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THE SOLAR SAILING ISSUE

HOW SUNLIGHT WILL PROPEL
SPACE EXPLORATION FURTHER

THANK YOU, LIGHTSAIL

A mission that fulfilled decades of dreaming

by Bill Nye

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IT'S BEEN A FEW MONTHS now since The Planetary Society's beloved LightSail 2® burned up in Earth's atmosphere. We hoped for just one year up there, and our little spacecraft flew for three and a half! It was a huge success. And thanks to the mission team — that includes you, fellow member — LightSail 2's impact will continue well into the future as we analyze the data and share them with other engineers and scientists in the spacefaring community.

The LightSail program is part of us, part of The Planetary Society. As early as 1976, before the Society was founded, Lou Friedman and Carl Sagan very much wanted to fly an enormous solar sail, almost a kilometer long on each side. Its 10-year objective was to catch up to comet Halley and collect pictures and data up close. I was in Professor Sagan's class in the spring of 1977 when he talked about this idea enthusiastically. NASA did not choose the comet Halley mission, favoring human spaceflight instead. Decisions like that led Carl, Lou, and Bruce Murray to form the Society and to keep the dream of solar sailing alive.

Years later, around 2001, we had the opportunity to participate in a solar sail mission: Cosmos 1. As you probably know, in

2005, our Cosmos 1 managed to get a ride on a Cold War-era Russian rocket. It never made it to orbit. It's somewhere at the bottom of the Barents Sea, a region of the Arctic Ocean. But the dream of sailing on sunbeams lived on.

At last, we had enough support to fund an ambitious solar sail spacecraft of our own. It was funded by our members before the word "crowdfund" was even coined. The LightSail program began in 2009, the year before I became executive director (now I'm called the CEO). I often reflect (I guess that's a photon pun) on my history here. Solar sail missions have been a big part of my job here ever since I became a member of the board of directors in 1997. All this time, through all the ups and downs inherent in developing a completely new technology, we've been able to keep working at it thanks to the support of members like you. It really is your mission, and I hope you feel as proud of LightSail 2 — and even its test flight, LightSail 1 — as I do.

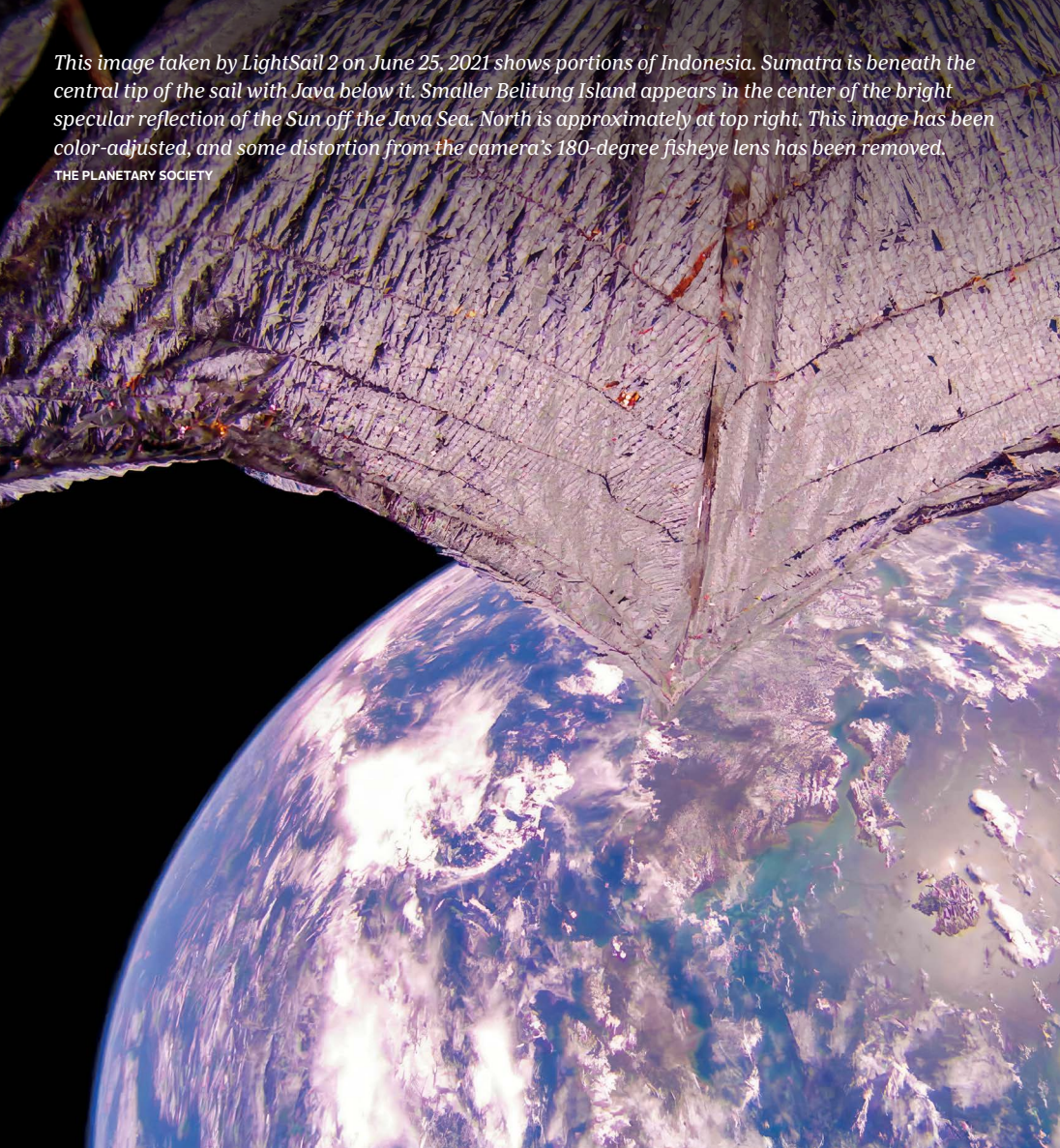
The big question now is: What's next? Well, LightSail 2 is going to continue to teach us about solar sailing from beyond its fiery end. We'll keep analyzing, sharing, and learning from the data sent down to Earth by both of our LightSail missions. Rest assured, new solar sailing missions will build on what LightSail 2 taught us. NASA's

ON THE COVER: This image taken by The Planetary Society's LightSail 2 spacecraft on Oct. 24, 2022 was the final image returned from the spacecraft before atmospheric reentry. It shows the central portion of South America centered approximately on Bolivia, including the large white Uyuni Salt Flats. *Image: The Planetary Society* * 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 the 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. ©2023 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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This image taken by LightSail 2 on June 25, 2021 shows portions of Indonesia. Sumatra is beneath the central tip of the sail with Java below it. Smaller Belitung Island appears in the center of the bright specular reflection of the Sun off the Java Sea. North is approximately at top right. This image has been color-adjusted, and some distortion from the camera's 180-degree fisheye lens has been removed.

THE PLANETARY SOCIETY



Near-Earth Asteroid (NEA) Scout mission flew aboard the Artemis I rocket. It made it to space, but something went wrong. To the NEA Scout mission team, we say, "Stick with it." We've been there and learned. You will hear more about this mission and a few other new solar sailing missions in this issue of The Planetary Report.

Beyond the technical applications of what LightSail 2 taught us, the success of this crowdfunded mission shows what's possible when people who love space come together to do something big. I can't say it enough: As a Planetary Society member, be very proud of your role in the LightSail 2 mission. Our organization is showing the world that people believe in the value of space exploration and can

come together to make innovative missions like LightSail happen.

Although this mission's culmination is bittersweet, there's plenty more for us to look forward to. Our STEP Grants (Science & Technology Empowered by the Public), which you'll read about in this issue, continue to fund game-changing science and technology projects, all thanks to member and donor support. And we'll continue to find new projects that give you a front-row seat in the adventure of exploration and discovery. 🚀

Bill Nye



BILL NYE is chief executive officer of The Planetary Society.

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HARNESSING THE POWER OF THE CROWD

The Planetary Society has a long history of helping the public make progress in space exploration

by Kate Howells

A LOT OF THE DISCUSSION around the impact of The Planetary Society's LightSail 2 focuses on its technological success. And indeed, proving that solar sails can propel a CubeSat was a major contribution to space exploration, and as you'll read in this issue, it's already influencing other missions. But there's another important aspect of the LightSail program's success: that the mission was entirely funded by individual, voluntary contributions.

"Crowdfunding" is a well-known term today, especially in the context of internet-based platforms like Kickstarter and GoFundMe. But the concept of pooling

individual resources to do something big has been around for a long time, and it's something The Planetary Society has been doing since our very beginnings.

In June 1981, we mailed our first project-specific fundraising letter to all Planetary Society members. NASA had cut all of its funding for the search for extraterrestrial intelligence (SETI), but plenty of people still believed in the endeavor's importance and pooled more than \$70,000 (more than \$200,000 in today's money) to support three SETI projects: sending scientists to Tallinn, Estonia for an international SETI conference; developing a high-resolution



hardware spectrometer to help process SETI data; and funding the work of pioneering researchers hunting for exoplanets.

Because our community responded so well to crowdfunding opportunities, we started to look for even more ambitious projects for our members to enable. Planetary Society members funded the search for exoplanets in 1981, back when none had ever been found. In 1982, members began funding Eleanor “Glo” Helin’s near-Earth object observations and continued to support her work for more than a decade. Member contributions even helped develop technologies to explore Mars, bringing citizen-based organizations into planetary missions for the first time ever.

These are just a few early examples; The Planetary Society’s 43-year history is full of many more crowdfunded projects. And all along, our sights have been set on doing something even bigger: funding our own space mission.

LightSail 2 is in many ways the pinnacle of our achievements as crowdfunders for

space. But what it proved is something our members have proven time and time again: that a huge number of people around the world believe in the value of space science and exploration so much that they’re willing to put in their own money to ensure its future.

In much the same way that LightSail 2 has influenced other missions to use solar sails, we hope that others draw inspiration from the mission’s crowdfunding success as part of the movement to “democratize space.” We have seen dramatic changes that have made outer space accessible not only to first-world countries, multinationals, and billionaires but also to developing countries, startups, universities, and even members of nonprofits like us. This opens up a new era in which everyday citizens like you can directly connect with space science and exploration. 🚀

OPPOSITE PAGE *Planetary Society members watched in awe as LightSail 2 launched atop the SpaceX Falcon Heavy rocket during the STP-2 mission on June 25, 2019.*

NAVID BARATY/THE PLANETARY SOCIETY

ABOVE *The Green Bank Telescope, located in West Virginia, is the world’s largest fully steerable radio telescope. The Planetary Society recently awarded a \$50,000 grant to support a citizen science SETI project that uses Green Bank data.*

THE GREEN BANK OBSERVATORY



KATE HOWELLS is the public education specialist for The Planetary Society.

To learn more about The Planetary Society’s history with crowdfunding, you can read a chapter by our Chief Operating Officer Jennifer Vaughn and co-founder Lou Friedman in the book “Space Science and Public Engagement: 21st Century Perspectives and Opportunities,” edited by Amy Paige Kaminski.

THOUGHTS ON LIGHTSAIL

AS WE LOOK BACK on the unprecedented success of LightSail 2, we asked our members to reflect on what it all means. Here is a selection of the amazing — and even poetic — responses we received.

LightSail is a pioneering idea, and I am delighted with its success! The project knowledge and data contribute toward future projects and goals. I cheer for all who supported this! [John Jeffrey Drew, USA](#)

An amazing journey displaying resiliency, dedication, and organisation. Proud to have been part in a tiny way. [Paul Barber, U.K.](#)

A publicly funded, nongovernment space mission doesn't happen every day. Projects such as this can open up possibilities that might not see the light of day if left solely to a bureaucracy. Good one, Planetary Society! [John J. Caito, USA](#)

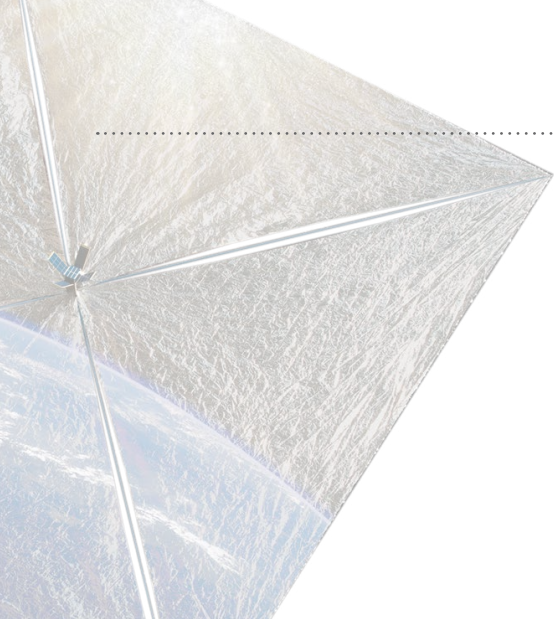
Being part of a cutting-edge project, even in a very small way, was amazing. Especially, knowing it was a concept promoted by Dr. Carl Sagan, I'm happy I could contribute to making it happen. [Seetha Sharma, Singapore](#)

What an inspirational success story this entire mission has been from start to reentry. During these troubled times in our country and the world, it is too easy to concentrate on issues that divide us. Exploring space has always been an issue that unites us, that reminds us we are all solar sailing on the same little blue marble. Sail on into history, LightSail 2. You are shining a spotlight on what can be accomplished when we all work together. This is not the end; it is just the beginning! [Donzella Hines, USA](#)

Amazing to see it actually work and sail. Additionally, the pictures were astounding; remarkable that a niche space society had a camera in orbit taking such photographs. Finally, extremely proud to play a tiny part in such an exceptional scientific endeavour, incredibly well planned, executed, and managed. [Peter Dollery, U.K.](#)

As an original member of The Planetary Society, I am SO PROUD that this organization has conceived, designed, created, and then put into practical use something that has actually gone into space to introduce new material, travel, and research! We have all hoped to see such a groundbreaking event. I keep thinking how pleased Carl (Sagan) would be. Keep it going, PS! [Marilyn Marlene Mathis, USA](#)

We all know space is huge and vast, but the LightSail project made space exploration something I could talk to my family and friends about that was easy to understand and fun to talk about. Proud to be even a small part of the success. [Steve Howard, USA](#)

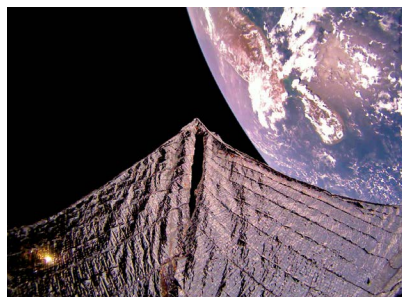
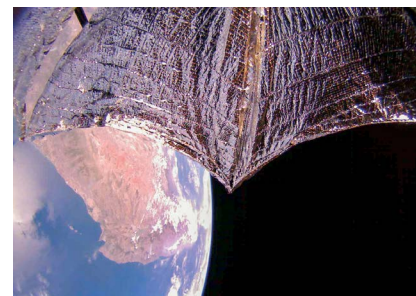
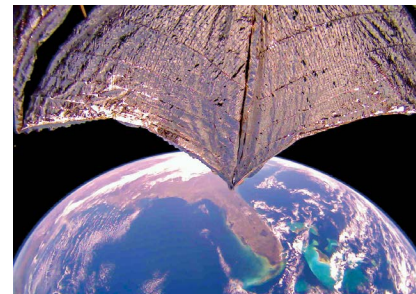
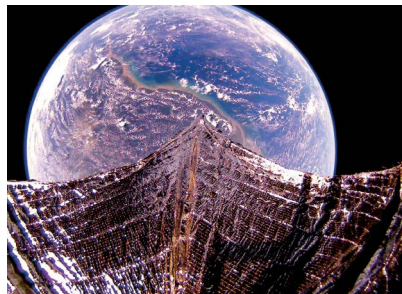
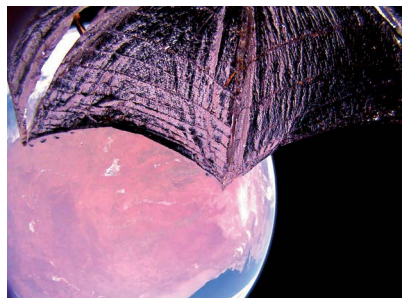


LIGHTSAIL SUCCESS

We waited breathless to hear the word
 Some telemetry from our CubeSat bird.
 Our launching to orbit around the world
 We learned at last that her sail unfurled.
 So finally, again, we heard the tale,
 That ancient cry, "Hoist the mainsail,"
 It paved the way for our next big try
 Around the Earth and away we will fly.
 Celebrating success of all our teams
 As we surfed away on the sunbeams.
 Now a mission has ended with a flash in the pan.
 We'll always remember how the missions began.
 So cap this one off with this tiny stanza.
 We wait for the next step. What a bonanza!

Jay William Preston, USA

I am a charter member of TPS. Our original logo was a ship sailing into the Solar System. Founder Carl Sagan was a visionary who imagined sailing on light from the very beginning. I'm proud and thrilled that it finally came to pass, its promise demonstrated, and the technology is already being used to further our exploration of space as well as our home planet. We did it! Sail on! Dr. Jackie Ericksen, USA



FROM TOP

- April 3, 2021 showing central and southern Australia
- Sept. 20, 2020 with French Guiana, Suriname, Guyana, and the Atlantic Ocean
- May 31, 2021 showing the Gulf of Oman leading to the Persian Gulf, Iran, the southern Arabian peninsula, Afghanistan, and Pakistan
- April 11, 2021 showing Sri Lanka and the southern tip of India

FROM TOP

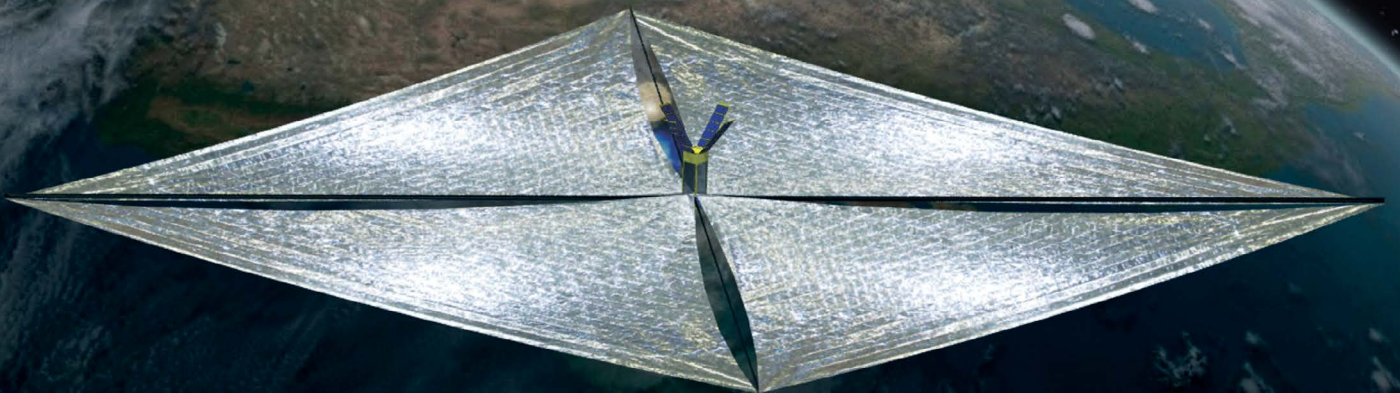
- Feb. 6, 2021 showing the Andes and a stretch of South America from the Pacific to the Atlantic
- Dec. 24, 2021 showing Florida and the beautiful waters of the Bahamas
- May 13, 2020 showing Mexico
- May 5, 2020 showing Cuba and the Bahamas

THE PLANETARY SOCIETY

The Future of Solar Sailing

by Jason Davis

*Early concept art
of LightSail 1.*
DAVID IMBARATTO/STELLAR
EXPLORATION/LOREN A. ROBERTS
FOR THE PLANETARY SOCIETY



THE PLANETARY SOCIETY'S LightSail 2 spacecraft sailed into history last year, successfully completing its mission to demonstrate flight by light.

The solar sail reentered Earth's atmosphere on Nov. 17, 2022 after 3 1/2 years in space. It was a bittersweet moment for Planetary Society members and supporters as well as the team that had flown the spacecraft since 2019. The reentry marks a turning point as the mission turns from operations to analysis and data archiving, said Bruce Betts, LightSail program manager and chief scientist for The Planetary Society.

"We don't have to worry about flying the spacecraft every day," he said. "Now we can focus on data analyses and presenting and publishing the results."

LightSail 2 was a technology demonstration. It was designed to show that small spacecraft — in this case, standardized spacecraft called CubeSats — can carry, deploy, and utilize relatively large solar sails for propulsion. LightSail 2 began its mission as a CubeSat roughly the size of a loaf of bread and deployed a reflective Mylar solar sail with an area of 32 square meters (344 square feet). Using a momentum wheel and three electromagnetic torque rods, the spacecraft oriented itself each orbit to get a slight push from sunlight.

At LightSail 2's starting altitude of about 720 kilometers (450 miles), Earth's atmosphere is still thick enough to create drag and slow down a spacecraft. Using solar sailing, LightSail 2 slowed its decay rate and even overpowered drag on some occasions, showing that the technology is ready for wider use.

New solar sail missions are already under development. Solar sailing is being considered for a wide variety of applications as scientists and engineers envision new advancements in sail technology. LightSail 2 may be gone, but the future of solar sailing is bright.

A USEFUL TECHNOLOGY

One of the biggest advantages of solar sail-powered spacecraft is that while they are near the Sun, they enjoy unlimited thrust. This allows them to reach complex orbits that require constant acceleration to maintain.

An example of this is an orbit that would allow a spacecraft to continually circle the poles of a planetary body. A "pole sitter" spacecraft could offer insight into polar processes happening on Earth, the Moon, and other planets.

Another use for the technology could be parking a spacecraft between Earth and the Sun, creating an artificial orbit from which to watch for solar storms. Solar storms are ejections of high-energy particles from the Sun. These particles can disrupt power grids, cause communication blackouts, and harm astronauts in space. A solar sail parked between Earth and the Sun could sound the alarm on incoming solar storms, allowing protective measures to be taken.

Solar sailing could also propel spacecraft to distant destinations more quickly than conventional propulsion. Proposed far-flung targets range from the outer planets to the Oort cloud to our Sun's gravitational lens region, where the Sun's gravity magnifies distant objects in a way that might allow us to image an exoplanet in high resolution.

The ultimate destination for a solar sail would be Proxima Centauri, our stellar neighbor. The organization Breakthrough Starshot has proposed using lasers to accelerate tiny Proxima-bound spacecraft up to 20% the speed of light, cutting the travel time to just 20 years.

NASA SOLAR SAILS

LightSail 2's immediate solar sail successor was NASA's Near-Earth Asteroid Scout. NEA Scout launched aboard the agency's Artemis I Moon mission in November 2022 along with nine other CubeSats. Unfortunately, NEA Scout didn't phone home as planned, and all efforts to communicate with the spacecraft failed.

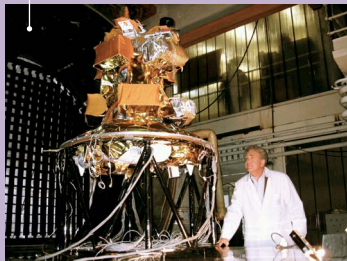
The CubeSat was equipped with a solar sail roughly 2 1/2 times larger than that of LightSail 2. It would have used the sail to leave the vicinity of the Moon and

perform a slow flyby of asteroid 2020 GE, which measures just 18 meters (60 feet) across. Had NEA Scout succeeded, 2020 GE would have become the smallest asteroid ever visited by a spacecraft.

The loss of NEA Scout came on the heels of news that NASA was no longer pursuing another solar sail mission named Solar Cruiser. Solar Cruiser would have deployed an ambitiously large solar sail with an area of 1,650 square meters (17,800 square feet), big enough to cover six tennis courts. The spacecraft would have parked itself in a straight line between Earth and the Sun, a location that future missions could use to watch for solar storms. Only a solar sail can reach and maintain such a unique orbit, given the perpetual thrust required.

That leaves NASA with just one upcoming solar sail mission: ACS3, the Advanced Composite Solar Sail System.

2005



COSMOS 1

The Planetary Society and Cosmos Studios planned to send a crowd-funded solar sail, Cosmos 1, aboard a Russian Volna launch vehicle to become the first-ever solar sail test. However, the rocket malfunctioned and Cosmos 1 never reached orbit.

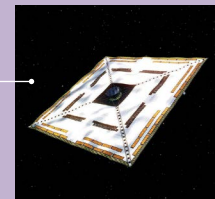
2008



NANOSAIL-D

NASA launched NanoSail-D on Aug. 3, 2008. However, an issue with the SpaceX Falcon 1 launch vehicle carrying it prevented the solar sail from ever reaching orbit. Another NanoSail-D was launched in 2010, although the satellite containing it failed to deploy it as planned. NanoSail-D was unexpectedly ejected in January 2011 and deployed a few days later. The solar sail then orbited Earth for more than 240 days, gathering information about atmospheric drag along the way.

2010



IKAROS

JAXA's IKAROS (Interplanetary Kitecraft Accelerated by Radiation Of the Sun) spacecraft launched on May 20, 2010. It is credited with being the first spacecraft to successfully use solar sailing in interplanetary space, as it flew with JAXA's Akatsuki probe to Venus. Though it completed its primary missions in 2010, IKAROS continued its mission so JAXA could gain more insights about the dynamics of solar sailing. JAXA's last contact with IKAROS was in 2015.

ACS3 is scheduled to launch into Earth orbit as early as mid-2023 for a test of next-generation solar sail technologies.

The spacecraft will use carbon fiber booms to deploy a sail with an area of about 80 square meters (860 square feet) — about 2 1/2 times larger than LightSail 2. NASA says the carbon fiber booms are 75% lighter than metal booms and less susceptible to buckling due to extreme temperature shifts in space.

W. Keats Wilkie, the mission's principal investigator at NASA's Langley Research Center, said ACS3 is essentially a scaled-down version of a much larger solar sail spacecraft that would measure roughly 500 square meters (5,400 square feet). He said that as the technology matures, scientists will come to see solar sail spacecraft as attractive options for their missions.

"Once we start flying these, we'll get

people who say, 'Hey, this isn't just science fiction anymore,'" he said.

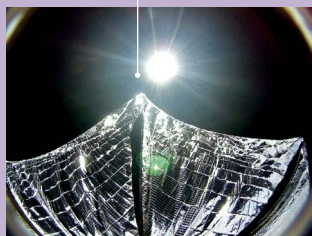
NO BOOMS, NO PROBLEM

The larger a solar sail gets, the more challenging it becomes for booms to deploy sail sections and hold them tight like a kite. One alternative is spinning the core spacecraft using centrifugal force to unfurl the sail and keep it tight. The concept was successfully tested in 2010 by Japan's IKAROS mission. Now, a French-based startup named Gama plans to take spinning sails further.

Gama is planning to debut the technology in Earth orbit with two missions named Alpha and Beta. Both will use sails of 73 square meters (786 square feet), more than double the sail area of LightSail 2.

In January 2023, Alpha launched to low-Earth orbit, where atmospheric

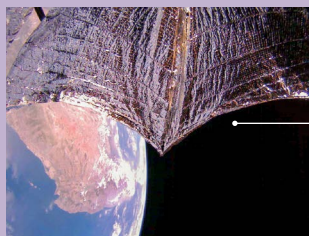
2015



LIGHTSAIL 1

Roughly 50,000 donors contributed to The Planetary Society's LightSail program, of which the test flight LightSail 1 was a part. LightSail 1 launched on June 1, 2015 and reentered Earth's atmosphere on June 15, 2015.

2019



LIGHTSAIL 2

The Planetary Society's LightSail 2 successfully demonstrated the capabilities of using sunlight as a means of propulsion in a small spacecraft. It launched on June 25, 2019 and reentered Earth's atmosphere on Nov. 17, 2022, after exceeding its planned mission by well over two-and-a-half years. The solar sail took hundreds of stunning images from its time orbiting Earth and influenced a number of published papers. The LightSail project also influenced at least three other solar sailing missions: NEA Scout, Solar Cruiser, and ACS3.

2022 2023

NEA SCOUT

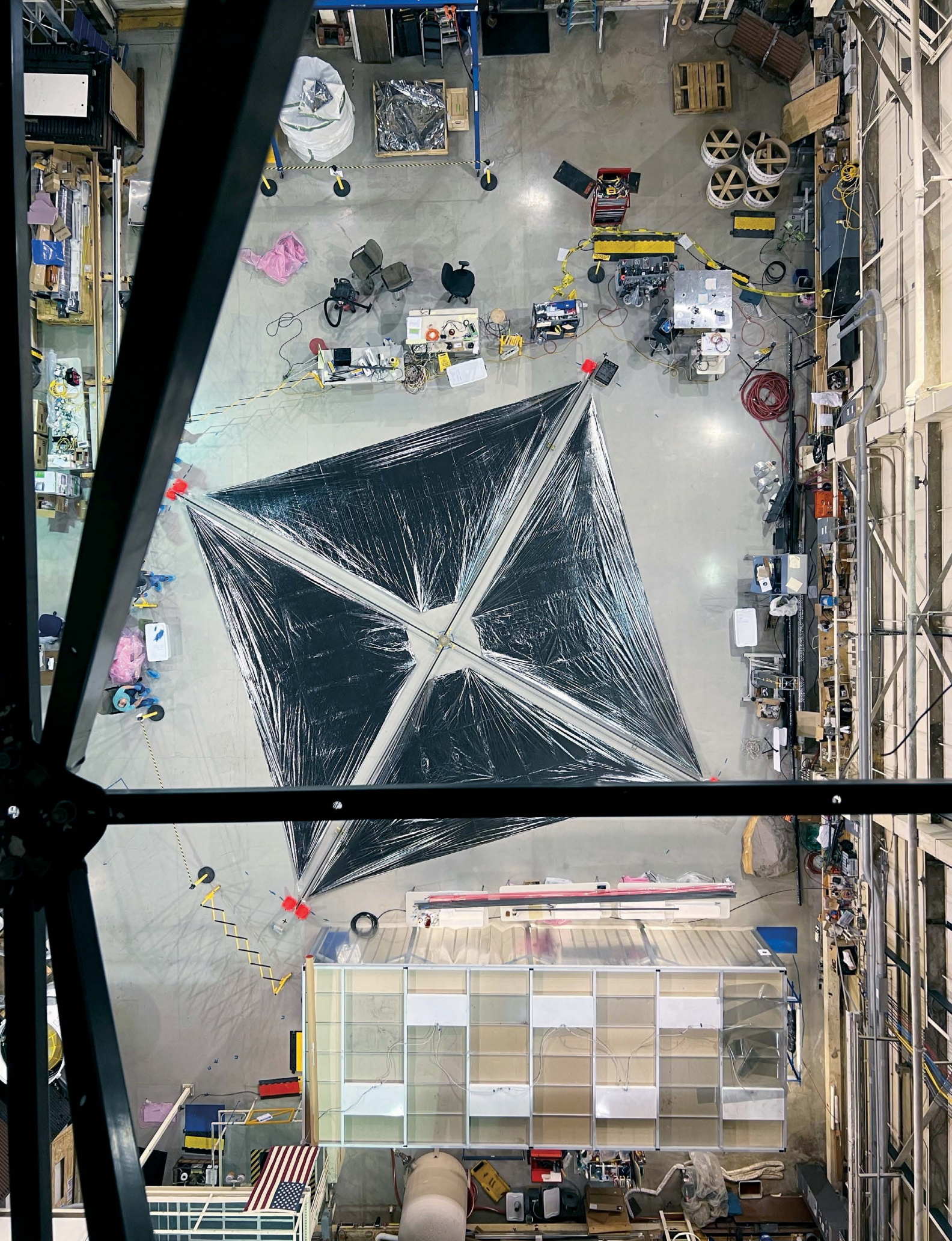
NEA Scout launched with NASA's Artemis I mission in November 2022. Since launch, NEA Scout has not yet been able to make contact with the spacecraft.

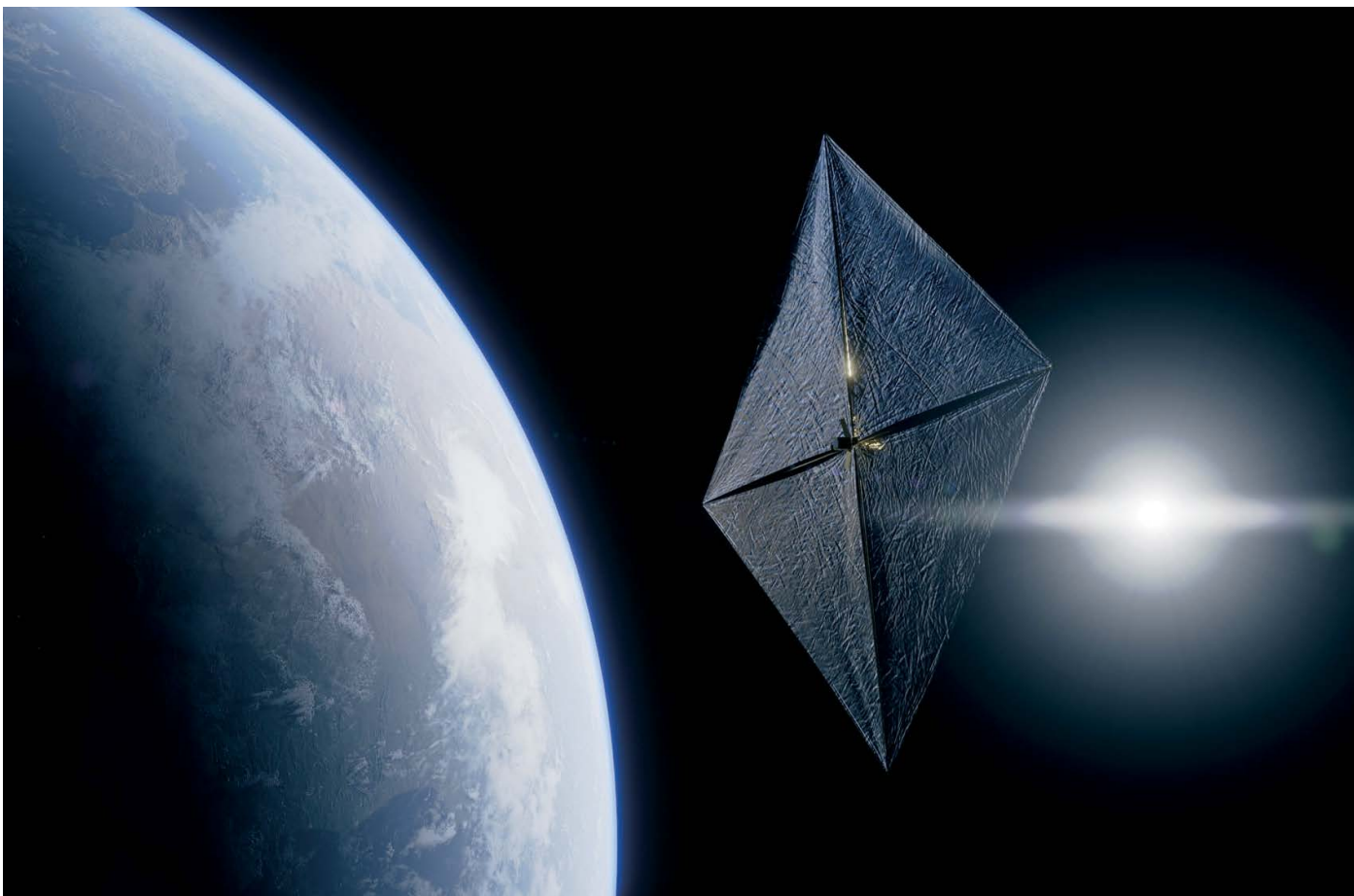
ACS3

NASA expects to launch its Advanced Composite Solar Sail System (ACS3) in early 2023. It will test the efficacy of certain kinds of sail booms.

GAMA ALPHA

Gama, a French aerospace company, raised 2 million Euros to begin a multi-mission solar sailing program and launched its first sail in January.





drag is still strong enough to overpower the thrust gained from solar sailing. At the time of publication, no information was available about the status of the spacecraft. Beta, which has a launch date of 2024, will fly higher, where its thrust will have a more noticeable effect.

Gama's goal is to offer an affordable solar sailing platform for a variety of scientific missions. The company's website envisions flights to Venus, the outer planets, and even the Oort cloud. Andrew Nutter, a Gama co-founder, said that the company's solar sails will hitch rides on high-energy rocket launches, such as trips to lunar space.

"It allows us to launch as a rideshare on many different types of missions without needing a private launch, reducing launch cost," he said.

OTHER TYPES OF SAILING

Solar sails like LightSail 2 work on a straightforward concept: As light bounces off a reflective surface, some of the light's momentum gets transferred, giving the surface a push. Like a sailboat, a solar sail gets where it wants to go by changing the angle of its sail with respect to the Sun's rays.

A reflective sail performs best when it is turned perpendicular to the rays, but this isn't always possible. A sail in solar orbit trying to spiral away from the Sun, for instance, needs to angle itself 35 degrees away from the incoming solar photons. This lowers the sail's thrust, making it less efficient.

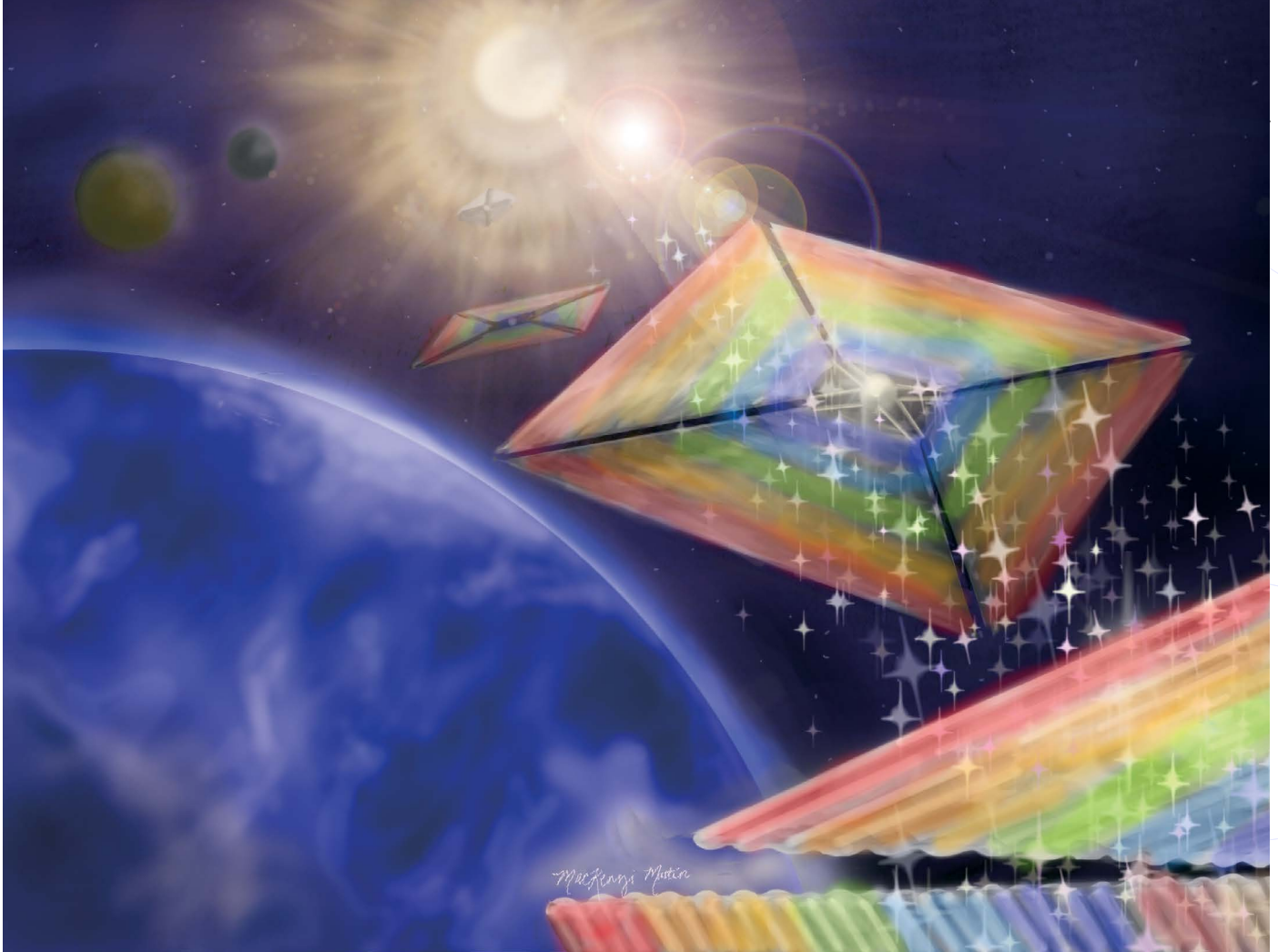
Diffraction solar sails seek to overcome this limitation. These sails use tiny gratings that diffract incoming light through the sail like a prism rather than reflecting it. The

OPPOSITE NASA's Advanced Composite Solar Sail System (ACS3) solar sail is seen from above during deployment testing. The ACS3 solar sail is approximately 9 meters (30 feet) on each side, and the boom-tip-to-boom-tip diagonal distance is 14 meters (46 feet).

NASA

ABOVE Gama, a French company, aims to increase access to deep space using low-cost, reliable, and scalable solar sails.

GAMA



ABOVE *Diffractive solar sails, depicted in this conceptual illustration, could enable missions to hard-to-reach places, like orbits over the Sun's poles.*

MACKENZIE MARTIN/NASA

diffracted light has a force component that pushes the sail in a direction perpendicular to the incoming solar photons, allowing the sail to capture the full force of the Sun's rays.

Rather than being made from shiny Mylar like LightSail 2, a diffractive solar sail might be manufactured from nearly transparent materials. As an aesthetic bonus, the diffracted light would give the sail a rainbowlike appearance.

The NASA Innovative Advanced Concepts program has previously funded diffractive sail research. The agency is now funding further development of diffractive sails in support of a possible technology demonstration mission. Amber Dubill, the project's principal investigator at the Johns Hopkins University Applied Physics Laboratory, said that diffraction technology could help make solar sailing mainstream.

"We think that we can overcome a lot of the challenges that are keeping traditional solar sailing from becoming widely implemented much more across the board," she said.


Another alternative to traditional solar sails is the electric sail, or E-sail. Instead of sailing on solar photons traveling at the speed of light, an E-sail rides on the solar wind — charged particles ejected by the Sun.

One E-sail concept studied by NASA's Marshall Space Flight Center consists of a small central spacecraft that would spin and deploy 20 thin, positively charged wires that are each 20 kilometers (12 miles) long.

As positively charged protons from the solar wind approach the sail, they are repelled by electrostatic forces, giving the sail a push. One advantage of this technique is that E-sails could be faster than traditional sails. NASA says an E-sail-powered mission could reach the heliopause — the bubble in interstellar space created by our Sun — in half as much time as a solar sail.

WHAT A DRAG

During its final days in space, LightSail 2 dipped farther and farther into Earth's atmosphere. The spacecraft's altitude



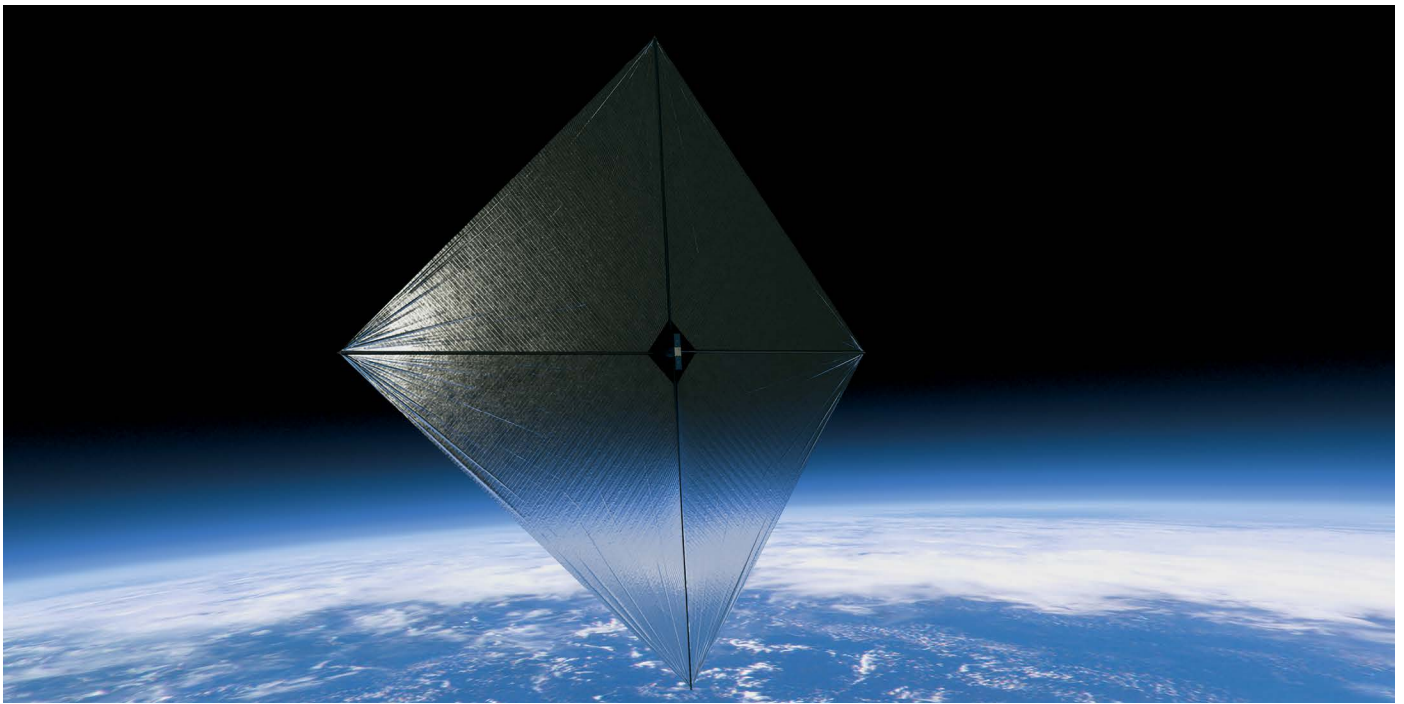
LONG (20 KM), THIN
(1 MM) CONDUCTING
TETHERS (WIRES)

SOLAR-POWERED ELECTRON
GUN KEEPS THE SPACECRAFT
AND WIRES IN A HIGH
POSITIVE POTENTIAL

THE ELECTRIC SOLAR WIND SAIL

Extending outward from the center of the spacecraft, 10 to 20 electrically charged bare aluminum wires would produce a large, circular E-Sail that would electrostatically repel the fast-moving protons of the solar wind. The momentum exchange produced as the protons are repelled by the positively charged wires would create the spacecraft's thrust. Each tether is extremely thin at only 1 millimeter – the width of a standard paperclip – and very long at nearly 12 1/2 miles – almost 219 football fields. As the spacecraft slowly rotates at one revolution per hour, centrifugal forces will stretch the tethers into position.

LOREN A. ROBERTS/THE PLANETARY SOCIETY



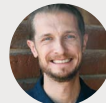
ABOVE *An artist's concept of NASA's ACS3 solar sail spacecraft in Earth orbit.*

NASA

dropped quickly as its kitelike sail trawled through the upper atmosphere. The forces and heating from air molecules compressed against LightSail 2's surfaces eventually tore apart the spacecraft.

Data on LightSail 2's reentry could prove useful for drag sails, which are designed to intentionally deorbit satellites. The capability can be used to speed up the reentry of satellites whose missions have ended, ensuring they don't contribute to a growing space junk problem in Earth orbit. NASA says there are over 25,000 objects in Earth orbit larger than 10 centimeters (4 inches). Derelict satellites can collide with other satellites and space debris, exacerbating the problem.

Satellites can be equipped with drag sails that are deployed at the end of a mission. Several organizations are studying the concept, including the company Vestigo Aerospace, which includes personnel who worked on the LightSail program.



JASON DAVIS is the senior editor for *The Planetary Society*.

LIGHTSAIL'S LEGACY

LightSail 2 was designed to demonstrate flight by light for small spacecraft. The LightSail program itself had wide-ranging objectives, including popularizing solar sailing and helping other missions advance solar sailing technology.

More than 50,000 Planetary Society members, Kickstarter backers, private citizens, foundations, and corporate partners supported LightSail 2 and the broader cause of solar sailing. With a variety of new missions and technologies on the way, the future of solar sailing looks bright. From its nighttime launch to the stunning images it sent back to Earth, LightSail 2 has inspired people far and wide.

The co-founders of The Planetary Society believed that sailing on sunlight could revolutionize space travel. As the LightSail 2 mission ends, the baton is being passed to the next generation of solar sailors. Who knows what distant shores they will visit as they explore our cosmic ocean? 🌟



LIGHTSAIL END OF MISSION

After nearly three-and-a-half glorious years in Earth orbit, our dear LightSail 2 spacecraft reentered the atmosphere as expected, successfully completing its mission to demonstrate flight by light for small spacecraft. LightSail 2 reentered on Nov. 17, 2022. The spacecraft showed that it could change its orbit using the gentle push of sunlight, a technique known as solar sailing. LightSail 2 demonstrated that small spacecraft can carry, deploy, and utilize relatively large solar sails for propulsion. The team continues working on data analyses, technical presentations, and journal articles to continue to feed forward what has been learned to all future solar sailing missions.

SPACE ADVOCACY VICTORIES

The Planetary Society notched a number of high-profile victories in space policy and NASA's 2023 budget after a full year of grassroots and targeted advocacy work. Our highest priority, protecting the NEO Surveyor asteroid-hunting mission from crippling budget cuts, resulted in Congress restoring \$50 million to the project, the largest correction to a robotic mission that year. Congress also passed legislation enshrining the mission as official U.S. policy. In response, NASA confirmed the project to launch in 2028. We also supported efforts to keep Mars Sample Return and Europa Clipper on track. Planetary science at NASA remains at record levels of funding. And in a critical step for our search-for-life efforts, we saw the inclusion of legislative language allowing NASA to investigate "technosignatures" — signs of intelligent life. SETI funding was removed from NASA in the 1990s, and this updated policy frees NASA to support scientifically sound expansive efforts to find life in our Cosmos.

WHAT THE MIDTERMS MEAN FOR SPACE POLICY

The 2022 U.S. midterm elections did not result in a red or blue wave but rather a divided Congress with Republicans gaining control of the House of Representatives and Democrats retaining the Senate. Our Chief of Space Policy, Casey Dreier, analyzed what this means for U.S. space politics in the coming year. Listen to the Space Policy Edition of Planetary Radio and subscribe to The Space Advocate newsletter for ongoing space policy coverage. planetary.org/spaceadvocate

THANK YOU FOR HELPING US CHANGE THE WORLD(S)

We were able to raise more than \$316,000 during our year-end fundraising campaign thanks to the generosity of members like you. Your support also helped us raise \$22,000 during our Giving Tuesday drive back in November 2022.





BEST OF 2022 AWARDS

At the end of 2022, we looked back at a fabulous year of exploration with our annual “Best Of” awards. With over 3,000 votes cast, the results are in for the Best of 2022! Here’s what our community of members and supporters picked for 2022’s most amazing images, inspiring missions, exciting moments in exploration, and more!

BEST SOLAR SYSTEM IMAGE

NEPTUNE FROM JWST

NASA’s JWST spacecraft took this image of Neptune using its Near-Infrared Camera, which captures light in the near-infrared range from 0.6 to 5 microns. In addition to several bright, narrow rings, the JWST images clearly show Neptune’s fainter dust bands.

NASA/ESA/CSA/STScI

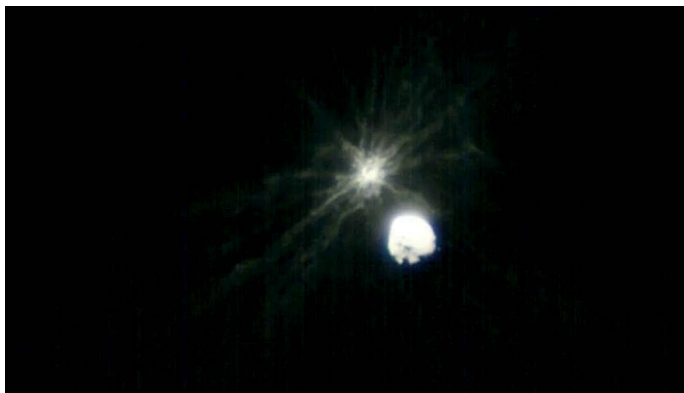
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BEST JWST IMAGE

THE PILLARS OF CREATION

JWST Near-Infrared Camera captured this view of the iconic Pillars of Creation. This region of the Eagle nebula was made famous when the Hubble Space Telescope imaged it in 1995.

NASA/ESA/CSA/STScI/JOSEPH DEPASQUALE (STScI)/ANTON M. KOEKEMOER (STScI)/ALYSSA PAGAN (STScI)

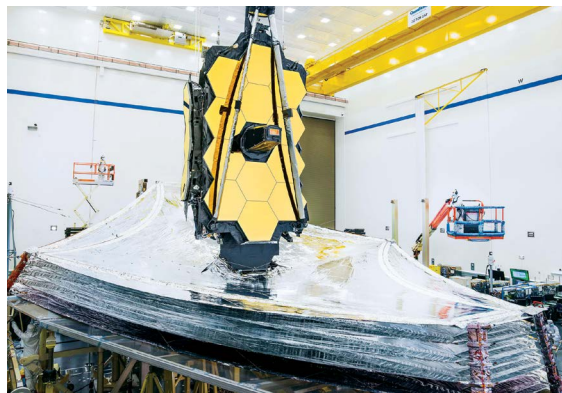


MOST EXCITING MOMENT IN PLANETARY SCIENCE

DART SUCCESSFULLY CHANGING THE ORBIT OF DIMORPHOS

In September, NASA’s Double Asteroid Redirection Test (DART) mission successfully altered the orbit of asteroid moonlet Dimorphos around its parent asteroid Didymos by smashing into it. This was the first-ever test of an asteroid deflection technique. Here you can see the aftermath, captured by the Italian Space Agency’s LICIACube spacecraft.

ASI/NASA



FAVORITE ACTIVE PLANETARY SCIENCE MISSION

THE JAMES WEBB SPACE TELESCOPE (JWST)

JWST sits with its five-layer sunshield fully deployed during testing at Northrop Grumman in Redondo Beach, California.

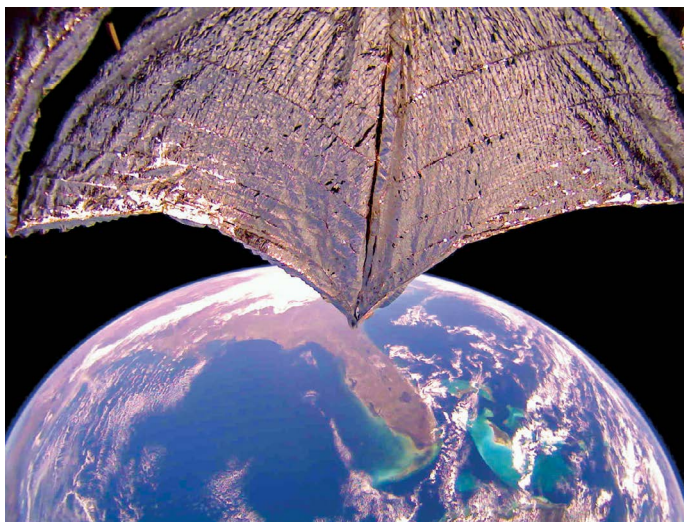
NASA/CHRIS GUNN

**MOST EXCITING
UPCOMING PLANETARY
SCIENCE MISSION**

NASA'S ARTEMIS PROGRAM TO SEND HUMANS BACK TO THE MOON

The Orion spacecraft's solar array camera captured this view of the Moon and Earth during its closest approach to the lunar surface as part of the Artemis I mission.

NASA

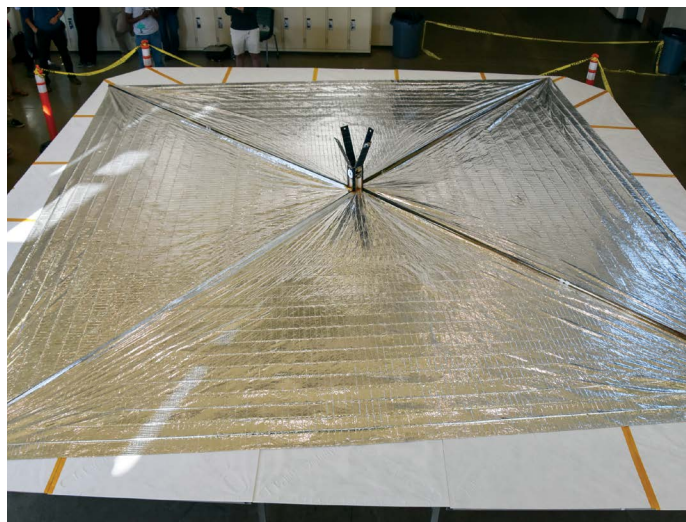


BEST SPACECRAFT IMAGE

LIGHTSAIL 2 OVER THE BAHAMAS

This image taken by The Planetary Society's LightSail 2 spacecraft shows Florida and the beautiful waters of the Bahamas. The image has been color-adjusted, and some distortion from the camera's 180-degree fisheye lens has been removed.

THE PLANETARY SOCIETY



**THE BEST PLANETARY SOCIETY ACCOMPLISHMENT
THANKS TO THE SUPPORT OF OUR MEMBERS**

LIGHTSAIL 2 INSPIRING ANOTHER SOLAR SAILING MISSION

The Paris-based company Gama announced that it has raised 2 million euros (\$2.2 million USD) to begin work on a solar sailing mission. In an interview, Gama's co-founder, Andrew Nutter, said his company "tried to learn as much as possible" from The Planetary Society's LightSail 2 solar sailing mission, which completed its mission in November 2022. Pictured here is LightSail 2 during sail deployment testing in 2016.

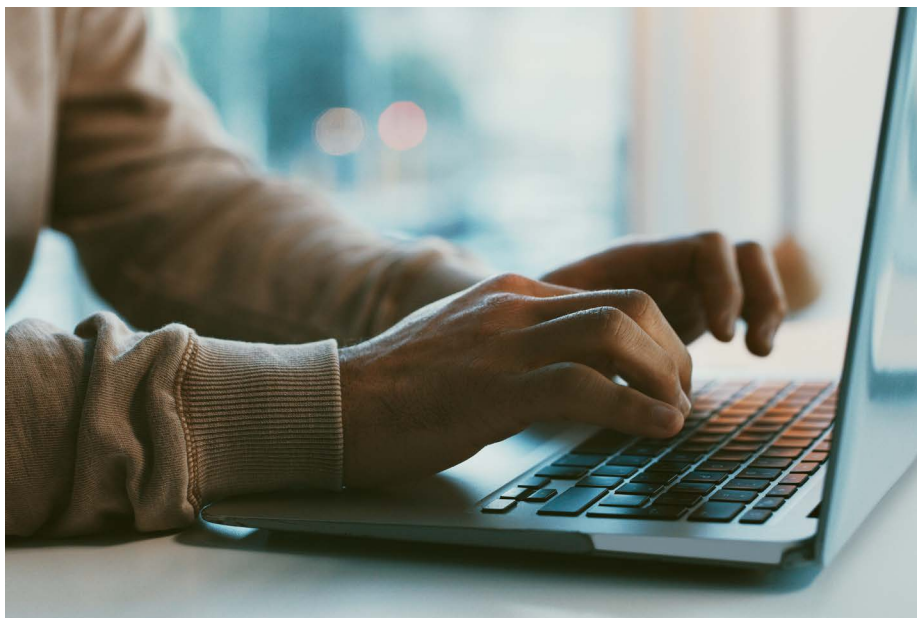
JASON DAVIS/THE PLANETARY SOCIETY

SPACE ADVOCACY ALERT!

As a Planetary Society supporter, you're part of the largest and most influential nonprofit space organization in the world. Together, we help create a bigger, bolder future for humankind.

Today we're building on our success and taking our advocacy work to the next level, but we need your support to do it. **Will you please power our urgent efforts? Go to planetary.org/takeaction to put your gift to work right away.**





SIGN UP FOR YOUR BRAND-NEW DIGITAL MEMBER COMMUNITY!

BY THE TIME you read this issue of The Planetary Report, our members-only community should be live and ready to explore. Connect with your fellow members via message boards and live chats, take online courses, join special live streaming events, and much more. It's all available to you at community.planetary.org.



MEET US IN VIENNA

SEE HOW SCIENTISTS use cutting-edge tools and techniques to detect and track asteroids in a vivid IMAX® experience at a free public screening of "Asteroid Hunters" during the 2023 Planetary Defense Conference in Vienna, Austria. A post-film roundtable discussion with the scientists from the film will follow, hosted by our very own Chief Scientist Bruce Betts. The screening will be at Cineplexx Donau Zentrum on Wednesday, April 5, 2023. Further details will be available at planetary.org.



ESA'S JUICE MISSION LAUNCH (APRIL 5-25)

THE EUROPEAN Space Agency is sending a spacecraft to investigate Jupiter and its three largest moons: Ganymede, Callisto, and Europa. JUICE, which stands for JUpiter ICy moons Explorer, will look for water beneath the surfaces of these icy worlds and search for signs of life. You can watch JUICE launch at planetary.org/live.



CELEBRATE THE INTERNATIONAL DAY OF HUMAN SPACEFLIGHT

APRIL 12 marks 62 years since Yuri Gagarin became the first person in space and 42 years since the inaugural launch of the Space Shuttle. This year, celebrate at Yuri's Night, the world's biggest space party, hosted by The SpaceKind Foundation. Find a local event near you at yurisnight.com.



HYBRID SOLAR ECLIPSE, SUPER-BRIGHT VENUS

IN THE SKY

Super-bright Venus, much brighter than the brightest star in the night sky, dominates the evening west. Reddish Mars is high above Venus in March and will get closer to Venus as the weeks pass. Mars will also dim as time passes as Earth and Mars get farther apart in their orbits. Mercury appears below Venus low to the horizon during April. In March, Saturn is very low to the horizon in the predawn east but will grow higher quickly as the weeks pass. Jupiter will appear low in the predawn east by June. On April 20, there is a hybrid solar eclipse visible across parts of western Australia and portions of Indonesia. A hybrid eclipse appears as a total eclipse in some locations and an annular eclipse in others. For more night sky tips, you can always check out planetary.org/night-sky.

RANDOM SPACE FACT

The circumference of the Moon (about 10,900 kilometers, or 6,800 miles) is approximately the same as the flying distance from New York City to Tokyo.

TRIVIA CONTEST

Our September equinox contest winner is Kathleen MacDougall of San Francisco, California, USA. Congratulations! The question was: **Who made the first discovery of a moon of Uranus?** The answer: **William Herschel discovered Titania and Oberon on the same night about six years after he discovered Uranus.**

Try to win a copy of the new book "Solar System Reference for Teens" by Bruce Betts and a Planetary Radio T-shirt by answering this question: **Other than on Earth, where in the Solar System is there a feature named Thor?**

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 June 1, 2023. One entry per person. 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.



Please contact Terri or Taunya at **Betchart Expeditions** for brochures and updated information on COVID and travel. Call 1-800-252-4910 or go to betchartexpeditions.com.

We invite you to join other members of The Planetary Society to discover the world on Betchart Adventures!

NEW MEXICO ANNULAR ECLIPSE OCT. 10-17, 2023

See the International Balloon Fiesta, the ancient Indian pueblos at Chaco Canyon and Mesa Verde, and the annular eclipse.

ANTARCTICA DECEMBER 5-18, 2023

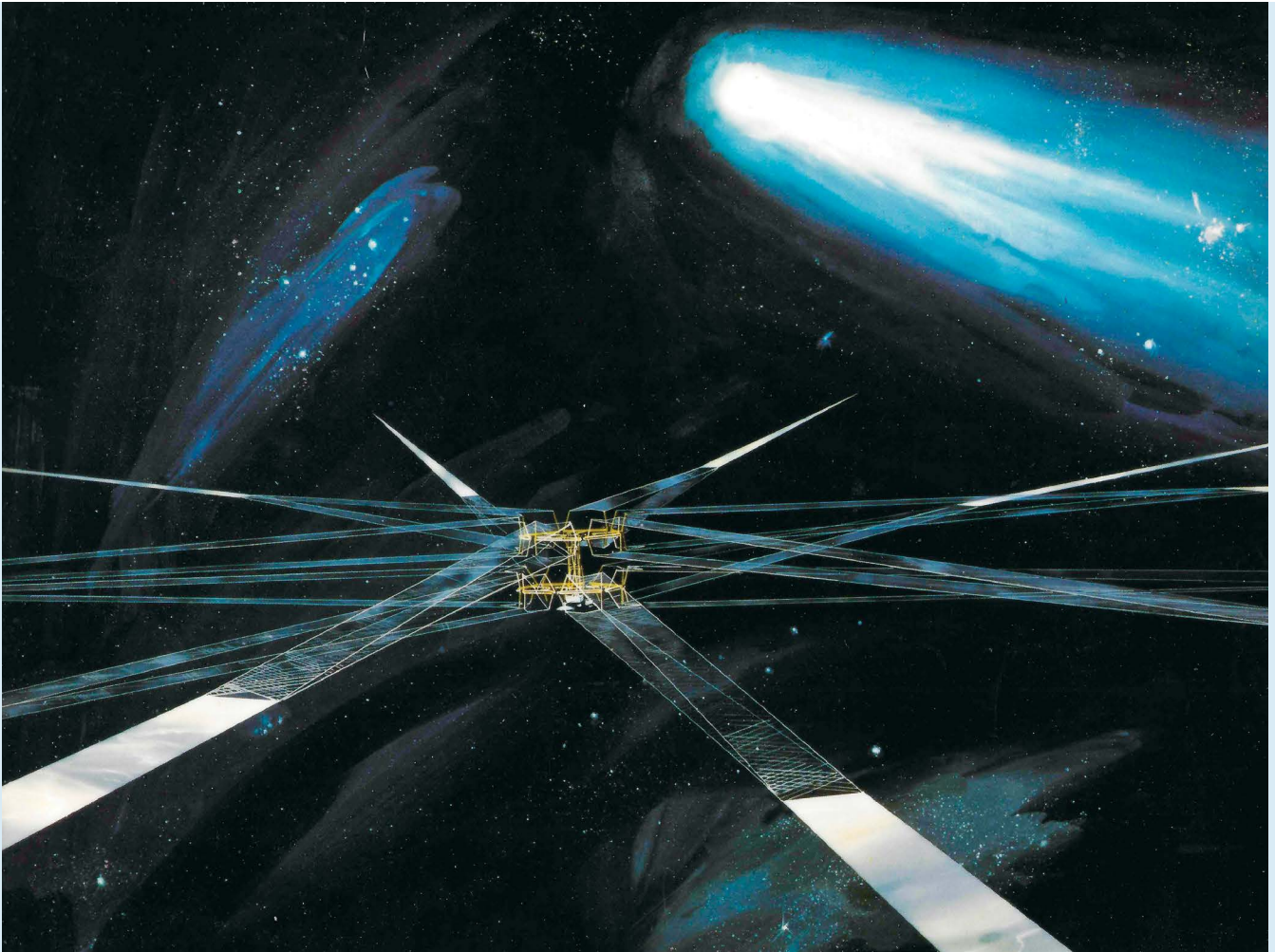
Discover this icy paradise of stunning mountains and wildlife!

ALASKA AURORA BOREALIS MARCH 7-13, 2024

Discover magnificent Denali and the northern lights in the pristine splendor of Alaska in winter.

MEXICO COPPER CANYON AND DURANGO TOTAL SOLAR ECLIPSE APRIL 1-9, 2024

Discover Copper Canyon and Mazatlan and then see Durango and the eclipse high in the Sierra Madre!



The heliogyro solar sail

This 1977 space artwork depicts a concept being developed by NASA at the time: the heliogyro solar sail. This enormous spacecraft would have 12 spinning blades, each 4 miles long and composed of lightweight, reflective material like LightSail 2's Mylar sails. The blades would deploy on reels and spin around a central hub, stiffened by centrifugal forces instead of needing rigid booms. Sunlight would bounce off the blades' reflective surfaces, propelling the spacecraft. The concept was never realized but remains in the vast realm of possibilities for the future of exploration.

NASA/JPL

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.