfates in the ancient rocks that provide information about the geochemical environment at the time the minerals formed. She also studies Mars analog rocks and soils at a variety of locations including volcanic islands, cold deserts, hydrothermal regions, acidic aqueous sites, and meteorites, which are the only Martian samples available on Earth to date. Another component of Dr. Bishop's research is collecting spectra under Mars-like conditions, which will aid in the identification of minerals on Mars.

DAVID HINSON

EXPERTISE: Planetary Atmospheres

Dr. David Hinson was a member of the Radio Science Team of Mars Global Surveyor, leading an investigation of the atmosphere through radio occultation sounding. He was involved in all aspects of experiment planning and execution, and he had sole responsibility for retrieving atmospheric profiles from the data. These experiments were conducted from January 1998 through September 2006, yielding 21,243 profiles of the neutral atmosphere and 5,600 profiles of electron density in the ionosphere. He is currently a member of the Radio Science Teams of both Mars Express and New Horizons, and he has experience with radio occultation experiments throughout the Solar System.

VIRGINIA GULICK

EXPERTISE: Geosciences

Dr. Virginia (Ginny) Gulick examines erosional features on Mars, looking for the tell-tale signs of running water. Some of the meandering valley networks that lace the Martian landscape may be proof of a warmer, wetter world, one that existed billions of years ago. But other features, including gullies found around many impact craters and valley walls, may bespeak water that's still erupting and flowing on the Martian surface today. Ginny is part of the HiRISE (High Resolution Imaging Science Experiment) team that directs the high-resolution camera on the Mars Reconnaissance Orbiter, now busy snapping pictures of this alien landscape.

PASCAL LEE

EXPERTISE: Planetary Sciences

Dr. Pascal Lee is a planetary scientist at the SETI Institute. He is also Chairman of the Mars Institute, and Director of the NASA Haughton-Mars Project at NASA Ames Research Center in Mountain View, California. His research focuses on the history of water on Mars and on planning the future human exploration of Mars. Dr. Lee has led over 30 expeditions to the Arctic and Antarctica to study Mars by comparison with the Earth. He also studies asteroids and the two moons of Mars.

JOHN MARSHALL

EXPERTISE: Planetary Geology

Planetary geologist Dr. John Marshall specializes in the study of particulate matter–dust and sand-size materials that comprise nebulae clouds, volcanic eruptions, dust storms, sand dunes, and beach and river sediments. He has overseen operation of the Mars Wind Tunnel at NASA Ames and conducted a number of laboratory simulations of Mars, Venus, Moon, and Titan. John has been involved in developing instruments for three Mars missions, for the Space Shuttle and Space Station, for the Moon, and for asteroid sample return. He has also developed a coffee-can size X-ray analyzer for deployment on the Moon or Mars. John was a co-investigator on the Phoenix mission and helped interpret the first microscopic images of Martian soil to be transmitted back to Earth.

KIM WARREN-RHODES

EXPERTISE: Astrobiology, Ecosystem Science, NanoClimate Modeling

As an ecologist and astrobiologist, Dr. Kim Warren-Rhodes has pioneered the study of some of the harshest and most remote deserts on Earth. Kim has a deep and abiding scientific fascination with the puzzle of life: specifically, how microbial life survives and adapts to the harshest conditions our planet has to offer. She led the first astrobiology surveys of the legendary Taklimakan and high-altitude deserts, and salt lakes of western China and the Qinghai-Tibetan Plateau. Her ground-breaking work established the limit for photosynthetic life on this planet, and she dreams of exploring the deserts of Mars for similar signatures of extant or extinct bacterial life.

ROSALBA BONACCORSI

EXPERTISE: Astrobiology, Environmental Science, Marine Geochemistry, Biosedimentology

Dr. Rosalba Bonaccorsi believes *where* to go on a planet to find evidence of life will determine our chance of finding it. She is currently focusing on the potential habitability aspects of surface/near-surface mineral analog environments. Her broad experience in Environmental Science includes biology and geology, marine mammals, sedimentology, and organic geochemistry.

PABLO SOBRON

EXPERTISE: Planetary Sciences, Astrobiology

Pablo has strong interests in robotic space exploration and comparative analog science—the study of places on Earth that are similar to environments on other planets and moons. To date, he has led or collaborated on 20+ projects focused on the development of instruments and data processing tools for missions to explore the Solar System, including Mars.

LORI FENTON

EXPERTISE: Planetary Sciences

Lori's primary research interests include aeolian geomorphology (how wind shapes a planetary surface) on Venus, Earth, Mars, and Titan; recent and ongoing climate changes; and the mobility of wind-blown sand and dust. Her research makes use of many different types of information, including analog fieldwork on Earth, visible and thermal imagery from spacecraft, wind predictions from atmospheric models, and simulations made in the Mars Wind Tunnel at NASA Ames. Lori's recent publications describe how climate change may have realigned ripples on Mars over the 400ka years, how some windblown features unique to Mars grow and migrate in ways different from those of dunes and ripples on Earth, and a new database of more than 2,000 previously unmapped dune fields on Mars.

PHILIPPE SARRAZIN

EXPERTISE: Instrumentation

Dr. Philippe Sarrazin focuses his research at SETI on the development of analytical X-ray instruments for in-situ planetary exploration. He works in close partnership with scientists in the Exobiology branch of NASA Ames Research Center, where his research lab is located.

Dr. Sarrazin played a key role in the development of CheMin, the only X-ray diffraction instrument deployed in space. Mounted inside the MSL Curiosity rover, CheMin has been roving Mars for over 5 years, and has provided critical science data to the mission.

Perseverance Touching Down on Mars
Credit: NASA/JPL-Caltech

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Mars Express captures Danielson Crater
Credit: ESA/DLR/FU Berlin (G. Neukum), CC BY-SA 3.0 IGO

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