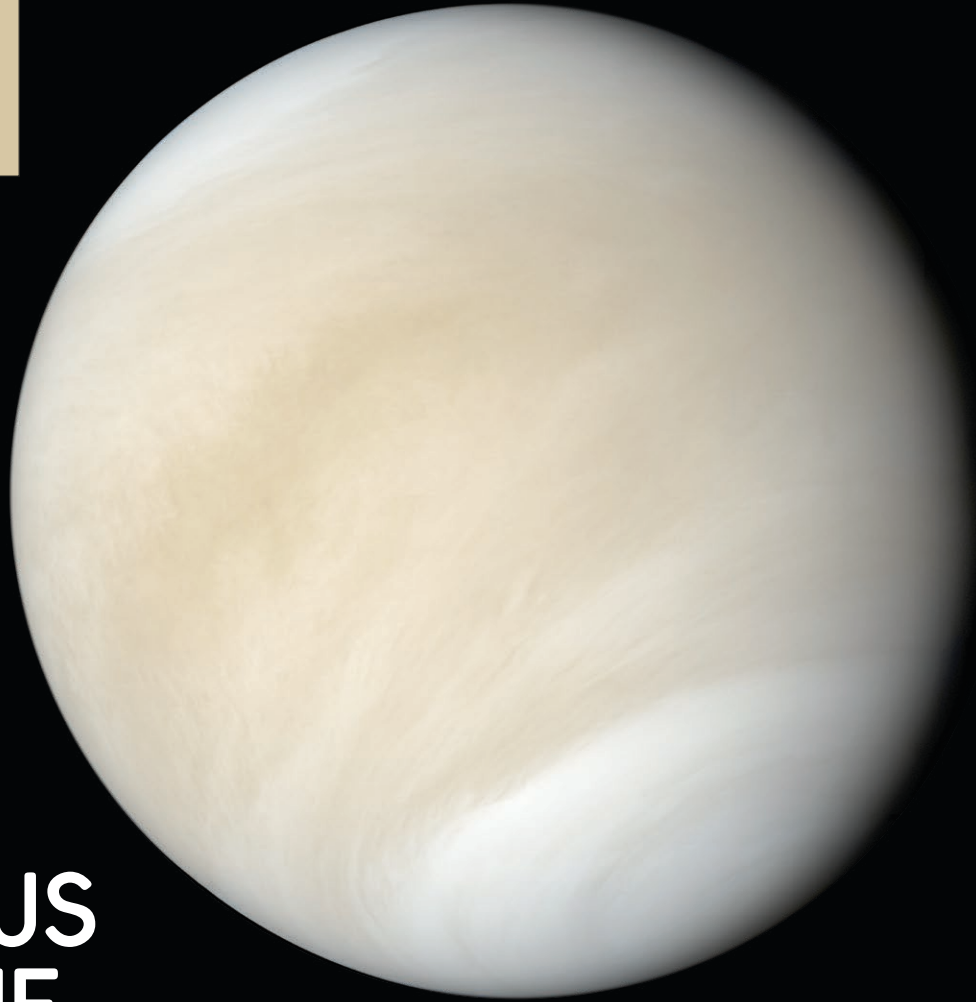


# THE PLANETARY REPORT

MARCH  
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VOLUME 41, NUMBER 1

*planetary.org*



## THE VENUS ISSUE

IS THERE LIFE IN  
THE VENUSIAN CLOUDS?



**BILL NYE** is chief executive officer of The Planetary Society.

# All Eyes on Venus

## Taking a Closer Look at the Mystery-Shrouded Planet Next Door

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**WHEN I WAS** a kid, Venus was imagined to be a tropical world inhabited by microbes, perhaps, but also a great many Venusians—and a few monsters. Since then, our understanding of Venus has changed substantially. Recent research has once again raised the possibility of Venusian life, inspiring us to devote this issue to a deep (and well-protected) dive into this mysterious and surprising world.

In September 2020, a group of researchers announced that they had detected phosphine gas in Venus’ atmosphere, perhaps indicating that some kind of life form(s) might be floating high in the Venusian sky. As I hope you’d expect, other scientists have challenged this claim, suggesting that the readings of phosphine, which is similar to ammonia, are not accurate. Even if this particular gas does exist in the atmosphere of Venus, there’s nothing to prove that life produced it. However this all pans out, one thing is certain: Venus has caught our attention.

We have glimpsed the surface of Venus with both radar measurements and a few images sent back during the Soviet Venera program in the 1970s and ‘80s, which included cameras on the surface for a few minutes (before being cooked to death) and spacecraft hulls sending back a little data about the extreme atmospheric pressure there (before being crushed to death). With so little information, the whole history of

the planet has been up for debate for at least 40 years.

Scientists generally agree that much like Earth, Venus once had liquid water on its surface, perhaps for as long as 2 billion years, but somewhere along the way, Venus went down a very different path. Because of a strong greenhouse effect that ran away billions of years ago, Venus is a hellscape with atmospheric pressure 90 times that of Earth and surface temperatures of more than 400 degrees Celsius (800 degrees Fahrenheit). Above Earth’s surface, we have clouds of water droplets that fall down to the land and sea as rain, sleet, or snow. On Venus, the clouds are sulfuric acid, and the surface is so hot that the resulting acid rain evaporates before it gets to the ground. As our own planet warms by means of our own greenhouse effect, the history of Venus serves as a cautionary tale of just how much a planet can change.

Phosphine or not, this fascinating world may hold answers to the most important questions of all: how does or did life begin? Are Earthlings the lone living things in the solar system? As we invest in the exploration of Venus, we’ll learn more about our own world and ultimately our place in the cosmos—our place in space. Onward! 🚀

**EDITOR’S NOTE:** A caption beneath the grid of asteroid images on page 6 of the December Solstice 2020 issue of The Planetary Report incorrectly identified the asteroid as Apophis. The asteroid is actually 2007 PA8. We apologize for the error.

**ON THE COVER:** This view of Venus was created using 78 frames captured by NASA’s Mariner 10 spacecraft in 1974 through orange and ultraviolet filters. It approximates Venus’ natural color, though ultraviolet filters make the cloud patterns more visible than they would be to the human eye. Credit: NASA/JPL/Mattias Malmer \* The Planetary Report (ISSN 0736-3680) is published quarterly at the editorial offices of The Planetary Society, 60 South Los Robles Avenue, Pasadena, CA 91101-2016, 626-793-5100. It is available to members of The Planetary Society. Annual dues are \$50 (U.S. dollars) for members in the United States as well as in Canada and other countries. Printed in USA. Third-class postage at Pasadena, California and at an additional mailing office. Canada Post Agreement Number 87424. \* Viewpoints expressed in articles and editorials are those of the authors and do not necessarily represent positions of The Planetary Society, its officers, or its advisers. ©2021 by The Planetary Society. All Rights Reserved. The Planetary Society and The Planetary Report: Registered Trademarks ® The Planetary Society. Planetfest® The Planetary Society.

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We asked members to share their **thoughts and feelings about Venus**. What fuels your curiosity about this world? Here are some of the responses you shared with us.

I grew up reading Robert Heinlein's science fiction and so imagined Venus as a warm, swampy place with interesting natives harboring strange taboos. The sequence of Soviet and American probes revealed a far less friendly place but equally intriguing. I hope to learn more of what sent it on its remarkable path and what this may tell us about possible exoplanets.

**THOMAS WM. HAMILTON, UNITED STATES**

Venus, named after the goddess of love, is a lot like love itself: at once beautiful and terrifying. I also appreciate that Venus is not a world that we hope to live on permanently, but one that reminds us to care for our own home planet so that it can continue to care for us.

**LUCY REID, CANADA**

For years I didn't care about Venus much, but when I heard about the new discovery of phosphine in the atmosphere, my whole body got the chills. Venus definitely deserves a NASA mission; they need to send a ship to get into Venus' atmosphere. If they discover life—even if it is bacteria—I will be the happiest man in the world. Ever since Carl Sagan injected me with the passion of science and the possibility of life elsewhere, I've been waiting all my life for the big news. It just would be nice to hear the news in my lifetime, hopefully before I leave this beautiful planet.

**HUGO E. RODRIGUEZ, UNITED STATES**

How Venus has changed since I read about Dan Dare's adventures there when I was a boy. It was so exciting, with the warlike Treens in the North and the friendly Therons in the South, separated by a flame belt around the equator. Now, however, it's far more exciting with its dense, acidic atmosphere and perpetual cloud cover. No wonder all the vegetation has vanished in the last 70 years or so! Will I actually live long enough (I'm 82 years old) to hear of the wonderful discoveries yet to be made? I do hope so, for some of them anyway.

**ALAN TURK, UNITED KINGDOM**

I always think of Venus as somehow more elegant than the other planets. Maybe it's because it's named after the Roman goddess of love and beauty, maybe because old science fiction so often depicted Venusians as more otherworldly, maybe because the planet's surface was a mystery for so long that it was harder to imagine being there. Venus is Earth's long-lost twin but so much more alien and inhospitable than the Moon or Mars. And we humans love a challenge. 🪐

**C.A. CRAVEN, UNITED STATES**

## 12 Every Picture From Venus' Surface, Ever

See all 6 panoramas from the 4 spacecraft that successfully imaged the surface.

## 14 A Quick Guide to Venus

An infographic full of facts worth sharing about Earth's cloudy twin.



## 16 The Quest for Life on Venus

How one researcher's startling discovery changed the way we think about Venus.

### DEPARTMENTS

## 2 Your Place in Space

CEO Bill Nye explains why Venus has our attention.

## 3 Members on Deck

Our members describe what fuels their curiosity about Venus.

## 4 In Context

Looking back at an early NASA Venus mission and looking ahead to possible human missions.

## 6 Your Impact

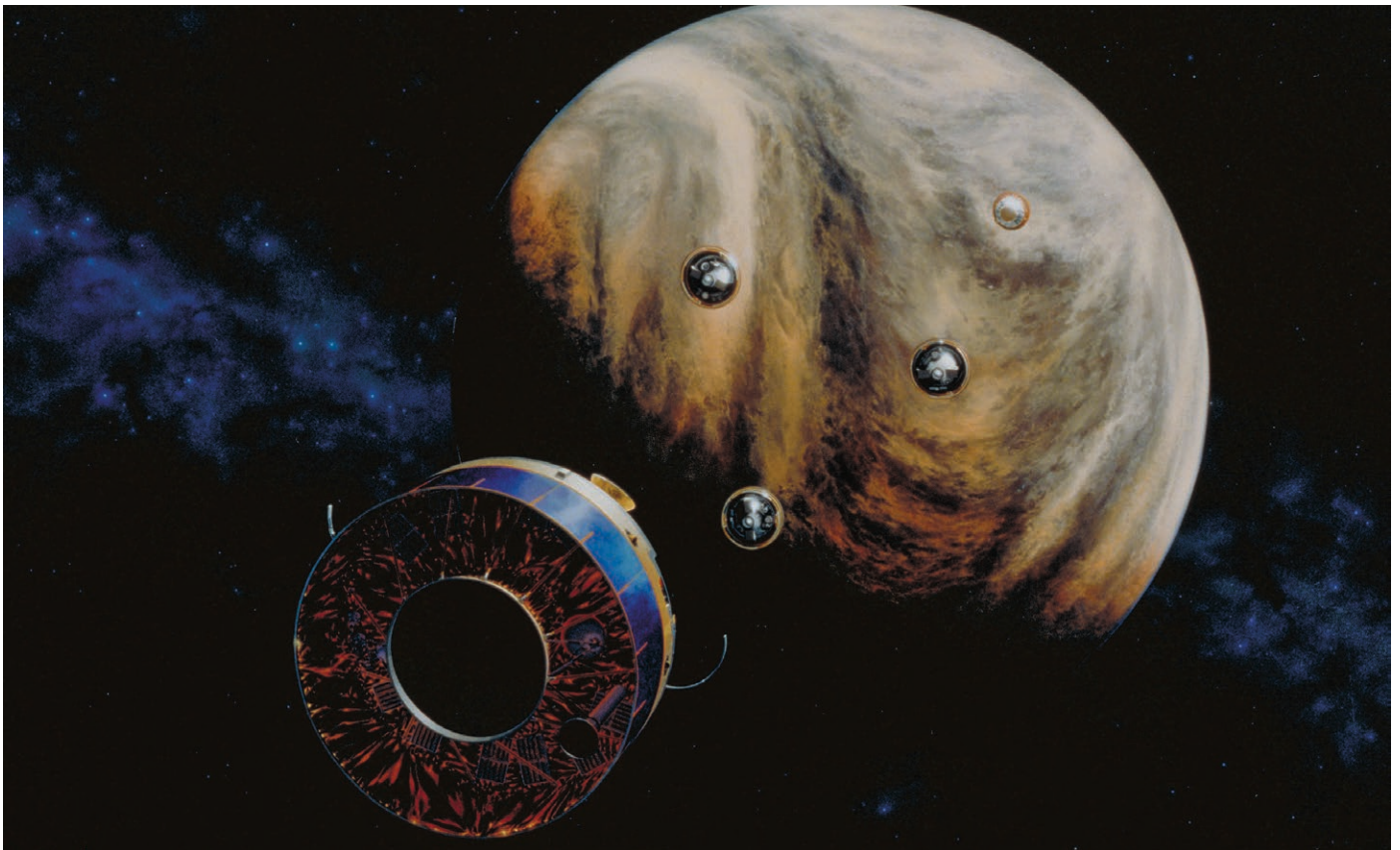
The results are in: here are your favorite space moments and images of 2020.

## 10 Get Involved

Planetfest and our annual Day of Action highlight a busy start to the year.

## 14 What's Up?

Looking ahead to upcoming lunar and solar eclipses.



NASA/PAUL HUDSON

**THE FORMER** Soviet Union is the undisputed leader of Venus surface missions, having received data from roughly a dozen landers between 1970 and 1985. Four of the country's Venera spacecraft captured pictures that you'll see later in this issue.

NASA is the only other entity to successfully transmit data from Venus' surface. In 1978, the space agency launched 2 missions as part of its Pioneer Venus program. The first was an orbiter that studied the planet for 14 years. The second, known as the Pioneer Venus Multiprobe, took a much closer look.

As it approached Venus, Pioneer Venus Multiprobe split into 5 separate spacecraft. The spacecraft bus, depicted in the above picture at lower left, made measurements before burning up in the upper atmosphere.

## Looking Back...

A large single probe, seen leading the pack in the upper right, used a parachute to float all the way to the surface. As expected, it stopped transmitting upon impact. The 3 identical silver probes in the middle had no parachutes and smacked into the surface at high speed. Incredibly, 2 survived, and 1 functioned for more than an hour.

Data from the multiprobe mission showed that the planet's atmosphere is relatively haze-free beneath 30 kilometers (19 miles) and that there is little variance in temperature around the planet below 50 kilometers (31 miles). Later in this issue, you'll learn how archival data from Pioneer Venus Multiprobe are being reexamined for indications of phosphine, a chemical associated with life. 🌫️



THE  
VENUS  
ISSUE





NASA LANGLEY RESEARCH CENTER

## ...Looking Ahead

**FOR MOST SPACE** enthusiasts, Venus doesn't jump to the top of the list when it comes to potential vacation spots. While that's certainly true for the planet's hellish surface, some areas in the upper atmosphere are surprisingly Earthlike. In 1985, the Soviet Union's Vega 1 and 2 probes used balloons to float through Venus' clouds, collecting data. Scientists, engineers, and science-fiction writers have envisioned that giant balloons or airships could one day ferry human explorers around the planet.

NASA's Langley Research Center recently studied the feasibility of Venus airships with HAVOC, the High Altitude Venus Operational

Concept. Though HAVOC sparks the imagination, it isn't likely to happen anytime soon. Among the challenges are delivering the airships to the right place and then inflating them, protecting them from the atmosphere's persistent sulfuric acid, and perfecting a reliable way to get humans back to Earth. One possibility is the rocket you can see hanging underneath the left airship.

Despite the challenges, a mission like HAVOC is not impossible. NASA's study concludes that "with advances in technology and further refinement of the concept, missions to the Venusian atmosphere can expand humanity's future in space." 🌱



## YOUR IMPACT

In November, members celebrated the end of 2020 by voting for their favorite space moments in our **Best of 2020 Awards**. These are our community's picks:

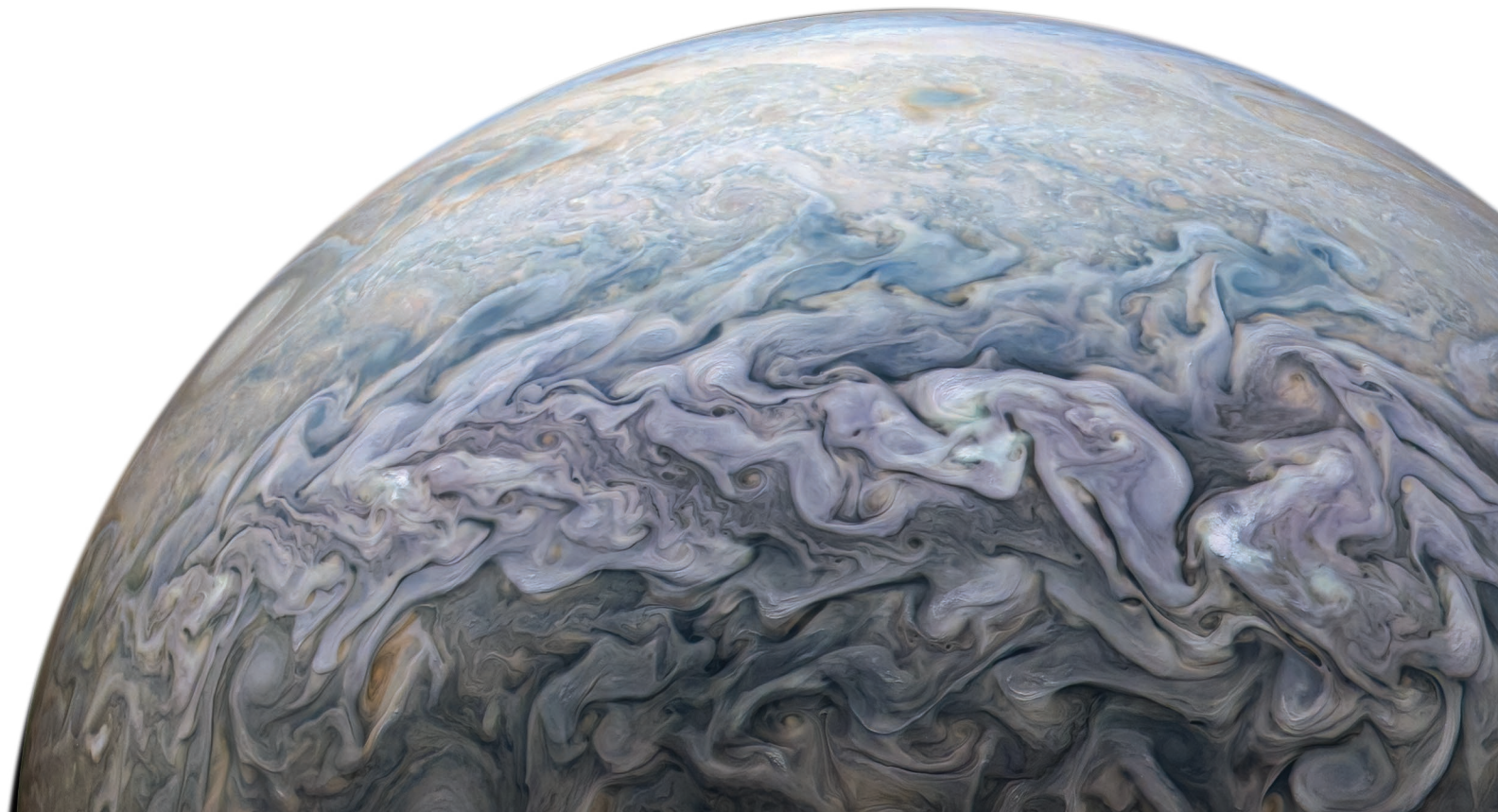


**BEST COMET  
NEOWISE IMAGE  
COMET NEOWISE  
ALIGNED TO THE STARS**  
This image of comet NEOWISE was taken with a 15-minute exposure and aligned to the background stars.

SimgDe

**BEST SOLAR  
SYSTEM IMAGE  
JUNO VIEW OF JUPITER,  
SEPTEMBER 2020**  
NASA's Juno spacecraft captured this view of Jupiter's swirling clouds during its 29th close pass over the giant planet.

NASA/JPL-CALTECH/SWRI/MSSS/KEVIN M. GILL







**BEST LIGHTSAIL 2  
PHOTO OF EARTH  
LIGHTSAIL 2 IMAGE OF  
SOUTHEAST AFRICA**

This image taken by The Planetary Society's LightSail 2 spacecraft on 7 September 2020 shows Zimbabwe, Mozambique, Malawi, and the southern portion of Madagascar across the Mozambique channel. At the lower right, you can see a piece of material similar to fishing line, called Spectraline, that held the spacecraft's solar panels closed prior to sail deployment.

THE PLANETARY SOCIETY



**BEST HUMAN  
SPACEFLIGHT IMAGE  
SPACEX CREW-1  
CREW MEMBERS**

The second crew to fly aboard SpaceX's Crew Dragon vehicle poses prior to its scheduled October 2020 mission to the International Space Station. From left to right: mission specialist Shannon Walker, pilot Victor Glover, Crew Dragon commander Mike Hopkins, and mission specialist Soichi Noguchi.

SpaceX

**MOST EXCITING MOMENT IN PLANETARY SCIENCE  
OSIRIS-REx COLLECTING A SAMPLE FROM ASTEROID BENNU**

In October, NASA's OSIRIS-REx spacecraft successfully collected and stowed a sample from asteroid Bennu. The probe is scheduled to depart Bennu this year and return the sample to Earth in September 2023. Researchers will study the sample to learn about the conditions of the early solar system.

**BEST  
ACCOMPLISHMENT  
BY PLANETARY  
SOCIETY MEMBERS**

LightSail 2 completing its primary mission to demonstrate controlled solar sailing for cubesats

**FAVORITE  
PLANETARY  
SCIENCE MISSION**

NASA's OSIRIS-REx asteroid sample return spacecraft

**MOST EXCITING  
UPCOMING MISSION**

NASA's James Webb Space Telescope



## Planetfest '21

As this issue of *The Planetary Report* goes to press, we are just wrapping up Planetfest '21, a festival celebrating the arrivals of 3 spacecraft to the planet Mars: Hope, Tianwen-1, and Perseverance. People from around the world joined the festivities, participating in an array of educational and celebratory activities. We were joined by JPL chief engineer Rob Manning, author Andy Weir, astronaut Jessica Watkins, *Star Trek* actor Kate Mulgrew, and many others. We also hosted a live broadcast of the Perseverance rover's landing with live captioning in English, Spanish, Mandarin, Hindi, and Arabic. We're grateful to all who participated, and if you missed it, we invite you to check out [planetary.org/planetfest](https://planetary.org/planetfest) for recordings of the events.

## Beyond the Horizon

During Planetfest '21, members joined CEO Bill Nye for our first-ever virtual fundraising gala. In addition to being a memorable evening of storytelling about the Society's work, members raised a remarkable \$27,700 in less than an hour. Finally, we announced a new comprehensive campaign, *Beyond the Horizon: Creating Space for Everyone*, that will provide \$40 million to fuel our efforts. With \$16 million committed to-date thanks to our members and lead donor Taner Halicioglu's \$9 million gift, we are in a great position to meet or exceed our goal by the close of our campaign in December 2024.



## Advocating for Space in Washington, D.C.

As a nonpartisan, nonprofit organization, The Planetary Society is committed to working with every U.S. presidential administration to advance our core enterprises: planetary exploration, the search for life, and planetary defense. As President Biden's administration gets to work, we're making sure that they know what needs to be done to advance these important endeavors. In February, we shared a video of Bill Nye delivering an open letter to President Biden stating the position of The Planetary Society and the 50,000 members we represent, urging Biden to invest in space science and exploration. We're looking forward to working together with Biden and his team to make the next 4 years as productive as possible toward the goal of knowing the cosmos and our place within it.

## A Big STEP Forward

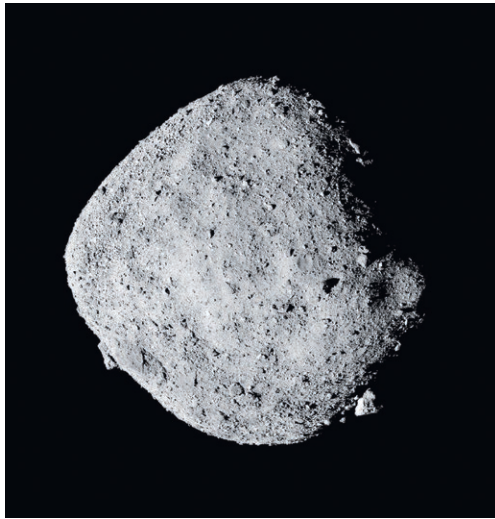
In February, we announced an exciting new chapter of our science and technology program: **The Planetary Society's Science and Technology Empowered by the Public (STEP) grants**. Building on the success of our crowdfunded LightSail mission, the STEP grant program will invest in innovative projects selected internationally through an open, competitive proposal process occurring every 2 years. We're calling on the brightest minds from around the world to find the next exciting developments in space science and technology, which we'll support with the help of members like you. Go to [planetary.org/stepgrants](https://planetary.org/stepgrants) to learn more.

Planetary Society members like you make this work possible. *Thank you!*



THE  
VENUS  
ISSUE





## Bringing Benu Home

By the time this magazine hits your doorstep, NASA's OSIRIS-REx spacecraft may already be on its way back to Earth from the asteroid Benu, bringing a sample back to Earth. This little piece of asteroid will yield decades of research, providing new insights about the early solar system. This mission means a lot to The Planetary Society and its members. Many of your names are aboard the spacecraft thanks to a campaign we ran in October 2014 to send a total of 442,803 names aboard the spacecraft on a microchip. The Planetary Society also held a contest to choose a name for the asteroid, which had been called 1999 RQ36. In 2013, along with the University of Arizona and MIT, we engaged more than 8,000 students from dozens of countries around the world and ultimately selected the name "Benu" at the suggestion of 9-year-old Mike Puzio of North Carolina, USA.

## Outstanding Support

Our year-end fundraising campaign was a huge success thanks to support from our members. We raised over \$325,000 to facilitate our work throughout 2021 and beyond. We're very grateful for the outstanding support that members like you provided. Thank you!

## FROM THE ARCHIVES: POSTCARDS FROM VENUS

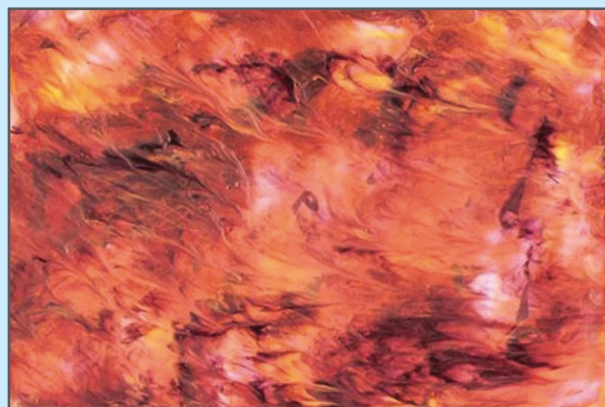
Because we're celebrating Venus in this issue, we took a look back at a very special project from The Planetary Society's history that invited people from around the world to turn their imagination toward our neighboring planet. In 2005 and 2006 during the lead-up to the European Space Agency (ESA) Venus Express mission's arrival at Venus, we teamed up with ESA to invite youths and adults worldwide to creatively depict the surface of Venus from an above-ground perspective, giving their artistic take on the mysterious world. We received hundreds of entries from more than 40 nations around the world and selected one youth winner, one adult winner, and one grand-prize winner. We thought you would enjoy looking back at the winning artwork, which still captures the mystery and allure of Venus.



Grand-prize winner: *Ominous Beauty* by Tatianna Cwick, age 17, from Cape Girardeau, Missouri, USA. "The title of my artwork is *Ominous Beauty*," said Cwick. "I think this captures the essence of the planet Venus, with its threatening volcanic environment and unique splendor." Cwick won a trip to witness the spacecraft's arrival at Venus from mission control in Darmstadt, Germany.



First-place winner (youth): *Hello Venus! Hello Alien!* by Yoo-Hong Sun, age 9, of South Korea.



First-place winner (adult): *Venus Burning* by Alejandra Gonzalez Quintana of Spain.

## GET INVOLVED

### The 2021 Day of Action

On 31 March 2021, The Planetary Society will hold our Day of Action, an annual event that brings together Planetary Society members to meet with their representatives in Congress and advocate for support of space science and exploration. Due to the coronavirus pandemic, this will be a virtual event. Registration is now closed for meetings, but you can still support the Day of Action by calling your representatives in government, sharing key talking points with your communities, and brushing up on your knowledge of space policy. Go to [planetary.org/dayofaction](http://planetary.org/dayofaction) to learn more.

**BELOW** *The Planetary Society's 2020 Day of Action in Washington, D.C.*

ANTONIO PERONACE  
FOR THE PLANETARY SOCIETY



What are the most influential ways to **advocate for issues** like space exploration?

MOST EFFECTIVE METHOD:

### PERSONAL VISITS

#1



#2



INDIVIDUAL LETTER

#3



INDIVIDUAL EMAIL

#4



PHONE CALL



VISIT FROM A LOBBYIST



SOCIAL MEDIA COMMENTS

### Keep Advancing Our Advocacy Work

Right now, we're fundraising to support our space policy and advocacy program, helping to advance activities like the Day of Action. If our work advocating for space science and exploration funding is important to you, we urge you to go to [planetary.org/takeaction](http://planetary.org/takeaction) to make a gift toward this program today. Your support will allow us to have a presence in Washington, D.C., making sure that space is always a priority for our members' representatives in government.

**LEFT TO RIGHT**  
*Perseverance, Tianwen-1, and Hope all arrived at the Red Planet this year.*

THE PLANETARY SOCIETY,  
ESA/MBRSC/CNSA/  
WEIBO/NASA



### Don't Miss a Mars Moment

Three new missions have arrived at Mars, and like parents of a new baby, we're excited for every first: the first images sent from the planet's surface, the first discoveries made, and the very exciting first flight of the Mars helicopter Ingenuity. To make sure that you're tuned in to every mission milestone, keep an eye on our Mars page at [planetary.org/mars](http://planetary.org/mars) and make sure you're subscribed to our weekly email newsletter, *The Downlink*, at [planetary.org/connect](http://planetary.org/connect). Together, we won't miss a single moment of the excitement.



## Celebrate Space on Yuri's Night



Every year on 12 April, the whole world celebrates an epic accomplishment: the first human to fly in space. This year is a very special anniversary. Yuri Gagarin, a Soviet cosmonaut, took this monumental flight 60 years ago on 12 April 1961. Go to [yurisnight.net](http://yurisnight.net) to find great online and at-home activities and invite your loved ones to join the celebration of 60 years in space.

## Space at Home: Organize a Launch Party!

**Watch parties** are a fun and informal way to bring together your family or other loved ones to experience the excitement of space exploration. Enjoying a milestone moment in spaceflight can be entertaining and educational and creates a great opportunity to share The Planetary Society's mission with more people.

Whether you're watching with the people in your household, gathering virtually, or planning something for after the pandemic, here are some tips for organizing events to celebrate space exploration milestones.

- > Find out what's launching. Stay up to speed with planetary science and exploration mission milestones by subscribing to our weekly email newsletter *The Downlink* at [planetary.org/connect](http://planetary.org/connect). If you're interested in seeing more than planetary missions, there are always lots of satellite launches taking place. You can find more by searching the web.
- > Find a stream. The Planetary Society live streams launches of missions that relate to our core enterprises at [planetary.org/live](http://planetary.org/live) and announces these streams in *The Downlink*. You'll also usually find a link to a stream on the launching space agency or company's website, press room, or YouTube channel. The website or press room will usually tell you in advance where the stream link will be found.
- > Plan a "run of show." Write down a schedule for the event and what you plan to do to fill the time before and after. Remember that launches are often delayed. Be prepared with a backup activity, like a discussion topic, a game, or something else space-related to watch.
- > Have fun! Turn up the volume so you can hear the roar of the rocket engines, cheers (perhaps virtually) with your friends when the launch is deemed nominal, and talk with one another about the excitement of space exploration! If you really love watching a launch from home, start thinking about planning a trip to go see one in person someday. Trust us, it's addictive!

## It's Time for Adventure!



We invite you to travel with The Planetary Society to see wonderful eclipses or the aurora borealis in 2021!

*As we go to press, travel restrictions during the COVID-19 pandemic are evolving, and countries are starting to open. For updated information, contact Betchart Expeditions Inc. at 800-252-4910 or go to [betchartexpeditions.com](http://betchartexpeditions.com).*

### ARIZONA SKIES & NEW DISCOVERIES 18-25 APRIL 2021

Explore the natural and astronomical wonders of a desert paradise.

### GRAND CANYON EXPEDITION, INCLUDING ZION & BRYCE CANYON 28 MAY - 5 JUNE 2021

Come explore and see the magnificent dark skies at night!

### DISCOVER THE GEOMAGNETIC NORTH POLE & WEST GREENLAND ANNULAR ECLIPSE 3-13 JUNE 2021

See extraordinary landscapes, sled dogs, glaciers, and the annular eclipse in this land of the midnight sun!

### BAFFIN ISLAND, CANADA ANNULAR ECLIPSE 6-11 JUNE 2021

Discover the "ring of fire" in the remote Canadian High Arctic!

### ANTARCTICA TOTAL SOLAR ECLIPSE 23 NOVEMBER - 15 DECEMBER 2021

See the total eclipse in one of the most remote places on Earth, plus South Georgia and the Falkland Islands.

# EVERY PICTURE FROM

Only 4 spacecraft have ever returned images from Venus' surface. The world next door doesn't make it easy, with searing heat and crushing pressure that quickly destroy any lander.

In 1975 and 1982, 4 of the Soviet Union's Venera probes captured our only images of Venus' surface. The Veneras, which mean "Venus" in Russian, scanned the surface back and forth to create panoramic images of their surroundings. They revealed yellow skies and cracked, desolate landscapes that were both alien and familiar—views of a world that may have once been like Earth before experiencing catastrophic climate change.

Ted Stryk, a philosophy professor at Roane State Community College in Oak Ridge, Tennessee, specializes in reconstructing images from early space missions. Using data from the Russian Academy of Sciences, he has over time reconstructed the best-possible versions of the original Venera panoramas.



THE  
VENUS  
ISSUE



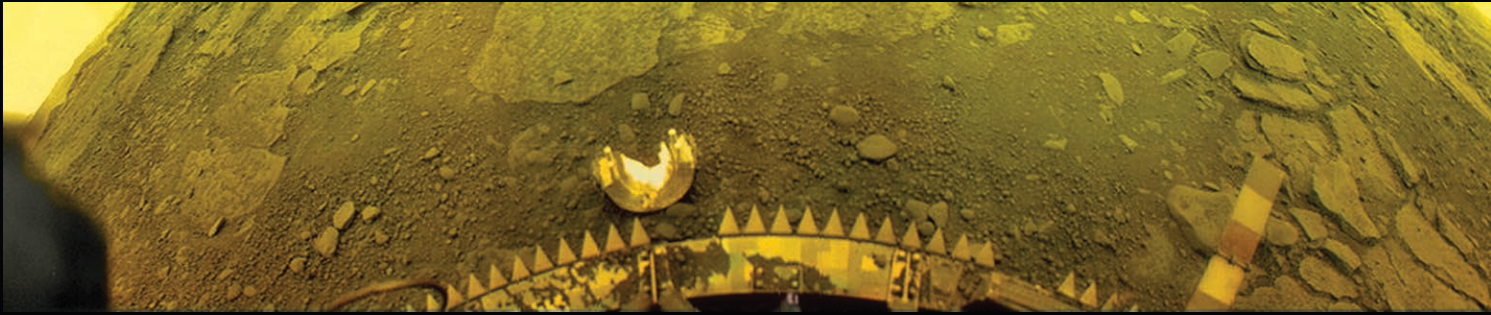
Venera 9, 1975



Venera 10, 1975



# VENUS' SURFACE, EVER



Venera 13, 1982 (front camera)



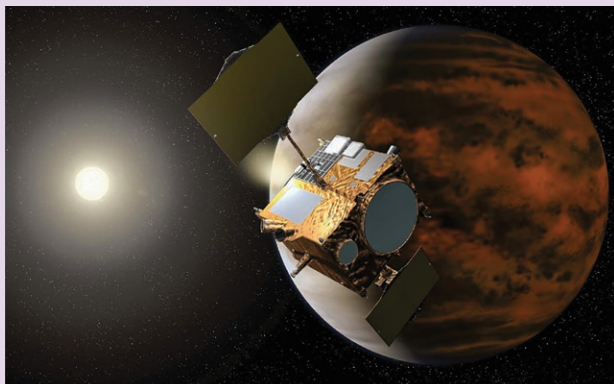
Venera 13, 1982 (rear camera)



Venera 14, 1982 (front camera)



Venera 14, 1982 (rear camera)



LEFT JAXA artist's impression of Akatsuki at Venus. Note the planar circular high-gain antenna and the relatively small solar arrays. The rocket nozzle is just visible at upper right.

JAPAN AEROSPACE EXPLORATION AGENCY (JAXA)



THE VENUS ISSUE

## IN THE SKY

Mars is in the evening west looking like a bright reddish star. Very bright Jupiter and yellowish Saturn are in the predawn east. Mercury is very low in the west in May. A total lunar eclipse on 26 May 2021 will be visible from eastern Asia, Australia, the Pacific, and the Americas. On 10 June 2021, an annular solar eclipse will be visible from limited portions of Canada, Greenland, and Russia with a partial solar eclipse visible from the northeastern U.S. and Canada, Europe, and Russia.

## RANDOM SPACE FACT

A solar day on Venus is about 117 Earth days long. That is how long it takes Venus to rotate so the Sun is at the same place in the sky. A solar day is what we commonly call a day: 24 hours on Earth. A sidereal day on Venus is 243 Earth days. That is the time for a single rotation relative to the distant stars, which is 23 hours and 56 minutes for Earth.

## TRIVIA CONTEST

Our September equinox contest winner is Kathleen MacDougall of San Francisco, California, USA. Congratulations! The question was: **In 2020, about how much farther away is the Moon from Earth (average distance) than it was when *The Planetary Society* was founded in 1980?** The answer: **About 1.5 meters.**

Try to win a copy of *Space Exploration for Kids* by Bruce Betts and a *Planetary Radio* T-shirt by answering this question:

***For more than 5 years, the Japanese Akatsuki spacecraft has been orbiting and studying Venus. What does "Akatsuki" mean in English?***

Email your answer to [planetaryreport@planetary.org](mailto:planetaryreport@planetary.org) or mail your answer to *The Planetary Report*, 60 S. Los Robles Ave., Pasadena, CA 91101. Make sure you include the answer and your name, mailing address, and email address (if you have one). By entering this contest, you are authorizing *The Planetary Report* to publish your name and hometown. Submissions must be received by 1 June 2021. The winner will be chosen in a random drawing from among all the correct entries received.

For a weekly dose of "What's Up?" complete with humor, a weekly trivia contest, and a range of significant space and science-fiction quests, listen to *Planetary Radio* at [planetary.org/radio](http://planetary.org/radio).

## FACTS WORTH SHARING

- Venus, the second planet from our Sun, may have had oceans and may have been habitable to life before being transformed into an inhospitable wasteland.
- Of all the solar system's planets, Venus is the most Earthlike. The two bodies are almost the same size, and Venus' composition is very similar to Earth's. Both have thick atmospheres with clouds, though the composition of each atmosphere is different.
- By studying Venus, scientists learn how Earthlike planets change over time and what conditions might be like on Earth-sized planets orbiting other stars.
- Scientists have predicted that life could currently exist in Venus' upper atmosphere, where some regions have Earthlike temperatures and pressures.
- The air pressure on the surface of Venus is almost 90 times higher than the pressure at sea level on Earth.
- Winds can sweep through Venus' atmosphere at up to 725 kilometers per hour (450 mph).
- If viewed from above, Venus rotates on its axis in a direction that's the opposite of most planets'. That means on Venus, the sun would appear to rise in the west and set in the east. Weird!



# A QUICK GUIDE TO VENUS

**VOLUME**  
86% of Earth

**AVERAGE DISTANCE FROM THE SUN**  
0.72 AU (Earth is 1 AU)



**LEFT** The VERITAS Venus orbiter mission, seen here in a proposed mockup, is one of the 4 finalists for the latest round of the Discovery program, NASA's fleet of low-cost planetary science missions.

NASA/JPL-CALTECH

**DIAMETER**  
**12,104 km**



**DIAMETER**  
**12,742 km**

**AVERAGE SURFACE TEMPERATURE**  
**460°C/860°F**



**AVERAGE SURFACE TEMPERATURE**  
**14°C/57°F**

**AVERAGE DISTANCE FROM SUN**  
**108 M km/67 M mi**



**AVERAGE DISTANCE FROM SUN**  
**150 M km/93 M mi**

**ORBIT DURATION**  
**224.7 days**



**ORBIT DURATION**  
**365.2 days**

**MOONS**  
**0**



**MOONS**  
**1**

**DAY**  
**117 Earth days**



**DAY**  
**1**

Venus is the second-brightest natural object in the night sky after the Moon.

Venus is named after the Roman goddess of love and beauty.

Venus was the first planet to be visited by a spacecraft; Mariner 2 flew by on 14 December 1962.

Venus has more volcanoes than any planet in the solar system.

## NOTABLE MISSIONS



### Mariner 2 (1962)

NASA's Mariner 2 was a flight spare for Mariner 1, which failed on the way to Venus. The spacecraft performed the first planetary flyby, detecting hot temperatures and high pressures, a carbon dioxide atmosphere, and no magnetic field.



### Venera 7 (1970)

The Soviet Union's Venera 7 returned the first data from Venus' surface. It survived for 23 minutes, recording temperatures of 475 degrees Celsius (887 degrees Fahrenheit). Other measurements revealed light winds and pressures 92 times that of Earth.



### Magellan (1989-1994)

NASA's Magellan used radar to pierce Venus' clouds and make the best global surface map to date. The spacecraft captured the planet's features and topography in resolutions of roughly 100 meters per pixel.



### Venus Express (2005-2015)

The European Space Agency's Venus Express found granitelike rocks that form in liquid water on Earth. The mission also found Venus sheds hydrogen and oxygen, which could be remnants of long-gone oceans.



# The Quest for Life on Venus

## Is something alive on the planet next door?

by Nancy Atkinson



**ONE NIGHT IN 2017**, the James Clerk Maxwell Telescope in Hawai'i turned its 15-meter dish toward the bright-yellow dot of Venus. The telescope's instruments dutifully recorded the light coming from the planet for Jane Greaves, an astronomer and astrobiologist at Cardiff University in Wales. Greaves and her team were looking for a little-known chemical called phosphine. On Earth, you can find phosphine in swamps, where bacteria produce it

as a waste product. It's also manufactured as an industrial fumigant to rid houses of moths, beetles, and fruit flies.

For decades, some scientists have theorized that Venus could harbor life in its upper atmosphere, where temperatures and pressures are benign despite the hellscape beneath. Nothing we know of on Venus could produce more than just a trace of phosphine—unless there is something living in the planet's pale clouds.



THE  
VENUS  
ISSUE



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A year later, as Greaves sat alone in her office, she saw what she was looking for in her Venus data: indications of phosphine. It wasn't a strong signal, but it definitely seemed to be there. "I spent ages thinking there was nothing there, but one evening, I was pushing the data around, and suddenly, I realized it all came together," Greaves told The Planetary Society. "That just blew me away. There really was phosphine."

Venus, once hoped to harbor paradise, was written off as the most inhospitable place in the solar system. But Greaves' finding has renewed interest in a planet some scientists say has been neglected for far too long. Did life ever flourish on Venus, and is there something still alive in its clouds, or will these latest findings only add to a long list of false hopes?



**BEFORE THE SPACE AGE**, scientists considered Venus as Earth's sister planet, perhaps even habitable like our own. The two rocky worlds share nearly the same size and density,

and because a thick veil of clouds shrouds Venus' surface, some hoped that the world next door was a tropical paradise with oceans and abundant vegetation.

NASA's Mariner 2 spacecraft, the very first successful planetary mission, dashed this idyllic view in December 1962. The probe flew past Venus, recording temperatures of at least 150 to 200 degrees Celsius (300 to 400 degrees Fahrenheit) and a punishing atmospheric pressure 20 times that of Earth's.

"Venus Says No," lamented a headline in the *New York Times*, opining that Mariner 2's "message from Venus may mark the beginning of the end of mankind's grand romantic dreams."

Some scientists remained hopeful. In 1963, a young Harvard assistant professor named Carl Sagan—still years away from becoming a well-known science communicator—conjectured in the NASA film *The Clouds of Venus* that the planet's harsh conditions might only exist in the atmosphere. "It is just possible that the surface temperature could then be almost Earthlike and life as we know it could exist there," he said. "However, it is more likely that if there is life on Venus, it is probably of a type that we could not now imagine."

**OPPOSITE PAGE** *Jane Greaves, an astronomer and astrobiologist at Cardiff University in Wales, led the team that announced they had detected phosphine in Venus' atmosphere.*

GORDON AULD

**BELOW LEFT** *This image from the 1963 NASA film The Clouds of Venus shows a 29-year-old Carl Sagan discussing the prospect of life on Venus.*

NASA



**OPPOSITE PAGE** *Sapas Mons is displayed in the center of this 3D view of Venus' surface created from U.S. Geological Survey maps with color recorded by the Soviet Union's Venera 13 and 14 probes. The viewer is more than 500 kilometers (300 miles) away from the mountain, and the vertical scale has been exaggerated 10 times. Lava flows extend for hundreds of kilometers across the fractured plains in the foreground.*

NASA/JPL

Subsequent Soviet, U.S., and European missions in the 1960s and '70s only made the prospect of life worse, confirming it was the surface, not the atmosphere, that was oppressive. Revised average surface temperatures shot up to a scorching 470 degrees Celsius (880 degrees Fahrenheit)—hot enough to melt lead.

Additionally, space missions found that unlike Earth's puffy water-vapor clouds, Venus' clouds contained mostly carbon dioxide with droplets of skin-searing sulfuric acid. The clouds and carbon dioxide lock in the Sun's warmth, creating a runaway greenhouse effect that bakes the planet.

"Our original vision of Venus was rudely destroyed," said David Grinspoon, a senior scientist at the Planetary Science Institute and a long-time proponent of Venus exploration. "Venus has never fully recovered from dashing our dreams. And while it's still shrouded in mystery, our attentions have since drifted to places in the solar system that are easier and more enticing to explore."



**ALTHOUGH VENUS' SURFACE** turned out to be uninhabitable, another picture of the atmosphere began to emerge. Around 40 to 60 kilometers (25 to 37 miles) high, air pressures are similar to Earth, with temperatures between 0 and 50 degrees Celsius (32 to 122 degrees Fahrenheit). If you went flying through this region in a specialized gondola, you could probably step outside if you brought supplemental oxygen and wore protective gear for the sulfuric acid.

Encouraged by new findings, Sagan refined his thinking. In 1967, he coauthored a paper with biophysicist Harold Morowitz, pondering how life could exist in the Venusian clouds. "While the surface conditions of Venus make the hypothesis of life there implausible, the clouds of Venus are a different

story altogether," the authors wrote. "Water, carbon dioxide and sunlight—the prerequisites for photosynthesis—are plentiful in the vicinity of the clouds." They envisioned blobs of hydrogen with microbes inside, wafting through the clouds collecting nutrients from minerals stirred up from the surface.

However, Venus' fall from grace had already begun, and the world's space agencies turned their attention to other destinations. The Soviet Union sent its final probes to Venus in 1984. NASA's last Venus mission, Magellan, launched in 1989 to map the surface using a cloud-penetrating radar, allowing scientists to conclude that the planet's volcanic surface has likely remained unchanged over the past several hundred million years.

The European Space Agency's Venus Express spacecraft launched in 2005 and studied the planet until 2015, and Japan's Akatsuki probe has been there since 2015. These missions found hints of past global oceans on Venus and in studying the atmosphere saw dynamic cloud formations, hurricane-like vortices at the poles, and wind that whips around the planet at hundreds of kilometers per hour. Our picture of Venus remains far from complete, especially on the topic of life.



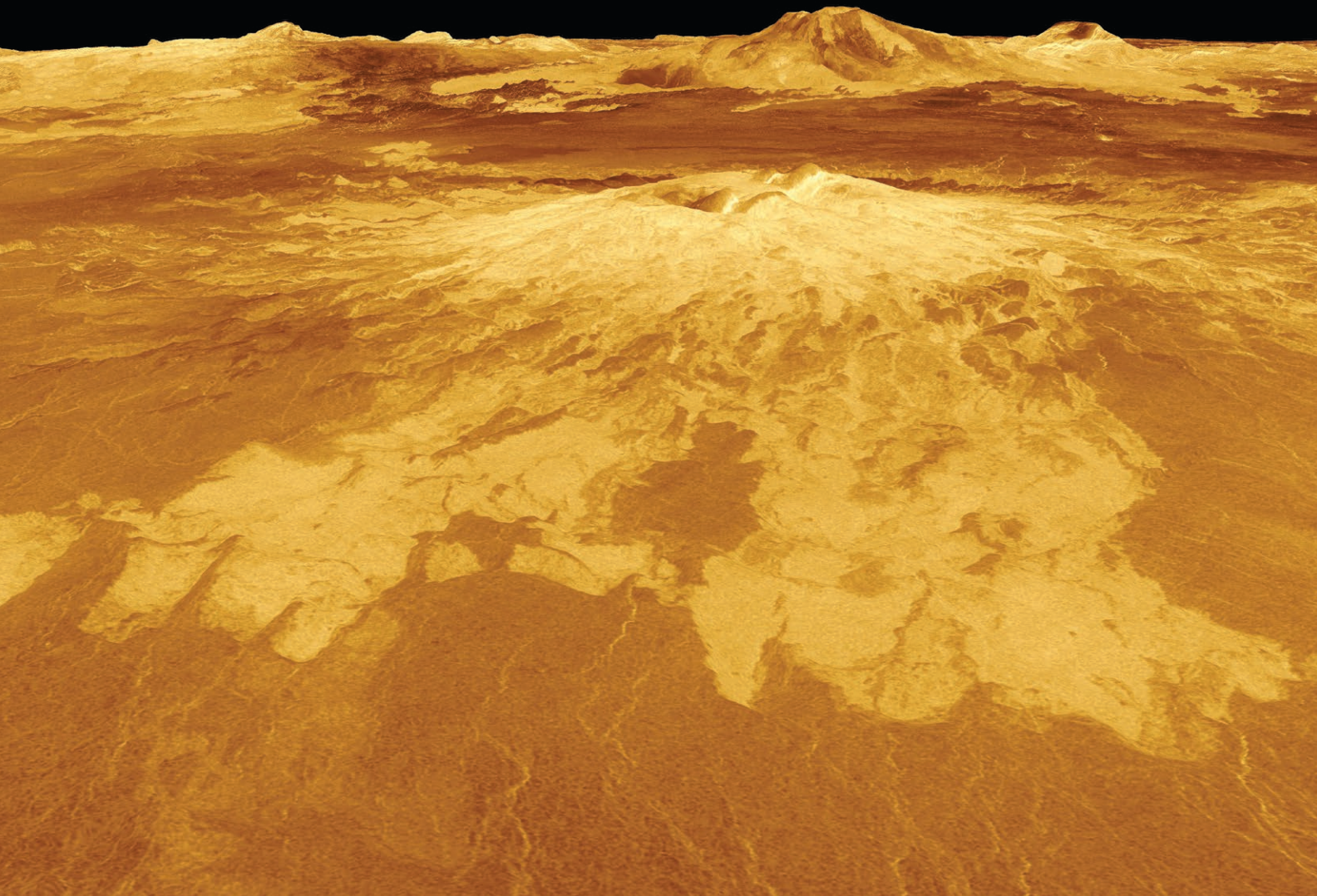
**THE POSSIBILITY** of Venusian life always intrigued Jane Greaves. As an astrobiologist with an astronomy background, Greaves has a reputation for looking for unusual things. She has observed debris from comet collisions around other stars and used the aforementioned James Clerk Maxwell Telescope to study Pluto's tenuous atmosphere.

In her Venus research, she learned that phosphine is considered a biomarker—a molecule related to biological processes—because it is hard to create from nonlife processes thought to occur on rocky worlds. On the off chance something were alive in the Venusian clouds,



“While the surface conditions of Venus make the hypothesis of life there implausible, the clouds of Venus are a different story altogether. Water, carbon dioxide and sunlight—the prerequisites for photosynthesis—are plentiful in the vicinity of the clouds.”

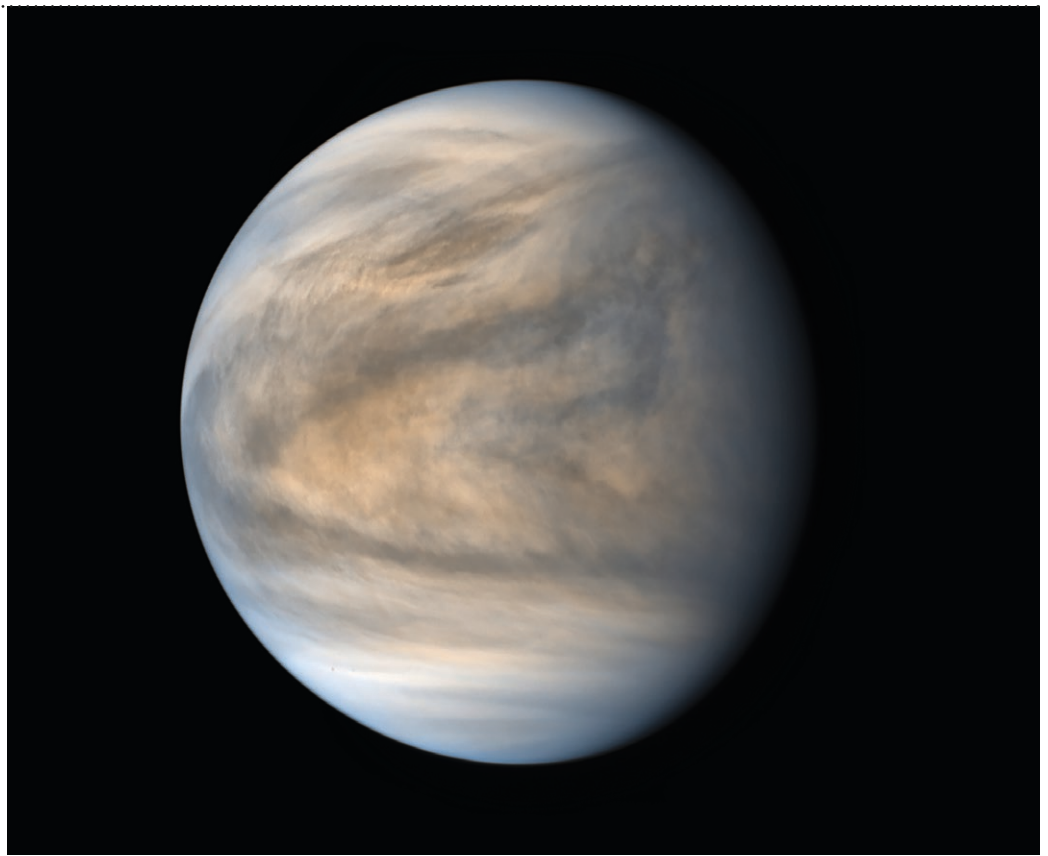
**CARL SAGAN AND HAROLD MOROWITZ IN A 1967 PAPER ON VENUS**



## THE QUEST FOR LIFE ON VENUS

**RIGHT** Japan's Akatsuki spacecraft captured this ultraviolet image of Venus on 17 May 2016. Whereas Venus' clouds appear relatively plain to human eyes, ultraviolet imagery reveals their complex global patterns.

JAXA/ISAS/DARTS/DAMIA BOUIC



it might release phosphine, Greaves reasoned. It also appeared that no one had ever searched for that particular biomarker on Venus.

The signal Greaves saw in 2017 was a dip in the amount of light coming from the planet at a wavelength of about 1.12 millimeters. Different molecules block or absorb specific wavelengths, and for phosphine, that happens at 1.12 millimeters. These signals can be weak and difficult to detect without sensitive telescope instruments and advanced data-processing algorithms.

Greaves assembled an international team of 19 chemists, biologists, and astrophysicists to study her findings. In 2019, they secured time on the powerful Atacama Large Millimeter/submillimeter Array (ALMA) radio telescope system in northern Chile to observe Venus again. The phosphine light dip was still there, showing the molecule in low quantities—about 20 parts per billion.

That amount of phosphine is a thousand

times less than what can be found in Earth's atmosphere. Nevertheless, it defied all known explanations, such as tectonic and volcanic activity, meteors, lightning, and other chemical processes. Sunlight or sulfuric acid in the clouds should destroy the Venusian phosphine before it could accumulate to the quantities detected unless some kind of life was producing more of it.

Team member Clara Sousa-Silva, a research scientist at the Harvard-Smithsonian Center for Astrophysics and one of the few phosphine experts in the world, said the analysis was painstaking. "On my side, just figuring out alternative candidates for the signal—a never-ending task of finding every other molecule that cannot be responsible for the signal and then estimating the properties of the signals—took me many months," she said.

On 14 September 2020, Greaves and her colleagues published the findings in the journal *Nature Astronomy*, stressing that the results



**ABOUT THE AUTHOR:** NANCY ATKINSON is a space journalist and author with a passion for telling the stories of people involved in space exploration and astronomy.



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were not a detection of life. *Nature Astronomy* made the article available for free, and the team published all of its data and methods for anyone to review. “We put the paper out in as open a way as possible,” Greaves said. “We wanted everyone—and we really meant everyone, even people at home—to work on it from different angles.”



**WHILE SOME MEMBERS** of the space community celebrated the findings, others were more skeptical. Within weeks, rebuttal analyses began appearing on arXiv, an open-access clearinghouse for preprint astronomy papers. Two groups examined Greaves’ original data and didn’t find evidence for phosphine, calling into question the processing techniques that were used. Another group searched for phosphine signals in archival Venus observations and came up empty. Then, technicians at the ALMA observatory found an error in the calibration system used to collect the Venus data. A corrected data set revised the amount of phosphine Greaves’ team detected from an average of 20 parts per billion down to 1, with spikes up to just 5

in some regions of the atmosphere. In early 2021, another paper suggested that the phosphine signal was actually sulfur dioxide, a gas that is common on Venus and is not a sign of possible life.

“All of this is not controversial—it’s science,” said Sousa-Silva. “My feelings are that all independent analyses of the existing data are not just uncontroversial but welcomed and crucial to this project. Over time and after revision, I expect our interpretations to converge on the truth, and I am impatient for that moment.”

The debate has at times been particularly contentious. One rebuttal took a condescending tone toward Greaves and her team; it has since been revised. A statement posted on the International Astronomical Union website chastised the researchers for announcing sensational findings that could lead to public overreaction. The IAU later removed the statement with apologies, saying it had been written by just a few members of an astrobiology subcommittee without broader input.

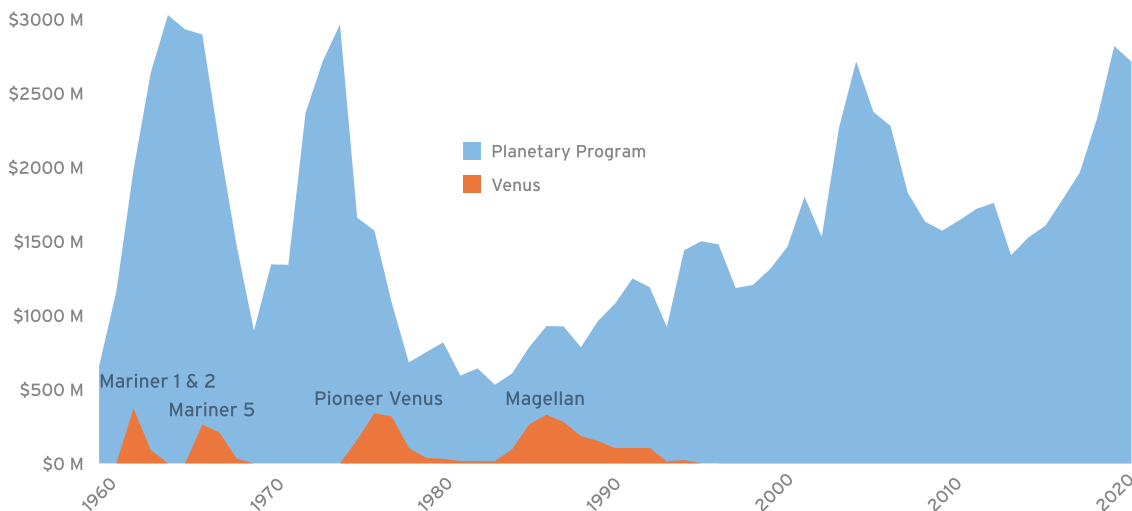
Grinspoon, the Venus scientist, noted there has been a history of strong reactions over scientific findings related to the search for life. Some observers attributed the backlash to gender issues—Greaves’ team is about half women—while others have pointed

**BELOW** *This image of Venus’ surface with the obscuring clouds removed was created by combining data from the Pioneer, Venera, and Magellan missions.*

NASA



VENUS SPENDING COMPARED TO TOTAL NASA PLANETARY PROGRAM EXPENDITURES



**ABOVE** NASA has spent approximately \$3.65 billion on dedicated Venus missions in its history out of roughly \$97 billion spent on its robotic planetary program (all values are adjusted for inflation to 2019 levels). To view the raw financial data, go to the Planetary Exploration Budget Dataset at [planetary.org/budget-dataset](https://planetary.org/budget-dataset).  
CASEY DREIER

to the current political environment amid a global pandemic as a potential hair-trigger. “The tenor of the conversations on this topic has been very much less than professional, which is unfortunate,” said Rakesh Mogul, a professor of biological chemistry at California State Polytechnic University, Pomona. “Harsh critiques shouldn’t have any place in science right now.”

Mogul leads a team that offered some unexpected support for the phosphine findings: archival data from NASA’s 1978 Pioneer Venus Multiprobe mission, which carried a mass spectrometer to determine the composition of chemicals in Venus’ atmosphere. Although the instrument was not specifically designed to look for phosphine, Mogul’s team reprocessed the data it recorded and found what thus far appears to be phosphine. “The available data was literally just a table in a publication,” Mogul said. “It took us a while to figure out ways to trust the data and not overinterpret it.”

One of Mogul’s challenges is simply understanding the design of the instrument and the way the data were originally processed. His team members have become de facto data archeologists digging through old records,

and they’ve called in one of the original mission scientists, Richard Hodges, to help. “He is pulling out code from 40 years ago, helping us to better understand these mass spectrometer signals,” Mogul said. “It’s been an honor and a great experience to work with him. We’re approaching this from multiple angles, trying to put this all together to have a full understanding of the data set.”



**THE PHOSPHINE QUESTION** is one of many secrets Venus still has to teach us. Scientists still don’t know how Venus changed from a potentially habitable planet with oceans to an inhospitable wasteland. The answer will help us understand the possibilities for similar planets outside our own solar system and may serve as a cautionary tale for Earth.

As the current debate shows, phosphine is difficult to detect from ground-based telescopes. NASA’s airborne SOFIA telescope could possibly provide stronger evidence from above more of Earth’s light-distorting atmosphere, but it will ultimately take new



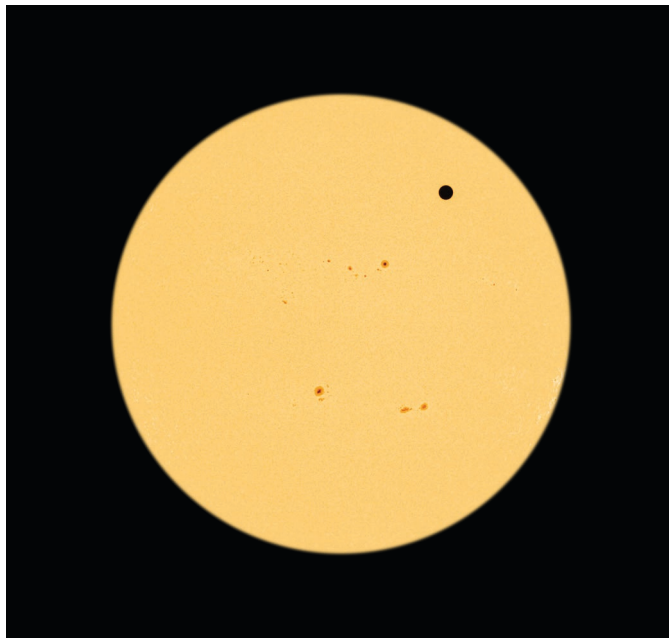
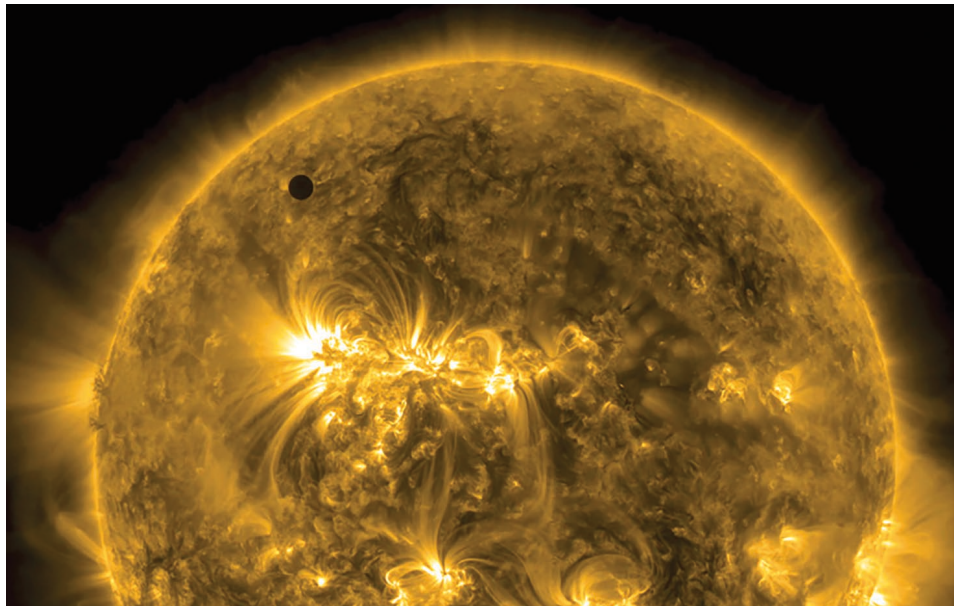
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Scientists still don't know how Venus changed from a potentially habitable planet with oceans to an inhospitable wasteland. The answer will help us understand the possibilities for similar planets outside our own solar system.

space missions to settle the question of whether life exists on Venus.

ISRO, India's space agency, is eyeing 2023 for the launch of its Venus mission, called Shukrayaan, which will use radar and infrared cameras to map the planet's surface. NASA is considering 2 Venus spacecraft concepts for its low-cost Discovery mission program; at least 1 of those could potentially detect phosphine or be tweaked to look for it more specifically. However, those spacecraft are up against 2 equally compelling missions to Neptune's moon Triton and Jupiter's moon Io. The agency will pick up to 2 winners this year, and some scientists and space fans are crossing their fingers that one will go to Venus.

"Sending a spacecraft there is long overdue," Grinspoon said. "There are 1,001 reasons we need a new mission to Venus, and even if it turns out that there isn't phosphine in the atmosphere, there will still be 1,000 reasons. There are so many mysteries there, and the ultimate way to answer them is to dive into those clouds, sample some particles, and figure out what's going on." 🪐



**ABOVE** In June 2012, the world watched as Venus glided across the face of the Sun for over six hours as seen from Earth. NASA's Solar Dynamics Observatory implemented specially planned operations to view the event in great detail across many wavelengths of light. The results were the best high-definition views of a transit ever captured.

NASA/GSFC/Solar Dynamics Observatory



### **David A. Hardy, *Volcanoes of Venus***

Until the advent of robotic spacecraft, when humans looked at Venus, we could only see a bland white disc with thick clouds obscuring the surface. Many types of surfaces were proposed, from prehistoric forests to planet-wide oceans or a wind-blown dust bowl. We now know Venus to have an arid, cracked landscape dotted with great volcanic formations. This artwork by longtime Planetary Society member David A. Hardy shows a view of the Venusian surface as it may look beneath the clouds.

Do you want to see your artwork here? We love to feature our members throughout this magazine. Send your original, space-related artwork to [connect@planetary.org](mailto:connect@planetary.org).