The Planetary Society

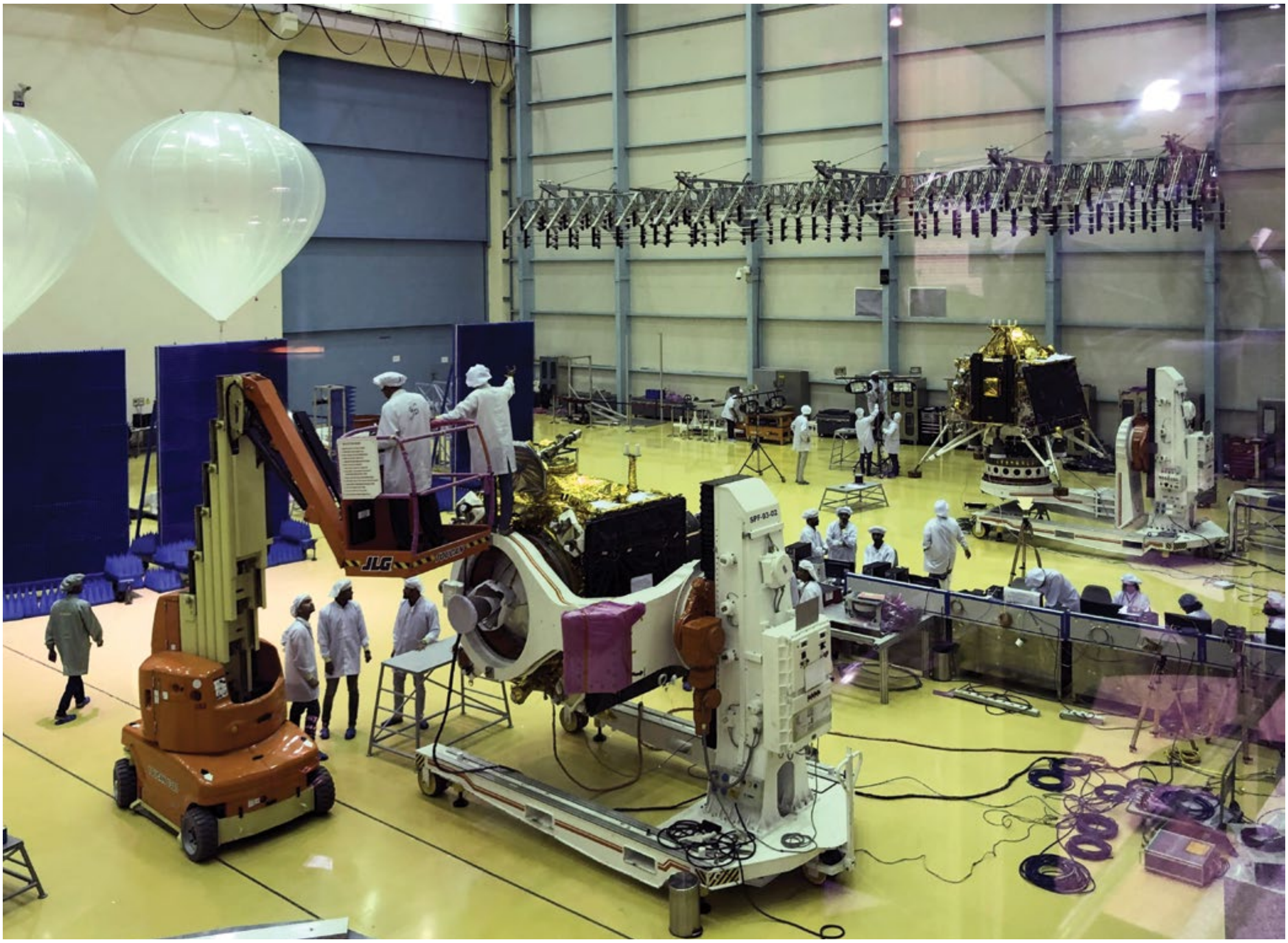
THE PLANETARY REPORT

SEPTEMBER EQUINOX 2019
VOLUME 39, NUMBER 3
planetary.org

LIGHTSAIL 2 MISSION SUCCESS

SPREADING SILVER SAILS
RAISING ORBIT APOGEE
PROVING FLIGHT BY LIGHT

EUROPE & JAPAN EXPLORE VENUS ✻ STATUS OF PLANETARY DEFENSE ✻ WHY WE EXPLORE



Mooncraft

Putting the Finishing Touches on a Founder's Dream

BEFORE SPACECRAFT CAN take flight, thousands of people spend years working on Earth to turn dreams into hardware. The assembly facility at the Indian Space Research Organisation (ISRO)'s Satellite Integration and Test Establishment buzzes with activity as workers prepare for Chandrayaan-2's launch to the Moon. Near the center is the Chandrayaan-2 orbiter, mounted on a rotating test stand. In the background on the left, 2 helium-filled balloons await use in the testing of the lander and rover; their buoyancy can counteract a spacecraft's Earth weight to simulate lunar surface gravity. To the right stands the large Vikram lander, named for Vikram Sarabhai (1919-1971), who founded numerous Indian research institutes and advocated the establishment of an Indian space program.

ISRO treated local media to a rare glimpse of the clean room facility on 12 June 2019. This photo was taken from the viewing gallery by Sandhya Ramesh, science editor for ThePrint India. On 22 July, both orbiter and lander successfully launched toward the Moon. Vikram aims for a 7 September landing; its fate is unknown as of the time this magazine went to print. If successful, India would be only the fourth nation to soft land on the lunar surface.

Sandhya Ramesh

SNAPSHOTS FROM SPACE

NASA/JPL/Cassini-ISS/Justin Cowart

WHEN THE VOYAGERS viewed Dione from afar, they saw "wispy terrain"–bright scratches of unknown origin across the surface. Cassini got a lot closer to Dione on 11 October 2005 and observed the "wisps" to be bright ice exposed along steep-walled fractures. To craft this view, Justin Cowart assembled 7 high-resolution images of the sunlit crescent of Dione onto a lower-resolution view that included some detail on Dione's nightside where it's lit by Saturnshine.

–*Emily Stewart Lakdawalla*

SEE MORE AMATEUR-PROCESSED SPACE IMAGES PLANETARY.ORG/AMATEUR

SEE MORE EVERY DAY! PLANETARY.ORG/BLOGS

CONTACT US: The Planetary Society, 60 South Los Robles Avenue, Pasadena, CA 91101-2016; General calls: 626-793-5100; Email: *tps@planetary.org*;Internet:*planetary.org*; *Editor* **EMILY LAKDAWALLA**; *Art Director* **LOREN A. ROBERTS for HEARKEN CREATIVE**; *Copy Editors* **NICOLE YUGOVICH** and **KELLY BEATTY**; *Technical Editor* **JAMES D. BURKE**; *Science Editor* **BRUCE BETTS**

ON THE COVER: LightSail 2 documented half of its fully deployed sail as it passed over Baja California within sight of its San Luis Obispo ground station on 31 July 2019. The sail, which is actually square, appears warped because of the camera's 185-degree fisheye lens. *Credit: The Planetary Society*

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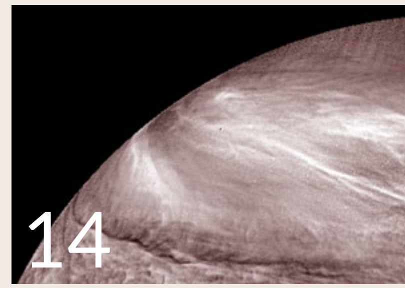


BILL NYE *is chief executive officer of The Planetary Society.*

Mission Success!

LightSail 2 Demonstrates Flight by Light

WHAT A JOURNEY! What a success! Your LightSail 2 spacecraft is in space, controlling its orbit solely on the power of sunlight.

Along with a few hundred fellow members, I was at the night launch of LightSail 2 on 25 June 2019. A SpaceX Falcon Heavy rocket took us to orbit. It was spectacular.

One week later, our CubeSat deployed and began its adventure in space. Three weeks after that, we were sailing! As I write, LightSail 2 is building orbital altitude by hundreds of meters per day.

LightSail 2 is part of our legacy and a dream come true. Back in the 1970s, as comet 1P/Halley was on its way toward the Sun, our founders Carl Sagan, Bruce Murray, and Louis Friedman advocated for a solar sail mission to catch up with it. Carl showed the idea to Johnny Carson on *The Tonight Show*. It was an inspiring concept, but it never got off the drawing board.

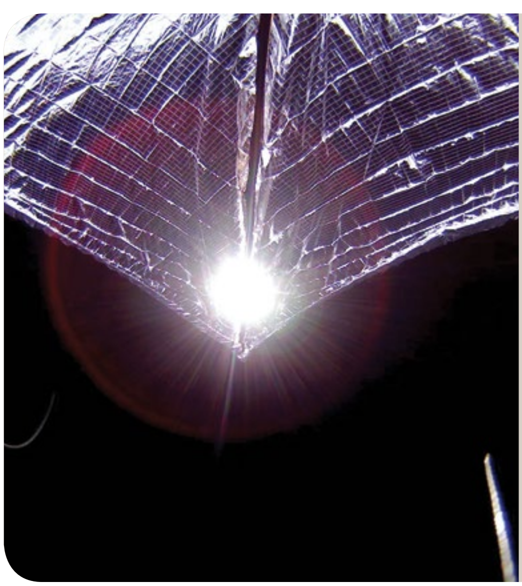
Then, in 1999, The Planetary Society, partnering with Russian space companies and Ann Druyan's Cosmos Studios, began work on the Cosmos 1 solar sail. Cosmos 1 could have been the first demonstration of solar sailing, but the rocket failed, and the spacecraft ended up in the sea.

We might have given up on the dream were it not for all of you-our members. You responded with a resounding "try again," and now we're sailing in space. Thanks to you, LightSail 2 is flying and proving the concept of flight by light.

As a member, you appreciate how hard it is to design, build, test, retest, and finally fly a space mission. For the first time in history, we demonstrated fast tacking, twice in every 100-minute orbit, near Earth–with a spacecraft propelled by sunlight. LightSail 2 is extraordinary–and, we hope, precedent setting. Your passion and commitment got us here. Together, we have accomplished something wonderful. Sail on!

Bill Nye

For more about LightSail, including videos, detailed stories, more images, and how to track LightSail 2, go to **sail.planetary.org**.



LightSail 2 Proved Controlled Solar Sail Flight in Earth Orbit

SOLAR SAIL TECHNOLOGY is in its infancy. LightSail 2 is the first controlled solar sail flight in Earth orbit and only the second solar sail tested in space. (JAXA's IKAROS was the first solar sail flight.) LightSail 2 allows us to control the orientation of the solar sail and use the momentum of light to change the orbit much like how a sailboat uses wind. On 31 July 2019, the mission team confirmed that the spacecraft had raised its orbital high point, or apogee, by about 2 kilometers, meaning LightSail 2 had achieved mission success.

The Planetary Society

LEFT *On 25 June 2019, LightSail 2 launched to space aboard a SpaceX Falcon Heavy rocket. Space enthusiast Stephen Marr captured the launch along with this special light-painted message.*

You did it!

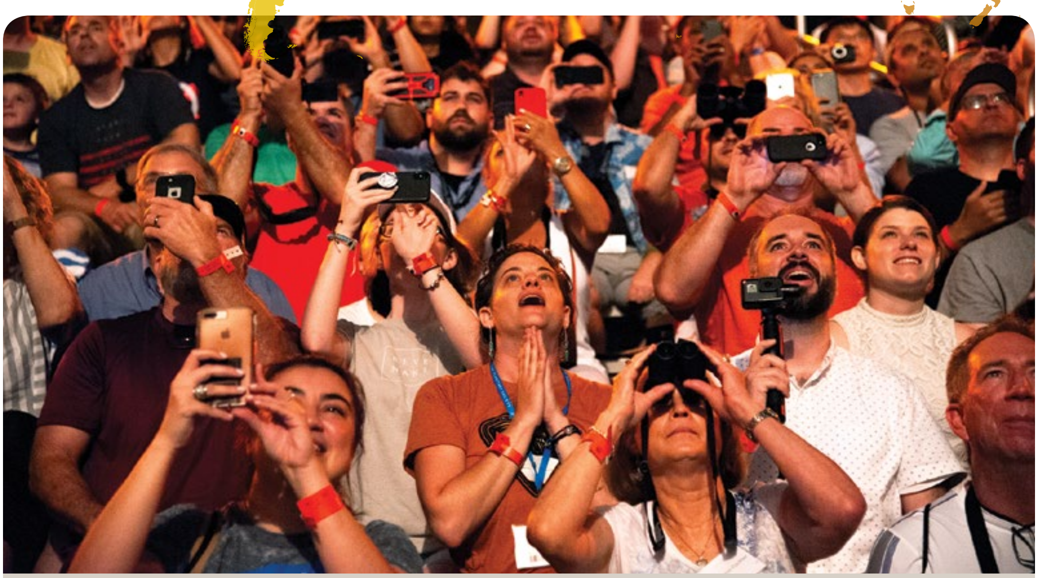
2 spacecraft

10 years

$7 million

49,426 donors

109 countries represented



Stephen Marr/spacecoaststeve.com; Navid Baraty for The Planetary Society

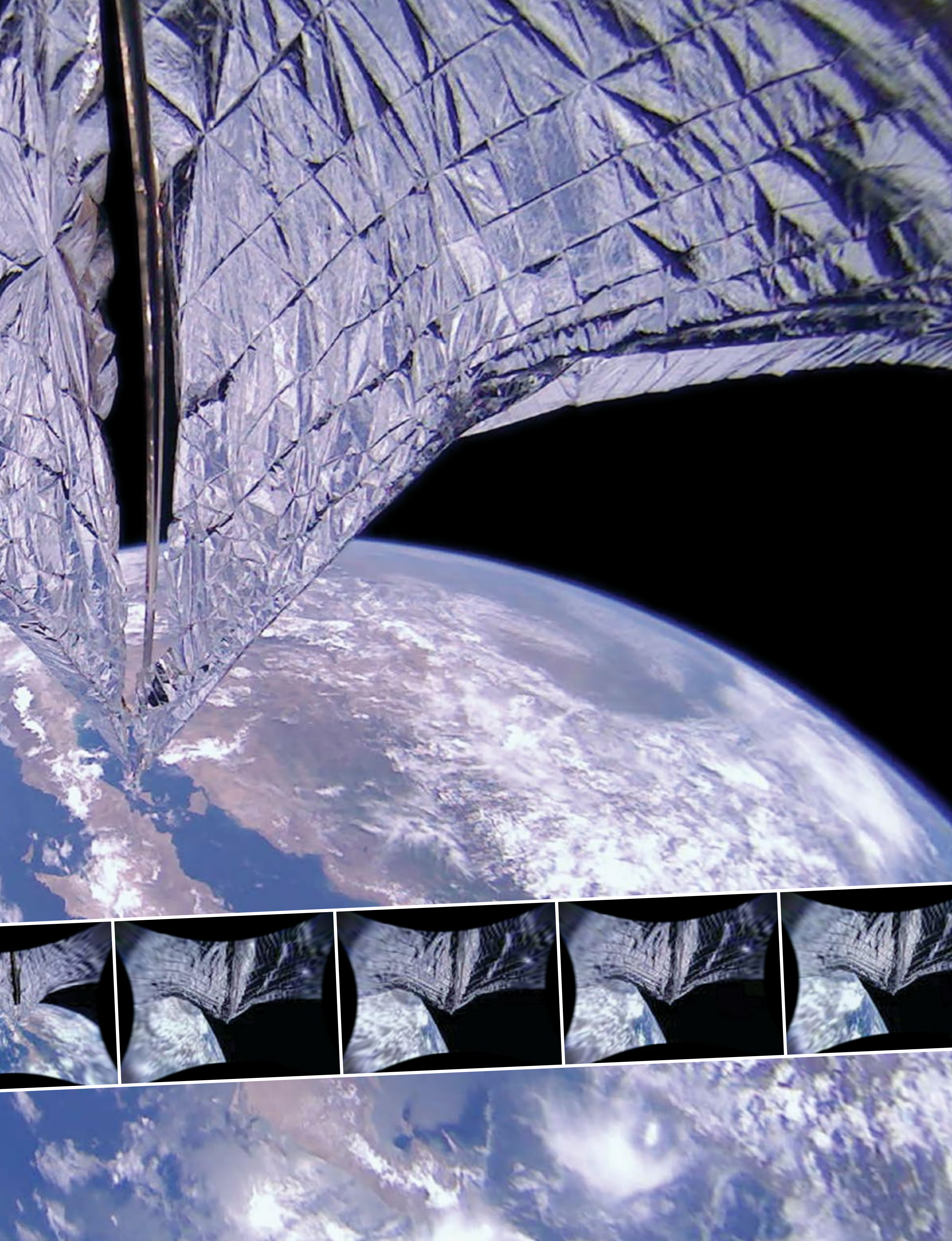
LightSail 2 Is 100 Percent Crowdfunded

TENS OF THOUSANDS of space enthusiasts from all over the world came together to make the mission possible. LightSail 2 has on board a mini DVD containing a Planetary Society member roster, a list of Kickstarter backers, and names and images from the Society's Selfies to Space campaign.

LightSail 2 Spreads its Wings and Begins to Fly

ON 23 JULY 2019, flight controllers at Cal Poly San Luis Obispo in California commanded LightSail 2 to deploy its 32-square-meter sail. These images capture the deployment sequence as seen from one of the spacecraft's 185-degree fisheye cameras. The view of Earth shows Baja California and part of Mexico. LightSail 2 is expected to continue to send back images as it orbits Earth until it reenters the atmosphere in approximately 1 year.

The Planetary Society



LightSail 2 Is the First Small Spacecraft Propelled by Sunlight

PAIRING SOLAR sail propulsion with small, relatively inexpensive spacecraft could open up solar system exploration to more people. More nations, universities, private companies, and nonprofits could participate in interplanetary missions.


Thomas Zurbuchen
@Dr_ThomasZ

Congrats to the single boat #LightSail2 space regatta by the @exploreplanets! Imagine the missions we at NASA Science could do with solar sail technology - a space weather sentinel, a solar polar mission, etc. #imagine #explore


Jim Bridenstine
@JimBridenstine

Congratulations to the Planetary Society! LightSail 2 Is Officially Soaring on Sunlight! @exploreplanets

Solar Sail Success! LightSail 2 Is Officially Soaring on Sunlight
Bill Nye thinks it's "romantic."
space.com

9:23 AM - 3 Aug 2019

200 Retweets 1,216 Likes

16 200 1.2K


Sasha Sagan
@SashaSagan

Replying to @DanielleRGunn

I know my dad would be thrilled about #lightsail2

2:47 PM · 7/26/19 · Twitter for iPhone

27 Retweets 153 Likes

ABOVE *From mission control at Cal Poly San Luis Obispo, the LightSail 2 mission team cheers after confirming successful sail deployment.*

Bruce Betts/The Planetary Society

LightSail 2 Captured the World's Attention


habr
Публикации Новости Пользователи Хабы Компании Песочница

marks 21 июня 2019 в 00:42

В понедельник Falcon Heavy запустит на орбиту спутник с солнечным парусом

Научно-популярное, Космонавтика

О солнечных парусах как одном из инструментов освоения близкого и дальнего космоса говорят и пишут как фантасты, так и ученые. Одним из активнейших сторонников внедрения солнечного паруса в космическую сферу стал известный ученый-физик Карл Саган, который в своих работах описывал достоинства такой системы.


NOTÍCIAS

Vela solar americana LightSail 2 abre no espaço

Washington, 23 Jul 2019 (AFP) - Um mês depois de seu lançamento ao


infobae

AMÉRICA ARGENTINA TENDENCIAS DEPORTES

CIENCIA

La vela solar LightSail 2 logró su misión en el espacio

El equipo detrás de este experimento dijo que había logrado probar una nueva forma de propulsión alternativa que algún día podría transformar la exploración del espacio profundo al eliminar la necesidad de costosos cohetes y combustible

Compartir en Facebook Compartir en Twitter

MÁS LEÍDAS infobae América


LightSail 2太阳帆卫星证明其可以利用光线在太空中推进

2019-08-01 07:47

据外媒The Verge报道，行星协会的实验性LightSail 2太阳帆卫星被设计用于在太阳光线下飞行。该非营利组织周三宣布，由于太阳能推动该卫星的大型反光太阳帆，该卫星已成功地绕地球运行。这标志着地球轨道上的航天器首次使用太阳帆来改变其绕行星的路径。


The New York Times

LightSail 2 Unfurls, Next Step Toward Space Travel by Solar Sail

The Planetary Society deployed LightSail 2, aiming to further demonstrate the potential of the technology for space propulsion.


MENU CERCA la Repubblica ACCEDI

Scienze

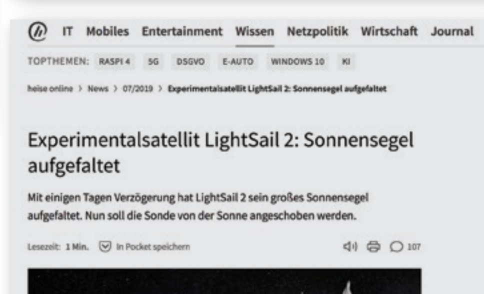
HOME POLITICA ECONOMIA SPORT SPETTACOLI TECNOLOGIA MOTORI TUTTE LE SEZIONI D REP TV

Il volo di una vela spaziale spinta dal Sole: è LightSail 2, il lancio con il razzo Falcon Heavy

Alle 5.30 di domani mattina (ora italiana) partirà con il peso massimo dei razzi, il nuovo lanciatore della SpaceX che porterà in orbita anche 24 satelliti del Dipartimento della Difesa degli Stati Uniti.


'Uzay yelkenlisi' LightSail 2, Dünya'ya ilk fotoğrafları gönderdi

En Çok Okunan Haberler


IT Mobiles Entertainment Wissen Netzpolitik Wirtschaft Journal

TOPTHEMEN: RASPI 4 5G DSGVO E-AUTO WINDOWS 10 KI

heise online › News › 07/2019 › Experimentalsatellit LightSail 2: Sonnensegel aufgefaltet

Experimentalsatellit LightSail 2: Sonnensegel aufgefaltet

Mit einigen Tagen Verzögerung hat LightSail 2 sein großes Sonnensegel aufgefaltet. Nun soll die Sonde von der Sonne angeschoben werden.

Lesezeit: 1 Min. In Pocket speichern 107

Day of Action photos: Antonio Perance/The Planetary Society

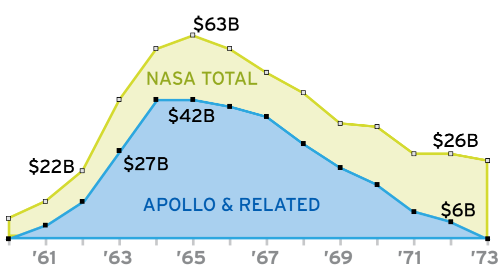
Science Advocacy Successes

PLANETARY SOCIETY MEMBERS impact legislative and budgetary priorities in the U.S. Congress. Thanks to your advocacy efforts, The Planetary Society secured our top legislative priorities in the NASA fiscal year 2020 budget passed by the House of Representatives. The legislation rejected the White House's proposed cancellations of the Wide-Field Infrared Space Telescope (WFIRST), Earth Science missions; and NASA's education program; supported the start of a Mars sample return mission, and continued development of the asteroid-hunting NEOCam spacecraft. Congress also bumped NASA's top line by 4 percent to $22.3 billion. Chief Advocate Casey Dreier organized this advocacy effort with Chief of Washington Operations Brendan Curry. The thousands of Society members who contacted their congressional representatives in support of these issues led us to success.

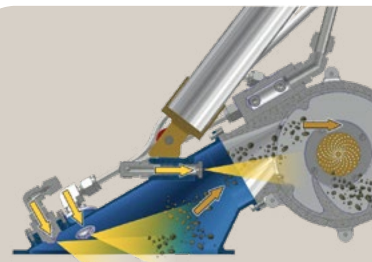
Notably absent from the House's bill was funding for Project Artemis, the new effort to land humans on the Moon by 2024. Action now shifts to the Senate, which had yet to release its version of NASA's budget by the time this issue went to press. Up-to-date information is available at **planet.ly/fy2020**.

How Much Did Apollo Cost?

YOUR MEMBERSHIP SUPPORTED new independent financial analysis that revealed that Project Apollo cost $264 billion in 2019 dollars. The total increases to $288 billion when related efforts such as robotic lunar probes and Project Gemini are included. This analysis provides critical historical context for evaluating modern political commitments to human exploration efforts.



The Planetary Society released the raw data behind this project to encourage open discussion and further analysis. Explore the cost of Apollo with beautiful charts and year-by-year and program-by-program cost breakdowns at **planet.ly/apollocost**.



A Moon Shot for PlanetVac

PLANETVAC, A PLANETARY Society member-funded technology that simplifies the process of collecting samples from other worlds, has been chosen for a possible Moon flight! NASA selected PlanetVac and 11 other science and technology payloads to join its Commercial Lunar Payload Services program, which will send a series of robotic spacecraft to the Moon. In 2021 and 2022, 3 commercially built spacecraft are scheduled to land on the Moon. You helped fund 2 tests of PlanetVac in 2013 and 2018 in partnership with Honeybee Robotics, which builds the device. You saw the promise of PlanetVac and supported its development. Thank you! **planet.ly/planetvac**

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

MISSION CONTROL DASHBOARD

You made the LightSail 2 mission possible. Now, you can track it in real time as it sails around Earth.

All the latest health and status information is available for download. Mission Control also helps you see when LightSail 2 will fly over your location. Sail watchers are most likely to see the shiny spacecraft at dawn or dusk. **planetary.org/missioncontrol**

Did you spot the sail? Tell us at *lightsail@planetary.org*!

LIGHTSAIL MISSION OUTREACH TOOLKIT

As a Planetary Society member, you've made history with the successful solar sailing demonstration by LightSail 2. Now, you can spread the word about LightSail in your own community. We've made it easy for you to inspire others about what is possible when everyday citizens come together to make the extraordinary happen. Download resources at **planetary.org/volunteer**.

THE COUNTDOWN TO THE HOLIDAYS HAS BEGUN!

Here are 3 easy ways you can support space exploration while checking off your holiday gift list this year:

SHOP TO SUPPORT
From T-shirts to mission patches, every purchase from our official store supports vitally needed work to advance space exploration through advocacy, education, innovation, and global collaboration.
planetary.org/shop

GIVE THE GIFT OF SPACE
Share your passion for space exploration by giving someone special a gift membership to The Planetary Society. It's the perfect way to introduce your loved one to an inspiring new level of participation in space exploration.
planetary.org/gift

AMAZONSMILE: YOU SHOP. AMAZON GIVES.
Did you know you can give back to space exploration every time you shop on Amazon? Select The Planetary Society as your AmazonSmile charitable organization, and Amazon will donate 0.5 percent of every eligible purchase.
amazon.com/smile

Need more ideas? Check out our annual gift guide at **planetary.org/giftguide**.

DAY OF ACTION IN WASHINGTON, D.C.

Mark your calendars: we're mobilizing citizen space advocates to support space science and exploration in Washington, D.C. on 9-10 February 2020.

Experience the thrill of advocating for NASA face to face alongside your fellow Planetary Society members. Early-bird registration ends 31 December 2019. Register today!
planetary.org/dayofaction

PLANETARY RADIO

INTERNATIONAL PODCAST DAY

International Podcast Day on 30 September celebrates how podcasts connect us to new people, ideas, and stories each day, worldwide.

This year, celebrate by listening to *Planetary Radio*, hosted by Mat Kaplan. Our weekly program brings you the voices of the fascinating people who make space exploration happen. You can help spread the word by using the hashtag #InternationalPodcastDay.
planetary.org/radio

YOUR APOLLO STORIES

For the fiftieth anniversary of Apollo 11, The Planetary Society asked you for your thoughts and memories of this epochal event. Below is a sampling of those stories. Add your own story or read more at **planet.ly/apollostory**.

"It was my eighth birthday…my parents let me stay up late to watch the moon walk. I remember President Nixon's phone call and asking my dad if we could call the astronauts after the president hung up. He said he didn't know the number, but it was probably a long-distance call anyway."

- Tim P.

"I first came to know about [Apollo] in school, and by then, landing on the Moon was a thing taken for granted…I never thought about how these things developed, and now that I know their history, I really feel lucky to live in a tremendously technological world where we get so many facilities to study our universe. No doubt this all started with Apollo."

- Sabiba H.

"I was enthralled. My family and I were glued to the set. I was taken by the world's different reactions to the landing. The Dutch sat in chairs and applauded, and the Italians were dancing around and shouting. I had to notice–I'm an anthropologist–but I too was energized. I was 48 at the time and an enthusiastic science-fiction fan since I was a child. Incidentally, that is why I joined The Planetary Society right off."

- Lillian A.

"The moment Neil Armstrong reached the surface of the Moon and spoke the historic words, my cousin looked around at me with the biggest grin I believe I have ever seen in my life…It must have been a direct reflection of the grin I had on my face at the time."

- Jim V.

Eclipse and Aurora Adventures for Members and Friends in 2020

You can see the "ring of fire" of an annular eclipse as the 21 June 2020 eclipse crosses from Ethiopia to Tibet and China on 3 different expeditions:

ETHIOPIA ANNULAR ECLIPSE 2020
9-23 JUNE 2020
Including the source of the Blue Nile

TIBET ANNULAR ECLIPSE 2020
10-23 JUNE 2020
See the eclipse at the "top of the world"

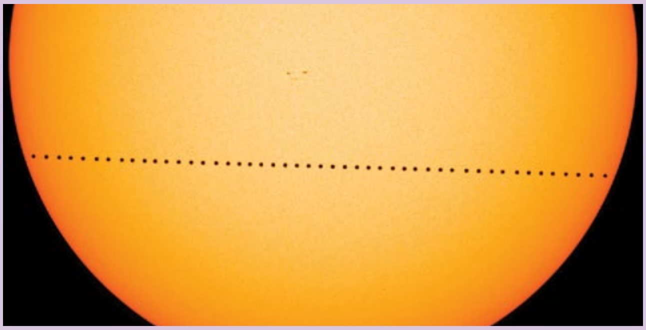
CHINA ANNULAR ECLIPSE 2020
13-25 JUNE 2020
Including Beijing, Xian, and the Yangtze River cruise

ARGENTINA TOTAL SOLAR ECLIPSE 2020
8-19 DECEMBER 2020
Join us in Argentina to see the total solar eclipse, 14 December 2020, including Buenos Aires and Iguazu Falls. With optional Peru or Easter Island pre trips, 2-8 December 2020

ALASKA AURORA BOREALIS
27 FEBRUARY-4 MARCH 2020
Come see the aurora dance across the night sky in this perennially favorite expedition!

For detailed brochures, please contact Betchart Expeditions Inc. at 800-252-4910 or go to *betchartexpeditions.com.*

The Planetary Society; NASA; Getty Images



ABOVE *Mercury appears as a black dot in this multiple-exposure photo of it crossing the Sun in a rare transit.*

IN THE SKY

A rare transit of Mercury across the Sun occurs on 11 November. To observe Mercury's small disk crossing the Sun, you'll need a telescope with proper safety filters, or you can tune in to telescope webcasts. This transit will be visible from South America and Africa and most of North America and Europe. The Geminids meteor shower peaks 13 and 14 December, but a full Moon at the peak will limit the number of meteors visible. Bright Jupiter dominates the western sky until even-brighter Venus starts appearing low in the West in October and November. These two brightest star-like objects in the night sky will be close together on 24 November. Yellowish Saturn is to their upper left, and the crescent Moon will join the group on 28 November. By November, reddish Mars begins to rise in the pre-dawn East.

RANDOM SPACE FACT

Mercury transits the Sun an average of 13.4 times per century. After 2019, the next transit of Mercury across the Sun will not take place until 2039.

TRIVIA CONTEST

Our March equinox contest winner is Peter Yanginski of Deerfield, New York. Congratulations! The question was: ***On what planet in our solar system have the fastest wind speeds been measured?*** The answer: ***Neptune, where wind speeds as high as 2,200 km/h (1,400 mph) have been measured.***

Try to win a copy of *Super Cool Space Facts: A Fun, Fact-filled Space Book for Kids* by Bruce Betts and a *Planetary Radio* T-shirt by answering this question:

As seen from Earth, in what year was the last transit of Mercury across the Sun?

Email your answer to 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 December 2019. 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 guests, listen to *Planetary Radio* at planetary.org/radio.

ABOVE *Juno made its twenty-first close pass by Jupiter on 21 July. Both Juno and Earth-based astronomers have seen dramatic changes near the Great Red Spot this year, with the storm shrinking.*

Where We Are

An At-A-Glance Spacecraft Locator

WE LOST AND GAINED spacecraft at the Moon last quarter. India's Chandrayaan-2 left Earth orbit for the Moon on 13 August, and its Vikram lander aims at a 7 September touchdown. I've optimistically sited it on the ground on the diagram to the right. Lunar Reconnaissance Orbiter just celebrated its tenth launch anniversary. China's smallsat Longjiang-2 crashed on 31 July, ending its successful mission.

Parker Solar Probe is racing away from perihelion number 3, which it passed on 1 September, and will fly by Venus for its second time on 26 December. The Spitzer Space Telescope, advancing ahead of Earth in its orbit, is nearing the end of its mission; it will be shut down on 30 January.

Asteroid Ryugu is near perihelion, which takes it closer to the Sun than Earth. The asteroid is too warm for Hayabusa2 to do any further touchdown activities. Late this quarter, Hayabusa2 will begin its journey home.

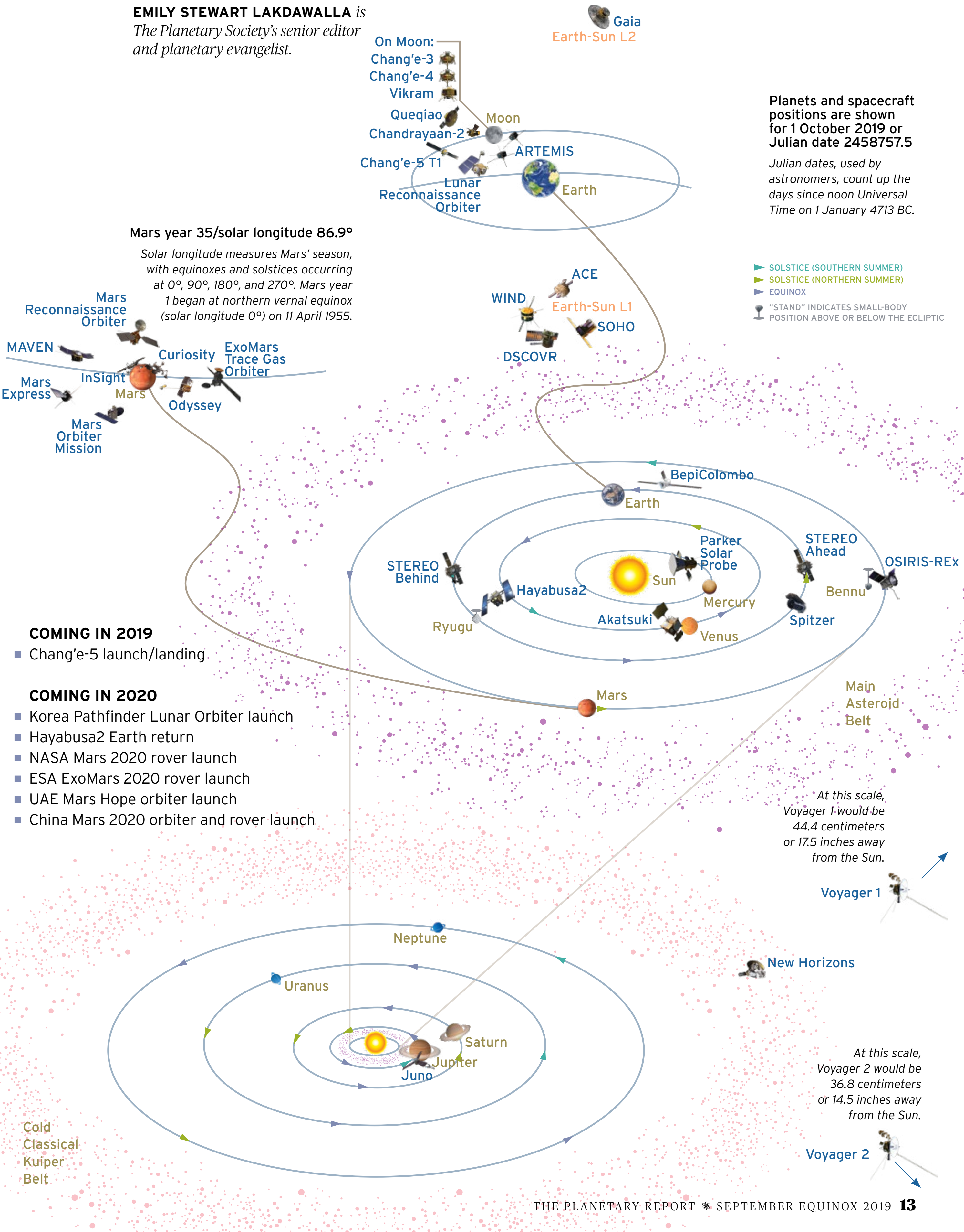
At Mars, it's near northern summer solstice; the Mars Express Visual Monitoring Camera views of the planet show a fully lit northern polar cap. InSight's engineers are still working to get the heat probe embedded in the sand. Seven years after landing, Curiosity saw its odometer turn over to 21 kilometers (16 miles) while crossing clay-rich rocks on Mount Sharp.

At Jupiter, Juno has 2 close approaches to Jupiter on 3 November and 26 December. In the Kuiper belt, New Horizons is doing distant science on Kuiper belt objects, Uranus, and Neptune.

At a reader's request, I've added numbers describing how far off the printed diagram Voyager 1 and 2 would actually be. It's far!

NASA/SDO; NASA/JPL-Caltech/SwRI/MSSS/Kevin M. Gill

EMILY STEWART LAKDAWALLA *is The Planetary Society's senior editor and planetary evangelist.*



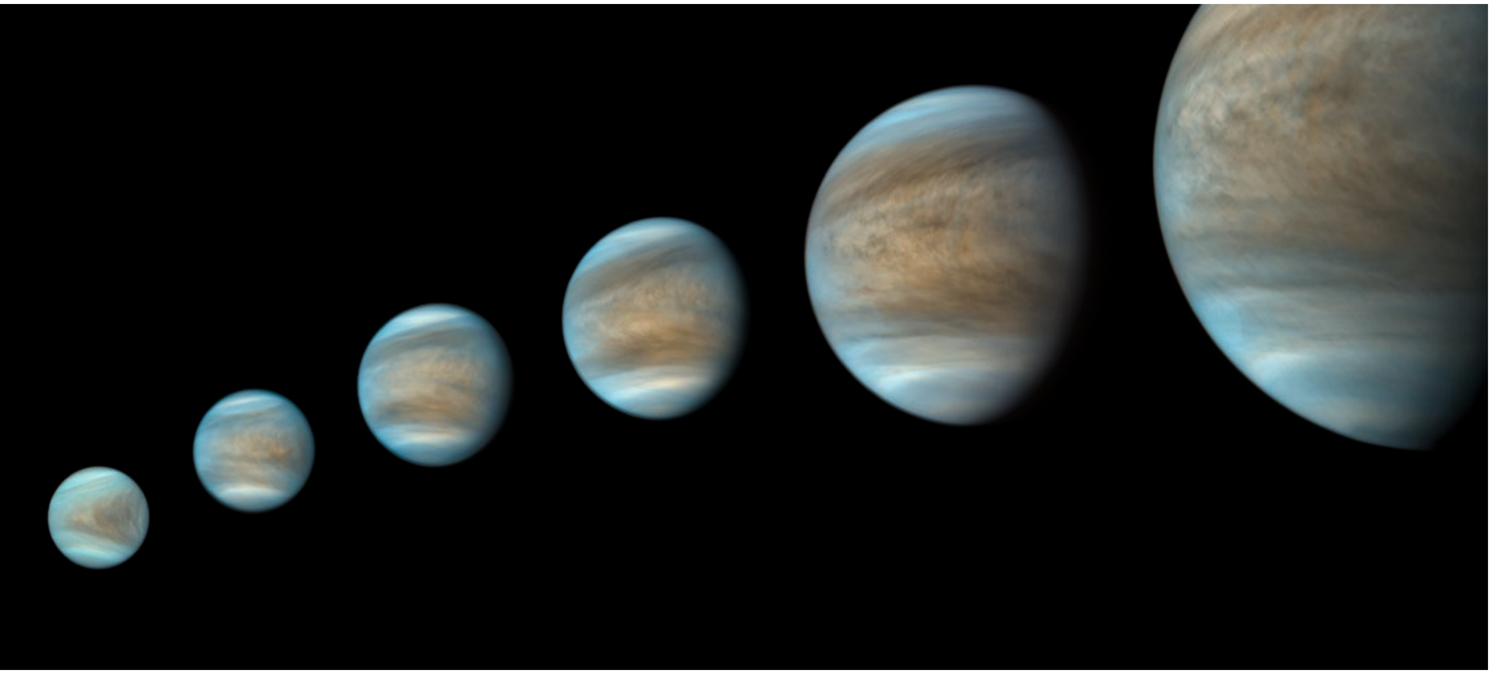
COMING IN 2019

- Chang'e-5 launch/landing

COMING IN 2020

- Korea Pathfinder Lunar Orbiter launch
- Hayabusa2 Earth return
- NASA Mars 2020 rover launch
- ESA ExoMars 2020 rover launch
- UAE Mars Hope orbiter launch
- China Mars 2020 orbiter and rover launch

JAVIER PERALTA *studies Venus atmospheric dynamics and is a member of JAXA's Akatsuki mission.*



ABOVE *Seen in natural color, Venus is as featureless as a cue ball. In ultraviolet wavelengths, a mysterious atmospheric component absorbs sunlight, outlining patterns in Venus' clouds. Like a weather satellite, Japan's Akatsuki orbiter swings far from Venus on each 10-day orbit and watches the clouds move through cameras that see in ultraviolet, visible, and infrared wavelengths.*

JAXA/ISAS/DARTS/Damia Bouic

Venus' Ocean of Air and Clouds

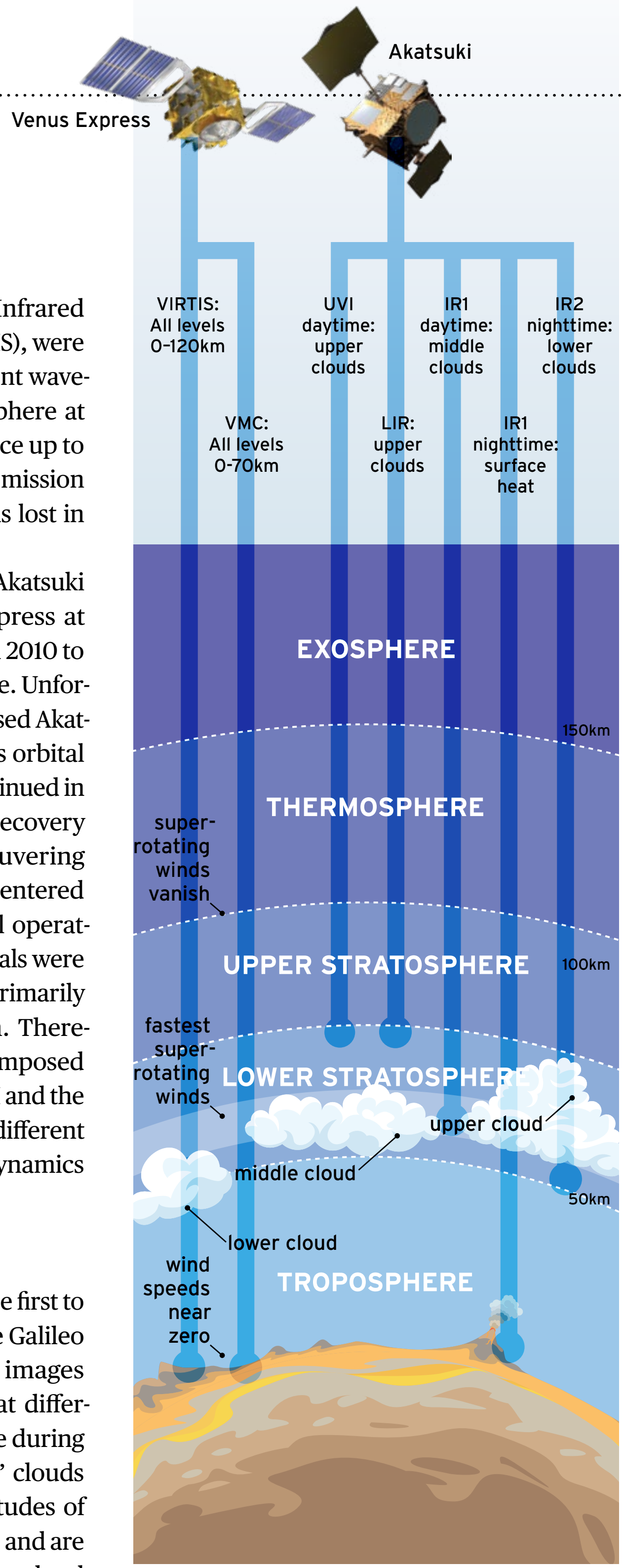
Deep, Dynamic Currents Revealed by Venus Express and Akatsuki

VENUS' APPEARANCE is deceptive. The history of scientific research about Venus is full of mistaken assumptions that are sooner or later refuted by new observations. Ancient civilizations wrongly interpreted the morning and evening stars as 2 stars. Giovanni Cassini claimed to have observed moons. More recently, scientists assumed that Venus' reflective clouds prevented solar energy from reaching its surface, leaving it cold. Its surface is actually hotter than Mercury's surface. Even today, sophisticated numerical models that work to predict the behavior of atmospheres on other planets are unable to reproduce even basic properties of the atmosphere of Venus.

Consider one particular mystery. Why, when Venus is the slowest-rotating planet in the solar system, does its atmosphere whirl around it at 300 kilometers (200 miles) per hour, 60 times faster than the planet's spin? Understanding this atmospheric superrotation has become a more urgent goal in recent decades because it also happens on Titan and even in exoplanetary atmospheres, especially those tidally locked to their stars.

NEW ORBITERS

More than 20 space missions visited Venus from 1962 to 1999, but there was a long gap in orbital missions after NASA's Magellan entered the atmosphere in 1994. Finally, in 2006, European Space Agency's Venus Express arrived, initiating 2 decades of breakthroughs in Venus science. Venus Express carried 5 instruments that could measure the temperature of the atmosphere from 40 to 170 kilometers (25 to 106 miles) above the surface. Two of them, the Venus Monitoring



LEFT *Venus Express orbited Venus from 11 April 2006 to 18 January 2015. Its Venus Monitoring Camera (VMC) had 4 ultraviolet to infrared filters that enabled it to probe from the surface to an altitude of 70 kilometers (43 miles), above the clouds. Its Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) had hundreds of channels and saw all levels of Venus' atmosphere, from 0 to 120 kilometers (0 to 75 miles). Akatsuki arrived on 7 December 2015, bringing an ultraviolet imager (UVI), a pair of near-infrared cameras (IR1 and IR2), and one longwave infrared camera (LIR). UVI sees the daytime upper clouds in reflected sunlight. LIR sees the upper clouds' radiant heat at a wavelength where there is little incoming solar energy. IR1 sees sunlight reflecting from the middle clouds on the dayside-and heat emanating from the surface on the nightside. IR2 sees the opacity of the lower clouds as they are silhouetted against heat emanating from the surface and deep atmosphere.*

Emily Lakdawalla and Loren A. Roberts for The Planetary Society

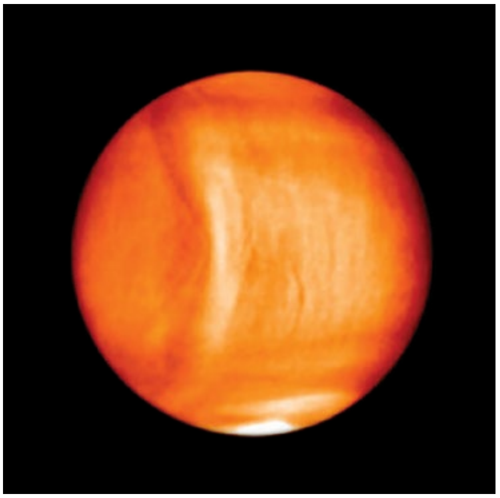
Camera (VMC) and the Visible and Infrared Thermal Imaging Spectrometer (VIRTIS), were able to take images of Venus at different wavelengths and thus observe the atmosphere at different vertical levels from the surface up to about 120 kilometers (75 miles). The mission operated for 9 years until contact was lost in November 2014.

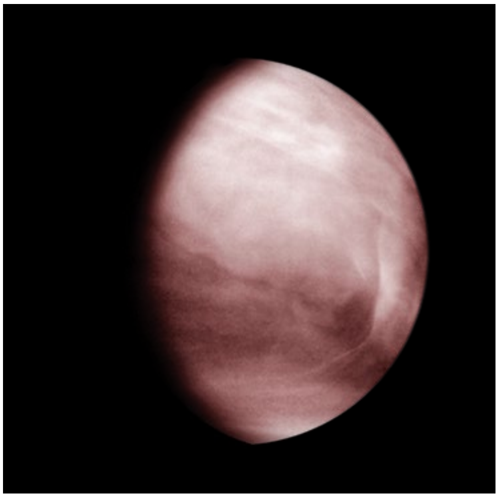
Japan Space Exploration Agency's Akatsuki launched in 2010 to join Venus Express at Venus, targeting an equatorial orbit in 2010 to complement Venus Express' polar one. Unfortunately, an obstruction in a valve caused Akatsuki's main engine to break during its orbital insertion attempt. The spacecraft continued in a solar orbit. There followed an epic recovery effort using the spacecraft's maneuvering thrusters, and Akatsuki successfully entered orbit on 7 December 2015 and is still operating. While Venus Express' scientific goals were wide ranging, Akatsuki's goals focus primarily on the conundrum of superrotation. Therefore, Akatsuki's payload is mainly composed of cameras (the ultraviolet camera UVI and the infrared cameras IR1 and IR2) whose different filters observe the morphology and dynamics of clouds at multiple levels.

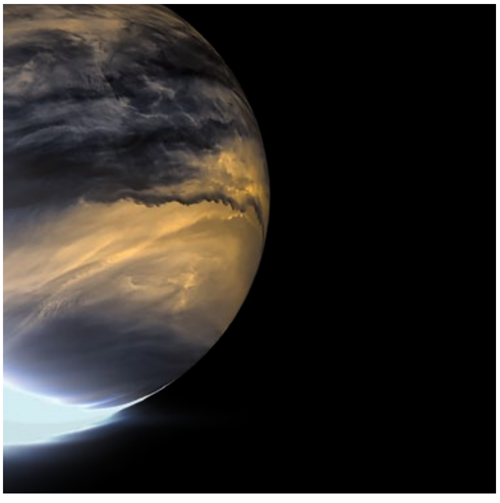
CLOUDS UPON CLOUDS

Although NASA's Pioneer Venus was the first to try to study different cloud levels, the Galileo Jupiter mission achieved the first images showing different cloud structures at different altitudes on dayside and nightside during its flyby on 10 February 1990. Venus' clouds float in its troposphere between altitudes of 47 and 70 kilometers (29 and 43 miles) and are divided into lower, middle, and upper cloud layers. The upper clouds of Venus are of major interest for several reasons: first, because most of Venus' absorption of solar energy occurs in these clouds; second, because the superrotation reaches its fastest speeds precisely at the top of the upper clouds; and third, because the upper clouds possess high concentrations of a mysterious absorber-an unknown atmospheric constituent chemical responsible for more than half of the solar energy absorbed by Venus.

Akatsuki's UVI is uniquely capable of studying the topmost clouds, with one filter that is more sensitive to the distribution of the mysterious absorber, making its presence known as dark streaks on ultraviolet images.







TOP *Just after it entered orbit, Akatsuki's LIR camera spotted an enormous stationary wave running completely across the globe from north to south on Venus. The camera sees heat emanating from Venus' uppermost clouds, day or night.*

MIDDLE *Akatsuki's IR1 camera is specially designed to penetrate beneath the upper clouds and image the middle cloud deck, whose patterns are intriguingly variable. Akatsuki's images have revealed patterns that vary with time and from one side of Venus to the other and has seen the superrotating winds change speed by as much as 20 meters per second (about 25 percent) from year to year.*

BOTTOM *Akatsuki's IR2 camera relies on heat emanating from the lower atmosphere of Venus to image the nightside lower clouds. The infrared radiation originating beneath the clouds silhouettes the lowermost cloud deck, so areas of thicker cloud appear darker in this photo. At lower left, the camera's detector is overwhelmed by the brilliance of sunlight reflecting off the daylit crescent.*

JAXA/DARTS/ISAS; bottom image JAXA/DARTS/ISAS/Damia Bouic

Examining both missions' data, Yeon Joo Lee (Technische Universität Berlin) discovered that the reflectivity of the upper clouds of Venus varies over time. The variation might result from changes in the abundance of the unknown absorber and affects the capacity of the atmosphere to absorb solar energy. This could be the first detection of climate change at another planet.

Months before Akatsuki's arrival, Toru Kouyama (of IAST, Japan) and I discovered (independently, Kouyama using NASA's Infrared Telescope Facility and myself using Venus Express' VIRTIS) that some cloud patterns on Venus kept still despite the strong winds at high altitudes. We interpreted the cloud patterns to be stationary waves in the atmosphere called Lee waves, which happen where winds encounter obstacles like high mountains. Our findings were confirmed right after the orbit insertion of Akatsuki, when the very first image acquired by its longwave infrared (LIR) instrument contained the largest stationary wave ever spotted in the solar system.

Why are stationary waves in high clouds important? Their presence suggests that momentum and energy can be transported from Venus' surface, 70 kilometers (43 miles) below, to the superrotating atmosphere. However, this discovery creates more puzzles than it solves. The Soviet Venera landers measured only very slow winds of 2 to 3 kilometers (1 to 2 miles) per hour at the surface. How can that connect to such high speeds at high altitudes? Even more puzzling is that VIRTIS sees stationary waves in the upper clouds but does not see them in simultaneous observations of the lower clouds.

These middle clouds, located at a height of 50 to 56 kilometers (31 to 35 miles), have contained other surprises for us. They appeared featureless to Galileo in 1990 but have shown

Born in Algeciras, Spain, **JAVIER PERALTA** *is an astrophysicist who studies waves and cloud dynamics in Venus' atmosphere. He has experience in analysis of Venus Express data but currently holds as an International Top Young Fellowship on the Akatsuki mission.*

intriguing patterns to Akatsuki's IR1. Their surprisingly varied brightness suggests there is some other atmospheric absorber in the middle clouds, a hypothesis supported by measurements from infrared instruments on Venus Express and NASA's MESSENGER, which studied Venus during a flyby in June 2007. We have a lot to learn about Venus' atmospheric chemistry and how it varies with altitude.

Both Venus Express and Akatsuki imaged the lower clouds (from 47 to 50 kilometers or 29 to 31 miles) on Venus' nightside and found patterns that are strikingly different from the upper clouds. The clouds are more opaque near the equator, giving Venus a dark band in Akatsuki IR2 images, and more transparent (lighter) toward the poles. Impressive phenomena lie along the border between the equatorial band and the midlatitude bands, where shear makes billows and vortices, patterns like those seen on Jupiter. At Jupiter, these vortices are caused by the Coriolis effect. Venus rotates so slowly that its vortices can't have the same cause.

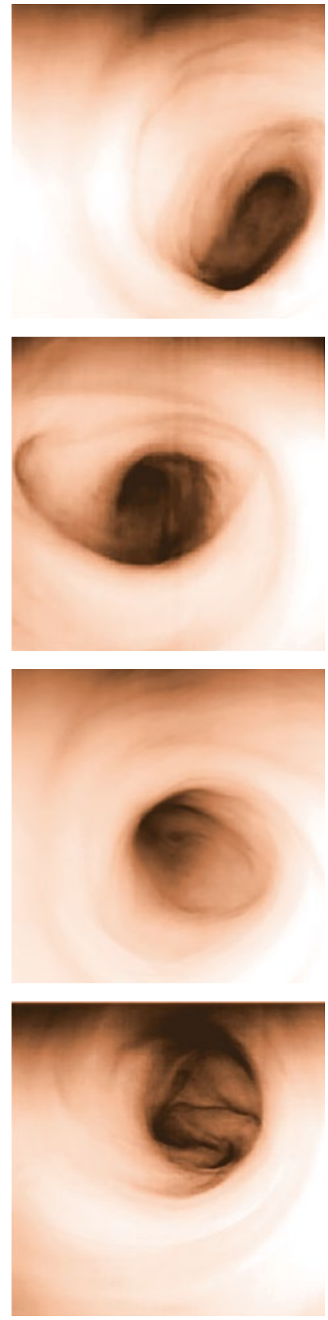
Venus Express' polar, elliptical orbit gave it brief, very close views of intricate cloud patterns at the north pole and distant views taking in the entire southern hemisphere. On each orbit, VIRTIS stared for hours at a vortex that whirls over Venus' south pole. We discovered that its shape changes rapidly from a dipole to a tripole to a circle in a matter of days. Itziar Garate-Lopez (UPV/EHU, Spain) used VIRTIS to map the vertical structure of the south polar vortex and found it to be both tall and deep: it extends up to an altitude of 80 kilometers (50 miles), while its base lies at 55 kilometers (34 miles) or perhaps deeper. Intriguingly, the vortex's location in the upper and lower clouds can be different, so its 3-dimensional structure might be helix-shaped.

WINDING WINDS

The unknown absorber in Venus' clouds helps us measure the speed of its winds through the tracking of cloud features seen in multiple ultraviolet images. We can also measure instantaneous wind speeds with spacecraft or ground-based spectrometers by examining how features in atmospheric spectra are Doppler-shifted by the fast motion of the atmosphere. Venus Express and Akatsuki's monitoring have together produced more than 4 million cloud-tracking measurements.

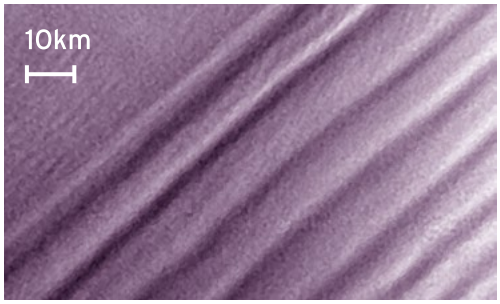
Venus Express discovered that the velocity of the superrotation at the dayside upper clouds increased from 300 to about 380 kilometers (190 to 240 miles) per hour from 2006 to 2013. Akatsuki observed that wind speeds had decreased again by 2016, though not to their 2006 levels. This behavior correlates well with the changes in brightness of the upper clouds. The correspondence strongly suggests that the solar tides are a main cause of the superrotation. When there is more of the unknown absorber in the clouds, the atmosphere absorbs more incoming solar energy, powering faster winds. In contrast, the winds within the dayside middle clouds seem to keep more constant over time.

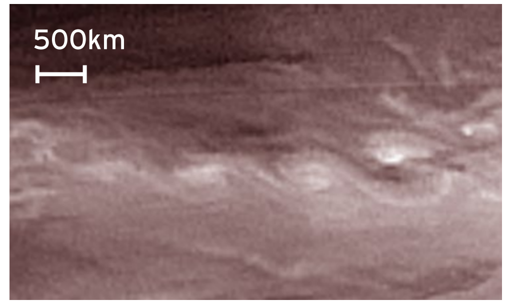
The 2 spacecraft have produced a less-continuous record in the lower clouds because the longer-wavelength infrared instruments capable of observing at this altitude (the infrared channel of VIRTIS on Venus Express and the IR2 camera on Akatsuki) both failed after fulfilling their expected lifetimes. VIRTIS studied the clouds from 2006 to 2008, finding that the wind speeds did not vary with latitude during that time period (although they did vary with time). However, when Akatsuki observed the lower clouds in 2016, Takeshi Horinouchi of Hokkaido University discovered that a jet with much faster wind speeds is sometimes present at the equator. This recurrent jet might explain the billows and vortices observed in the lower clouds. We combined Venus Express and Akatsuki data with low-cloud data from Galileo, NASA's Pioneer Venus entry probes, Soviet VEGA balloons, and numerous ground-based observations to reconstruct the equatorial wind speeds from 1978 to 2017 and found that their speed has varied by more than 100 kilometers (60 miles) per hour in that time.

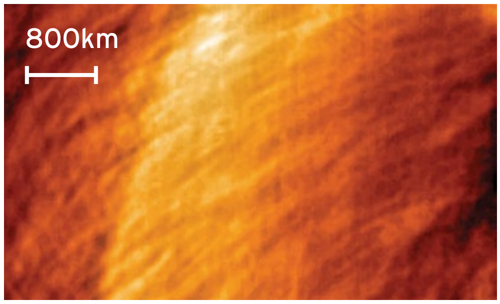


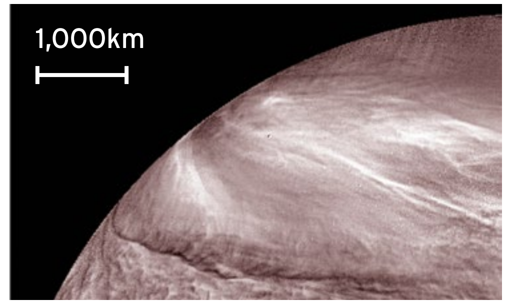
ABOVE *Venus Express' VIRTIS revealed a maelstrom at the south pole–a whirling storm that punches a deep hole into the upper clouds.*

ESA/VIRTIS/INAF-IASF/Obs. de Paris-LESIA









Venus' multilayered atmosphere abounds with fascinating cloud patterns.

TOP LEFT *An ultraviolet image taken by Venus Express' VMC on 10 May 2010 shows gravity waves in Venus' upper clouds–ripples along surfaces where atmospheric density changes with altitude.*

TOP RIGHT *Akatsuki's IR2 imaged well-developed vortices within Venus' lowermost clouds just south of the equator on 13 August 2016.*

BOTTOM LEFT *This is the highest-resolution image of stationary waves in Venus' nightside upper clouds, taken by Venus Express' VIRTIS on 7 May 2008.*

BOTTOM RIGHT *On 1 July 2016, Akatsuki's IR2 saw sharp, dark stripes edging the nightside lower clouds for distances of thousands of kilometers. These are some of the longest cloud patterns ever spotted on Venus.*

Top left: ESA; bottom left: ESA/VIRTIS/INAF-IASF/Obs. de Paris-LESIA; both right: JAXA/ISAS/DARTS

To get a more complete picture of the 3-dimensional circulation of Venus' winds through all levels of the nightside and dayside of Venus, we had help from the worldwide campaign of observations organized for the second Venus flyby of MESSENGER in June 2007. We performed feature tracking on images from Venus Express, MESSENGER, and amateur observations with small telescopes. We obtained Doppler wind speeds from spectra taken at large, ground-based telescopes, and we predicted wind speeds using temperature measurements from orbit and ground. We learned that the atmospheric circulation on the nightside of Venus is surprisingly different from the dayside.

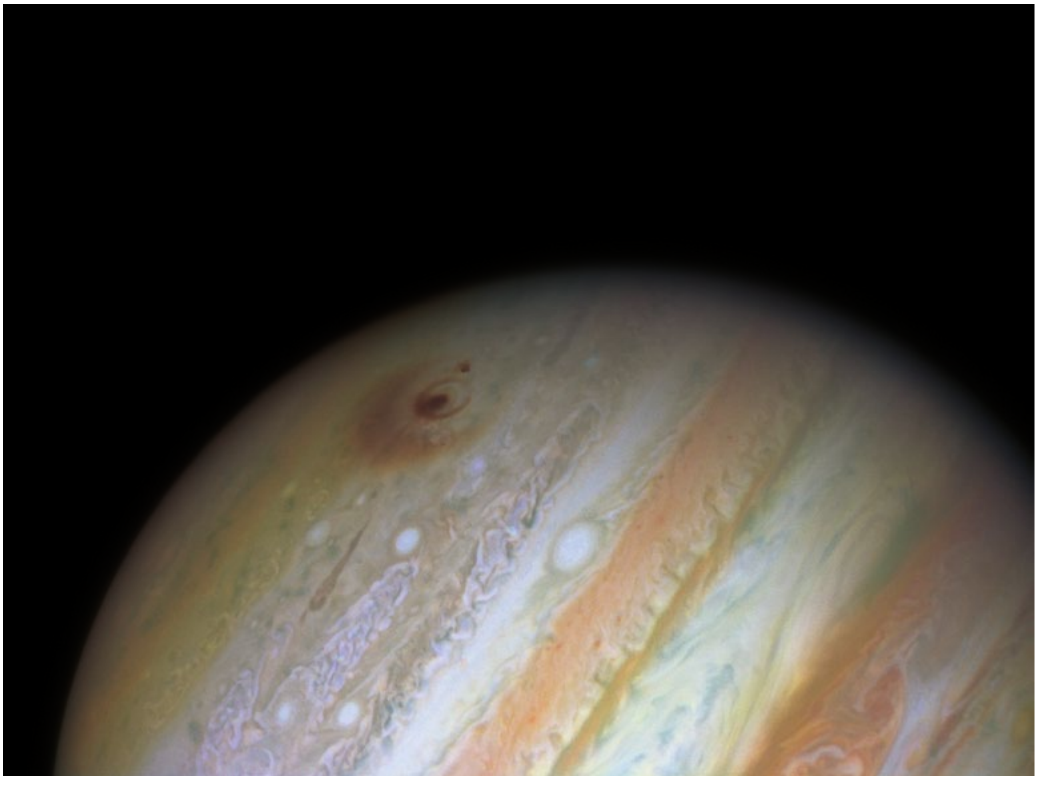
With VIRTIS, we were able to image the upper-level clouds on the nightside with high resolution for the very first time. Our measurements revealed that superrotation on the nightside, rather than being homogeneous like on the dayside, sometimes becomes chaotic, with wind speeds as slow as 70 kilometers (43 miles) per hour in some places. VIRTIS was also able to observe a particular emission from oxygen molecules that occurs at an altitude of about 100 kilometers (60 miles) on the nightside well above the clouds, where superrotation is supposed to vanish. Ricardo Hueso (UPV/EHU, Spain) and Dmitry Gorinov (Space Research Institute, Russia) performed enormously challenging tracking of these fast airglow emissions and confirmed that at this altitude, the east-to-west superrotation is replaced by another mean circulation called "solar to antisolar." As is hypothesized to happen on hot Jupiter exoplanets tidally locked to their stars, Venus' highest-altitude winds blow from the area where solar insolation is maximum (the subsolar point) to the antipode at the antisolar point.

WHAT'S NEXT?

In the short term, worldwide campaigns of observations are being prepared to coordinate with the Venus flybys of the ESA/JAXA Mercury mission BepiColombo in October 2020 and August 2021 and probably also NASA's Parker Solar Probe in December of this year. However, despite all we have learned from more than 60 years of spacecraft study, there are critical gaps in our knowledge of Venus' atmosphere.

We know almost nothing about the deep atmosphere of Venus below 40 kilometers (25 miles), which contains more than 75 percent of the total mass of the atmosphere and controls the interaction between the surface and the atmosphere. Only in situ measurements from probes and landers can provide information for this region. Descent probes and short-lived (1 hour) and long-lived (1 year) landers have been proposed; more futuristic projects consider low-altitude balloons or surface rovers. New missions capable of making in situ measurements after a gap of more than 30 years will likely change our view of the planet all over again. After all, Venus' appearances are deceptive.

VISHNU REDDY *is an associate professor at the Lunar and Planetary Laboratory, University of Arizona, Tucson.*



LEFT *Fragments of comet Shoemaker-Levy 9 crashed into Jupiter over a period of several days in July 1994. The relatively fresh fragment G impact on 18 July produced the concentric set of scars: an inner dark circle, an outer thin ring, and an outermost diffuse ring. Fragment D, which impacted 2 Jupiter days prior, is responsible for the small dark circle above the fragment G scars.*

Data: H. Hammel, MIT, and NASA; Processing: Judy Schmidt

The State of Planetary Defense

How Well Does Earth Understand the Impact Hazard?

JULY 1994 WAS A sobering time for planetary scientists. That's when fragments of comet Shoemaker-Levy 9 slammed into Jupiter, creating Earth-scale "powder burns" in the planet's atmosphere that could be seen even with backyard telescopes. The score of impacts over a week's time served to remind us that impacts from asteroids and comets are a real threat to life on Earth.

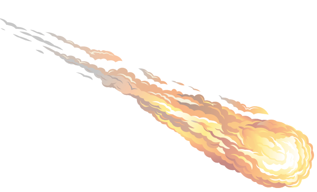
That same year, the U.S. Congress tasked NASA with discovering 90 percent of all near-Earth objects (NEOs) larger than 1,000 meters within a decade. Such an object, were it to hit our planet, would cause continent-scale devastation. Fortunately, telescopic searches accomplished this goal in a little more than a decade. Then, in 2005, Congress issued a new challenge to NASA: discover 90 percent of NEOs with diameters larger than 140 meters by 2020. Colliding with an asteroid of this size would likely cause significant damage over a large region of a single continent or create a tsunami of unprecedented devastation were it to strike an ocean.

As the deadline for this congressional mandate approaches, observers have cataloged only about a third of the estimated 25,000 NEOs larger than 140 meters and will almost certainly fall short of the 90 percent goal by next year. However, it's not for lack of trying. In fact, between 2009 and 2014, Congress increased NASA's budget for NEO searches tenfold–from $4 million to $40 million. However, objects this small are

The Hazard by the Numbers




ASTEROID SIZE	Bigger than **3 meters**	Bigger than **30 meters**	Bigger than **140 meters**	Bigger than **1,000 meters**
HOW OFTEN DO THEY HIT EARTH?	About once a year	About 1 time in every 100 years	1 in 100 chance in every 100 years	1 in 50,000 chance in every 100 years
WHAT HAPPENS IF THEY HIT WHERE HUMANS CAN WITNESS THE IMPACT?	Bright flash in the sky; worrying to some, entertaining to others, with no ground effects	If it's porous, a big air burst (like Tunguska); if it's solid metal, kilometer-size crater (like Barringer meteor crater); deadly over a city-size area but most likely to impact a location with few to no inhabitants	A crater of a few kilometers, devastating a country-sized area and causing mass casualties worse than any natural disaster in recorded history	A crater of 10 kilometers or more; global devastation and possible collapse of civilization
HOW MANY OF THEM DO WE THINK ARE OUT THERE?	About a billion objects between 3 and 30 meters in diameter	About a million objects between 30 and 140 meters in diameter	About 16,000 objects between 140 and 1,000 meters in diameter	About 1,000 objects larger than 1,000 meters in diameter
HOW MANY OF THEM HAVE WE FOUND?	0% of the 3-meter size; 0.02% of the 10-meter size	1.4% of the 30-meter size; 25% of the 100-meter size	40% of the 140-meter size; 77% of the 500-meter size	81% of the 1,000-meter size; 100% of objects 6.5 km and larger. The largest NEO, 1036 Ganymed, is about 35 km.



Teach yourself about the hazard! Take our **Asteroid Defense 101** class at **courses.planetary.org**.

Volunteer to educate your community with our **Planetary Defense Toolkit**, available at **planetary.org/volunteer**.

usually spotted only when they pass close to Earth, and it takes many years for all of them to be spotted with existing technology.

Leading these discovery efforts are 3 ground-based searches. The Catalina Sky Survey, based at the University of Arizona, has discovered roughly 50 percent of the 20,000 known NEOs. The University of Hawai‘i runs a program called Pan-STARRS (short for Panoramic Survey Telescope and Rapid Response System) that has found about 5,000 objects.

Complementing these two large surveys is ATLAS, the Asteroid Terrestrial-impact Last Alert System, whose 2 telescopes on the island of Maui cover 25 percent of the entire sky every clear night. Those scans serve as an early warning system because they're able to spot asteroids as small as 30 meters across that are within 1.5 million kilometers (a million miles) of Earth.

Once a NEO is discovered, it's critical to determine its orbit with enough precision to be able to predict where it'll be for decades into the future. Many NEO discoveries are followed up by other instruments ranging from huge professional telescopes to modest backyard setups operated by amateur astronomers.

Sometimes, objects in Earth's vicinity can be observed using radar, particularly the 70-meter-wide dish at NASA's tracking station at Goldstone, California and the 305-meter-wide dish at Arecibo Observatory in Puerto

VISHNU REDDY's *research focuses on understanding the behavior of space objects—both artificial and natural—in Earth orbit and beyond. He currently works on the OSIRIS-REx, NEOCam, and DESTINY+ missions and was a Dawn team member.*

Illustrations: Don Davis; Emily Lakdawalla and Loren A. Roberts for The Planetary Society

Rico. By bouncing microwaves off the surface of nearby asteroids, astronomers can measure precisely how far away they are and how fast they're passing by, key factors in refining their orbits.

MORE THAN JUST A DOT

While surveys discover what's out there, follow-up observations can characterize NEOs to determine of what they are made, how fast they spin, and something about their size, shape, and reflectivity. For example, merely recording how an object's apparent brightness changes with time can yield its spin rate. Astronomers have found that the fastest-rotating NEO spins once every 16 seconds, and the slowest takes more than 78 days to finish one round on its axis.

Most observations cannot resolve NEOs, so they appear as star-like dots in images. However, radar-equipped radio telescopes can create "maps" of the radar echoes' round-trip time vs. Doppler shift, pseudo pictures that reveal an asteroid's size, shape, spin rate, surface properties, and even surface features such as craters. The giant Arecibo dish has the most powerful radar system in the world, but it can only see a fraction of the sky. NASA's Goldstone radar system, though smaller and less powerful, can observe a larger swath of sky. Together, these facilities typically observe roughly 100 NEOs per year.

Two other key characterization assets observe passing objects at wavelengths beyond the range of human vision. NASA's Infrared Telescope Facility (IRTF) atop Mauna Kea in Hawai`i uses a workhorse instrument called SpeX to record the near-infrared wavelengths reflected from an asteroid's surface. These spectra reveal the composition of passing NEOs.

The second asset is NASA's NEOWISE spacecraft. Originally an astrophysics mission dubbed the Wide field Infrared Survey Explorer (WISE), it once observed the entire sky in 4 infrared bands. Once WISE's coolant was depleted 10 months after launch, it could no longer observe at the longest-wavelength bands, but the spacecraft itself remained healthy and could still observe at 2 shorter-wavelength bands in which solar-system objects radiate energy. Astronomers could combine NEOWISE's measurements with visible-light images from ground-based telescopes to determine the diameters for nearly 200,000 different asteroids and comets, including several hundred NEOs.

WHAT'S THE (DEFENSIVE) PLAN?

Suppose an asteroid was discovered hurtling directly at Earth. What could we do to protect our planet? Space officials at NASA and elsewhere continue to debate the best ways to deflect a rogue asteroid headed our way. Some schemes involve gently nudging the object onto a path that no longer collides with Earth, while others envision breaking it up into harmless pieces.

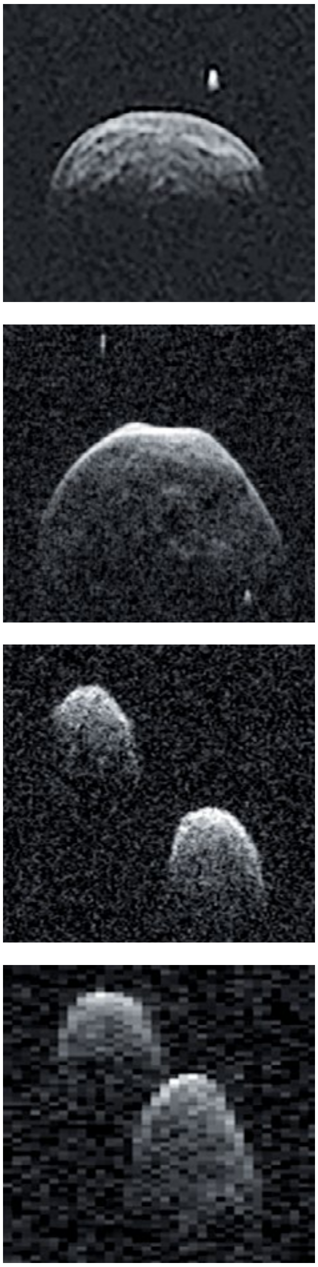
However, no defensive strategy is "battle ready" unless it has been tested in a real-life scenario. NASA has partnered with other federal agencies such as the Federal Emergency Management Agency (FEMA) to conduct "what-if" exercises involving hypothetical impactors.

In 2017, the United Nations-endorsed International Asteroid Warning Network (IAWN) conducted a global planetary-defense exercise involving a real asteroid known as 2012 TC4 that zipped past Earth on 12 October 2017 at a distance of just under 44,000 kilometers (27,200 miles). The goal was to recover, track, and characterize TC4 as a potential impactor using a global network of observations, modeling, prediction, and communication. In all, more than 70 people representing 14 countries participated in the exercise.

Unfortunately, at that time, the Arecibo radar system was offline due to damage it sustained just weeks earlier during Hurricane Maria, and the IRTF in Hawai`i had a power failure on the night of the flyby that prevented

ABOVE *Near-Earth asteroids come in all shapes, from round (2005 YU55) to faceted (2017 BQ6) to lumpy (2017 CS) to very lumpy (2014 JO25). Their shapes are revealed by radar images made by bouncing radio signals off the objects when they fly past Earth.*

NASA/JPL/GSSR



ABOVE *A surprising number of near-Earth asteroids are multiples. There are binaries (2004 BL86) and even triple asteroids (3122 Florence). Most have small moonlets orbiting bigger main bodies, but some have near-equal-size components (2017 YE5). Occasionally, the two bodies approach each other, forming a contact binary (1999 JD6).*

NASA/JPL/GSSR

it from collecting observations when the object was at its brightest. The big dishes at Goldstone and at Green Bank, West Virginia collected excellent radar data. Most of the campaign was successful, with seamless coordination and sharing of results in real time. Using all the observational information collected during the exercise, scientists ran risk assessments to determine the likelihood and consequences of an actual collision. The takeaway of this real-world exercise is that the extent of damage will depend on the object's mass and therefore its composition and size.

Building on the lessons learned from the TC4 campaign, NASA and IAWN conducted another planetary-defense exercise on 27 May 2019 with a binary near-Earth asteroid known as 1999 KW4. Unlike TC4, which was less than 20 meters in diameter, the primary KW4 body is 1,300 meters across, and its moon is 400 meters. Since its close flyby, scores of astronomers worldwide have been working to characterize this binary system and understand how to mitigate an impact from two bodies. (Earth's cratering record shows that about 1 in 7 impacts are from binary asteroids.)

KNOW THY ENEMY

Astronomers now realize that simply knowing the whereabouts of a threatening asteroid (or comet) is not enough. For any planetary-defense strategy to succeed, we'll need to know as much as possible about any potential impactor.

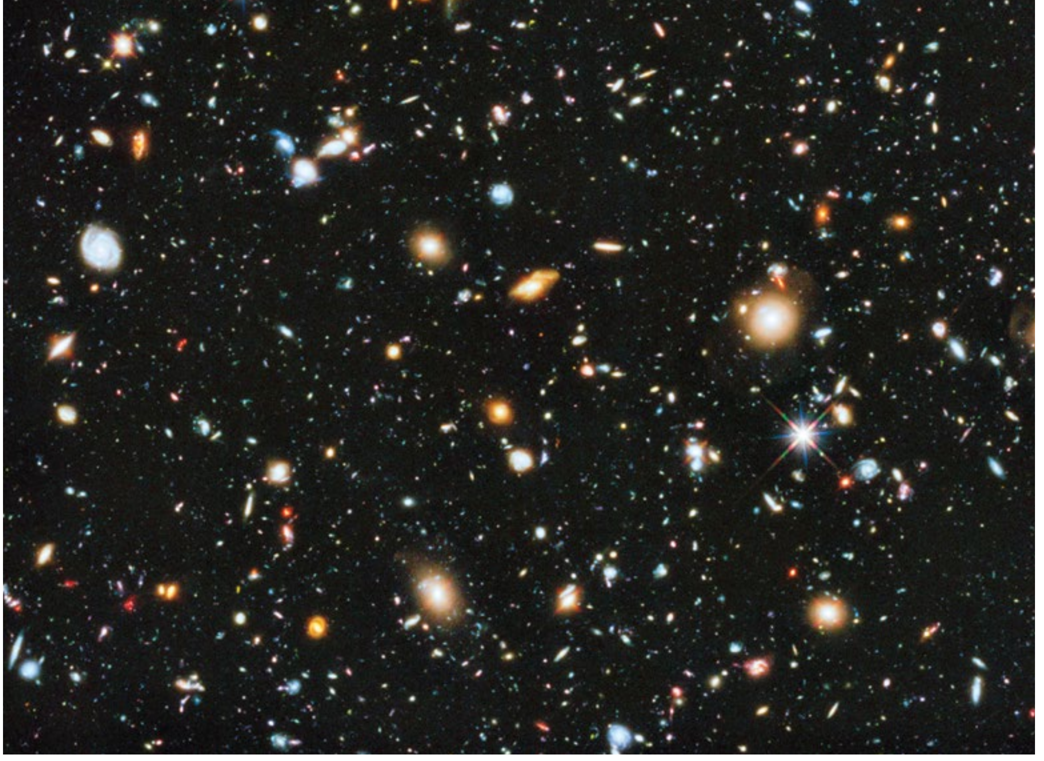
To that end, NASA and European Space Agency have teamed up for a 2-spacecraft mission called Asteroid Impact and Deflection Assessment (AIDA). The target is 65803 Didymos, a binary NEO that consists of a main body roughly 800 meters across and a much smaller moon that circles every 11.9 hours.

The current plan calls for NASA to dispatch a spacecraft named Double Asteroid Redirection Test (DART), which will launch in 2021 and strike the asteroid's moon in October 2022. The collision should change the companion's orbit in a measurable way and thus help determine whether such "kinetic impactors" offer a practical means of defense. Then, if it gets funded later this year, ESA's spacecraft, called Hera, should begin orbiting the Didymos system in 2026 and assess not only the change in the moon's orbit after DART's hit but also the characteristics of both bodies.

Another project awaiting funding is NASA's NEOCam mission. With heritage from NEOWISE, this new spacecraft would be positioned at a gravitationally stable Lagrange point between Earth and the Sun. From that vantage point, NEOCam's infrared detectors would scan ahead and behind Earth's orbit, where ground-based observatories struggle to discover objects, and potentially find two-thirds of the missing 140-meter-wide NEOs as well as large numbers of smaller objects during its 5-year primary mission. The National Academy of Sciences released a report on NEO surveying and recommended that NASA fund a space-based infrared survey telescope to accomplish the congressional mandate.

While not a spacecraft, the Large Synoptic Survey Telescope (LSST) should make major contributions to the discovery of NEOs once it begins science operations in late 2022. Funded by the Department of Energy and the National Science Foundation, LSST's 8-meter-wide optics will scan the entire observable sky several times per month using detectors that can record very faint objects. Astronomers expect it to discover large numbers of NEOs and main-belt asteroids.

Clearly, planetary scientists are working hard to achieve the congressional mandate of discovering 90 percent of all Earth-threatening NEOs, even if it takes beyond 2020 to do so. Meanwhile, they're trying to learn as much as possible about not only those objects that might someday strike our planet but also asteroids and comets in general. Identifying those celestial threats and creating dependable ways to defend against them will be an evolving effort that extends decades into the future. However, it's reassuring to know that the first steps are well underway.



Welcoming the Unknown

I EXPLORE SPACE because I like feeling insignificant. I crave a dark night sky that reminds me that our Sun and even our galaxy are not unique. I find comfort in thinking about countless generations of humans looking at the same sky and asking questions similar to the ones I ask. I delight in the images sent back from distant explorers that reveal faraway worlds, many of which look much like our own. I look forward to one day seeing images of exoplanets that may make our Earth seem ordinary.

I recognize that this desire to feel insignificant may seem counterintuitive. I liken the feeling to mediation or prayer. When I remember that I am one of billions of people living on this planet that is orbiting one of billions of stars in our galaxy that is one of billions of galaxies in our universe, I find perspective. When I immerse myself in the wonders and mysteries of the cosmos, I feel the sharp edges of daily life soften, and I feel part of something immense, eternal, and beautiful. The more I recognize that my experience on Earth is barely a blip on the cosmic timeline, the more inspired and more empowered I feel to do my best while I'm here.

I first remember noticing this feeling when I was 25 years old and experiencing my first serious family health crisis. My world suddenly seemed unfamiliar, and the unknown events ahead of me felt overwhelming. It was fall in the northern hemisphere, and I had a long, overnight car ride to reach my family. On that journey, my old friend Orion showed up in the night sky to greet me, and he, along with all his celestial friends, not only kept me company on the drive, but that familiar, welcoming sky helped ground me and prepare me to face the hours, days, and weeks ahead.

In that time of stress, I discovered a new personal passion. I wanted to know more about space and expose myself to a broader perspective. I began to learn about stars and then planets, which led me to The Planetary Society, where I'm surrounded by opportunities to welcome the unknown, lean into my curiosity, revel in the joy of discovery, and find deep significance in feeling insignificant.

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WHY I EXPLORE *Planetary Society members are explorers. We share this common passion, although we have different stories that drive our passion. I'm curious to know your story. If you'd like to share, we've set up a form at* **planetary.org/whyexplore***, where you will also be able to read other "Why I Explore" stories. We'll also continue to share stories in future issues of* The Planetary Report.

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astronomical art

Mark Garlick, *Molten Planet CoRoT-7b*

Celebrated as the first rocky exoplanet to be discovered (in 2009), CoRoT-7b orbits a Sun-like star. Apart from that, it is nothing like Earth. The planet circles its star so closely that its sun-facing surface is probably molten lava. It is likely tidally locked, making the dayside permanently molten and the nightside permanently frigid. Daytime temperatures on the planet may reach 2,000 degrees Celsius (3,600 degrees Fahrenheit) but may drop to -200 Celsius (-330 Fahrenheit) on the nightside. It may have begun its existence as a more distant and massive gas giant, like our solar system's Saturn. However, CoRoT-7b's orbit has shrunk and is now only a sixtieth of Earth's distance from the Sun. As a result, CoRoT-7b lost its original gaseous envelope; all that is left now is its rocky former core.