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THE PLANETARY REPORT

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AI IN SPACE

HOW ARTIFICIAL INTELLIGENCE WILL SHAPE THE FUTURE OF EXPLORATION

THE PLANETARY SOCIETY 45 CELEBRATING 45 YEARS

Spacewalk over the Bahamas
NASA astronauts James H. Newman and Carl E. Walz performing a spacewalk during a 1993 Space Shuttle mission. Part of the Caribbean Sea and the Bahama Islands is visible behind them.

NASA

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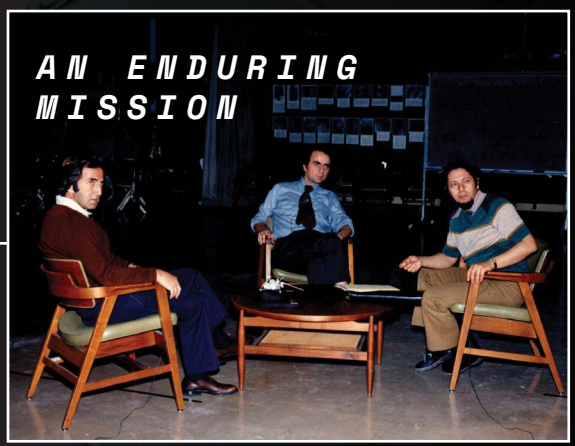
ON THE COVER

Version 1.0 of JPL's EELS (Exobiology Extant Life Surveyor) robot raises its head from the icy surface of Athabasca Glacier in Alberta, Canada, during field testing in September 2023.

NASA/JPL-Caltech



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AN ENDURING MISSION

Celebrating 45 years of The Planetary Society

by Bill Nye

This year, The Planetary Society celebrates our 45th anniversary. Nearly a half-century ago, Carl Sagan, Bruce Murray, and Louis Friedman founded this organization with clear goals: to prove that there was popular support for the exploration of the Solar System and beyond and to create opportunities for the public to get involved. Today, our mission remains the same; we're still at it.

Looking back on all that has happened since 1980, it's astonishing to consider how far we've come, not just as a Society but as a species of explorers.

When The Planetary Society was founded, humanity's exploration of the Solar System was already underway. Humans had walked on the Moon. We'd landed extraordinary spacecraft on the surface of Mars. We had sent the Pioneer and the Voyager missions into the outer Solar System. Still, the progress we've made in those 45 years has been remarkable.

In July 1987, The Planetary Society hosted a meeting of American and Soviet scientists and engineers to discuss future Mars exploration over a SpaceBridge satellite link. From left to right: American participants Carl Sagan, Joseph Kerwin, Buzz Aldrin, John Logsdon, and Thomas O. Paine.

The Planetary Society

Humans, via our robotic envoys, have now explored every planet in the Solar System and its largest dwarf planets. We've driven rovers through ancient riverbeds on Mars and landed on Saturn's moon Titan. We've discovered unexpected ocean moons and thousands of exoplanets. We have a spacecraft on its way to Jupiter's moon Europa to sniff around for organic molecules. The twin Voyagers have even entered interstellar space.

Through it all, The Planetary Society has been a champion of exploration, ensuring missions get the funding they need and that the public knows about the discoveries they make. Our STEP and Shoemaker grants are actively advancing space exploration and keeping Earth safe from potential asteroid impacts. We've grown and engaged a global community of members and supporters who share a passion for discovery. We have been influential in advocating for space, helping to ensure that government decision-makers understand the value of investing in exploration. And today, I'm proud to say that The Planetary Society is the best it's ever been. We remain the world's largest independent pro-space organization, an increasingly rare entity in an industry dominated by corporate and government interests.

As we mark 45 years of progress, I want to celebrate not only how far we've come but also the role that members like you have played in making it possible. As you'll read about later in this issue, we completed our ambitious Beyond the Horizon comprehensive fundraising campaign in support of our strategic framework Space for Everyone. Collectively, over the past five years of our campaign, you all helped raise an astounding $40 million to support the future of this organization and the work we do together.

Thank you for being part of this journey. Here's to the next 45 years of exploration, discovery, and wonder.

Onward,
Bill Nye

MEMBERS ON DECK

Are you a space trivia whiz? Test your knowledge with these trivia questions submitted by Planetary Society members. To see if you got the answers right, go to planetary.org/trivia.

Read on for a trivia question from our chief scientist later in the magazine. And if you want to flex your space trivia skills even more, check out the weekly trivia contest in The Planetary Society's online member community. Log in at community.planetary.org and look for "Trivia!" on the left-hand menu.

QUESTION #1:

Which spacecraft was the first to successfully land on Mars and send back images to Earth?

—Christopher Dedman-Rollet, USA

QUESTION #2:

Three real-life astronauts for NASA also served aboard the U.S.S. Enterprise on "Star Trek": two on the original ship (NX-01 from "Star Trek: Enterprise") and one on the Enterprise-D (from "Star Trek: The Next Generation"). Can you name them all? And for a bonus point, can you tell us what else those three NASA astronauts have in common (other than being cool NASA astronauts who were also on "Star Trek")?

— Mel Powell, USA

QUESTION #3:

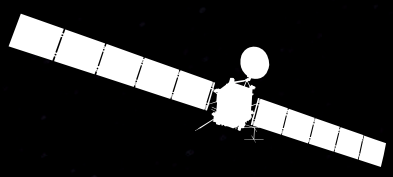
What is the total number of astronauts who have landed on the Moon?

— Ricky Gonzalez Flores, USA

QUESTION #4:

Who was the pioneering female astronomer whose meticulous research allowed her to define the "standard candle" with which to measure vast cosmological distances, thereby proving conclusively that Andromeda was a galaxy far outside of the Milky Way?

— Graham Mackintosh, USA



QUESTION #5:

Which spacecraft has been out as far as Jupiter's orbit without going near that planet?

— David Frankis, United Kingdom

QUESTION #6:

Which mission proved Murphy's Law is universal by landing on a planetary surface with a penetrometer to measure soil compressibility but instead measured the compressibility of one of the lander's camera's lens caps that had been ejected onto the surface?

— Allan Tarr, Canada

QUESTION #7:

In what way does Dragonfly's wind tunnel testing differ critically from other wind tunnel testing?

— Bob Ware, USA

COMPUTING IN SPACE EXPLORATION HISTORY

Before artificial intelligence, there was human ingenuity

by Kate Howells

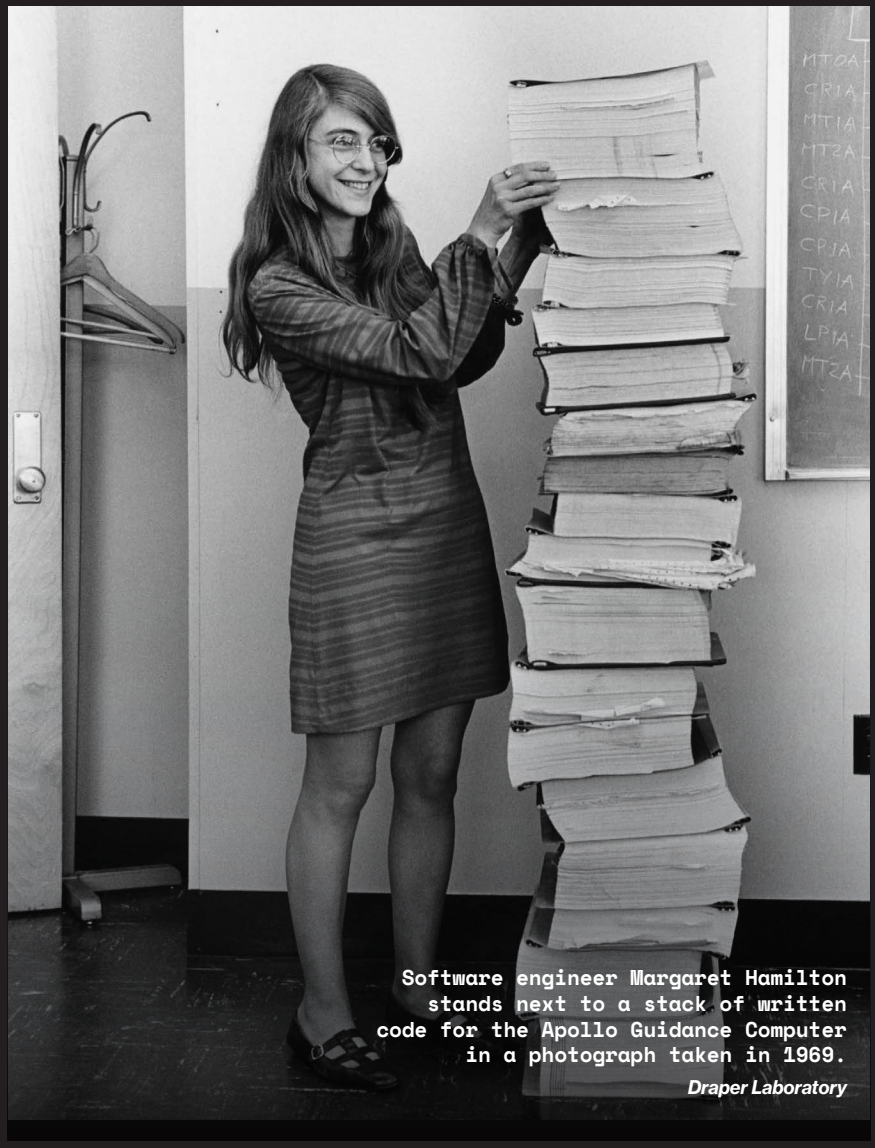
"In everyone's pocket right now is a computer far more powerful than the one we flew on Voyager. I don't mean your cell phone — I mean the key fob that unlocks your car."

— Rich Terrile, JPL scientist and member of the Voyager imaging team, quoted in Jim Bell's book "The Interstellar Age"

The computers available to us today enable feats of science and engineering that boggle the mind, like the artificially intelligent robotic explorers discussed later in this magazine. To those of us accustomed to today's technological capabilities, it can be equally mind-blowing to reflect on exploration achievements that happened before we had so much power available to us.

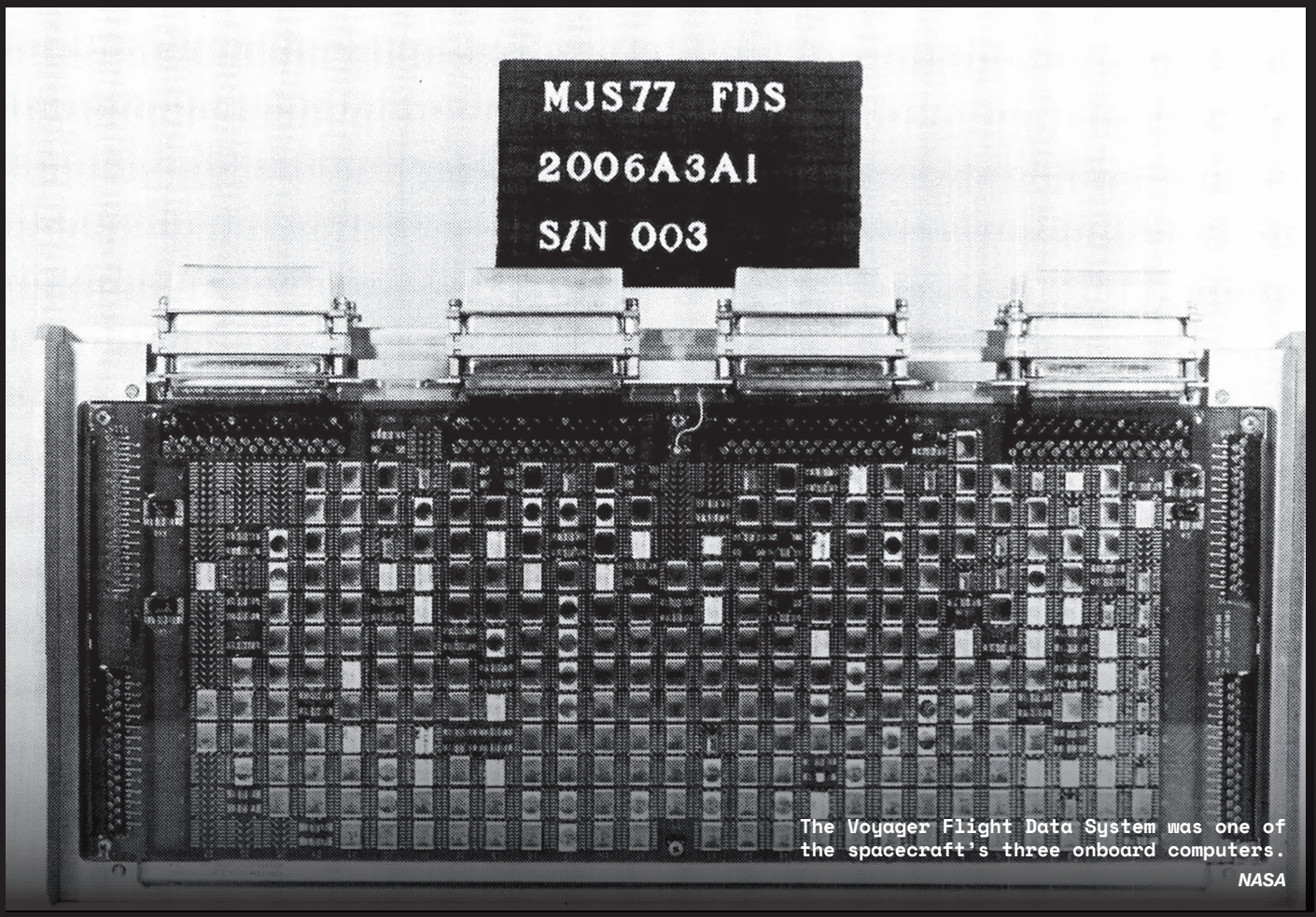
The Apollo Moon landing program is famous for (among other things) its sophisticated use of computing technology. In the 1960s, computing was still in its infancy, and programming still involved writing out code on paper, punching holes in cards, and painstakingly weaving long ropes of copper wire through and around tiny magnetic cores to represent machine logic.

The physical nature of Apollo's computer memory, while exceedingly resilient, took far more time and effort than what is common today and yielded a far smaller output. Apollo astronauts had access to only 72 kilobytes of computer memory, almost a million times less storage space than a relatively modest smartphone. And yet, the Apollo program's ingenious use of the technology available at the time — and the technological breakthroughs that the program



Software engineer Margaret Hamilton stands next to a stack of written code for the Apollo Guidance Computer in a photograph taken in 1969.

Draper Laboratory



The Voyager Flight Data System was one of the spacecraft's three onboard computers.

NASA

accomplished — led to one of the most monumental achievements in human history: landing astronauts on the Moon.

The Voyager program also made extraordinary use of the limited computer power available in the 1970s. Despite the twin spacecrafts' onboard systems having only about 69 kilobytes of memory in total, those computers enabled Voyager 1 and 2 to continue conducting science far beyond their original mission scope, sending back data from interstellar space to this day.

A major factor in the Voyager missions' longevity is that each of the spacecraft's three computers was designed to be reprogrammable — a remarkable feature at the time of their launch in 1977. This design allows engineers to send new sets of commands or software instructions to replace old ones, essentially rewriting the computers' programming for new tasks or conditions.

For example, as the spacecraft grew more distant from Earth, their computers could be reprogrammed to alter data compression methods as signal strength weakened. This also allowed the mission to adapt to answer new scientific questions, such as when Voyager 2 extended its mission to include flybys of Uranus and Neptune. The observations both spacecraft are conducting right now from beyond the heliosphere are very different from the science they originally set out to do. Their reprogrammable computers are the reason the Voyagers today aren't just inert objects hurtling through space. The mission team was even able to debug and reprogram Voyager 1 as recently as this year.

Space exploration has always been an area that pushes technology to new heights. Space poses challenges that demand innovation, and human curiosity about the Cosmos makes the hard work of innovating worthwhile.

From written code on stacks of paper to artificial intelligence, computers have come a long way. But it's human ingenuity that has made this all possible.

EXPLORATION ON AUTOPILOT

The future of AI in space

by Asa Stahl

The first to glimpse alien life, the first to explore another star, the first to deflect an asteroid about to hit Earth — these might sound like distinct heroic roles, but all could actually describe the same thing. Each milestone, if it ever does happen, might be accomplished by artificial intelligence (AI).

We are entering a new era of space exploration and not just because AI will make spacecraft more powerful. Artificial intelligence is set to transform both robotic and crewed missions. Though we are only just beginning to imagine the challenges and possibilities, in the near future, more and more of humanity's next steps in exploring the Cosmos could prove impractical, or even impossible, without AI.

HUMAN RESOURCES

Today, every active space mission relies on human control. Whether planning a spacecraft's trajectory or picking a rover's sample site, teams of experts on Earth intervene to keep missions on track. The downside is that the kinds of exploration demanding quick, complicated decision-making often stay out of reach. No space agency has ever flown a drone through a Martian cave, for example, though it could tell us a great deal about the planet's past.

Human guidance also comes at a cost. Over the course of the 2010s, NASA's Science Mission Directorate spent $2.4 billion on mission operations alone. If that work had been streamlined by just 15% — say, by reducing the number of hours spent managing probes — the agency could have saved $360 million. That's enough to pay for another mission, like the recent Double Asteroid Redirection Test (DART), in full.

BETTER, FASTER, STRONGER

AI will change this equation. When human control threatens to become too impractical or expensive, artificial intelligence can bridge the gap. AI allows probes to plan out their own activities, navigate complex surroundings, and both detect and adapt to onboard problems. Missions can lean on AI for efficiency and, sometimes, to achieve entirely new feats.

Take NASA's DART mission. In 2022, it used an onboard algorithm to guide itself into the asteroid Dimorphos. Unlike previous missions, DART did not just follow a set of prewritten rules to slightly adjust its trajectory; its algorithm made its own decisions, commanding the spacecraft by itself for the mission's entire final phase.

On Mars, rovers have also benefited from machine intelligence. Every NASA rover since Opportunity has used a built-in system to examine its wide-field images and automatically decide which spots to photograph in detail. The result is more photos for less work, freeing the rover teams to focus on other tasks.

But there is much more AI could do for robotic exploration. For example, experts currently plan detailed schedules for Mars rovers almost daily, but with greater onboard intelligence, future missions could instead make their own plans based on overarching goals. In one recent test at a Marslike site, a rover with this sort of "smart" software was able to complete a science campaign a full 80% faster than one using traditional methods.

At the same time, missions could use AI to physically get around with less oversight. As it stands, difficult maneuvers like gravity assists and landings require extensive planning from ground control. Landing zones have to be scouted in advance, sometimes by entirely separate missions, and while rovers know to avoid some hazards, they are mostly limited to terrain that is nicely lit and easy to traverse.

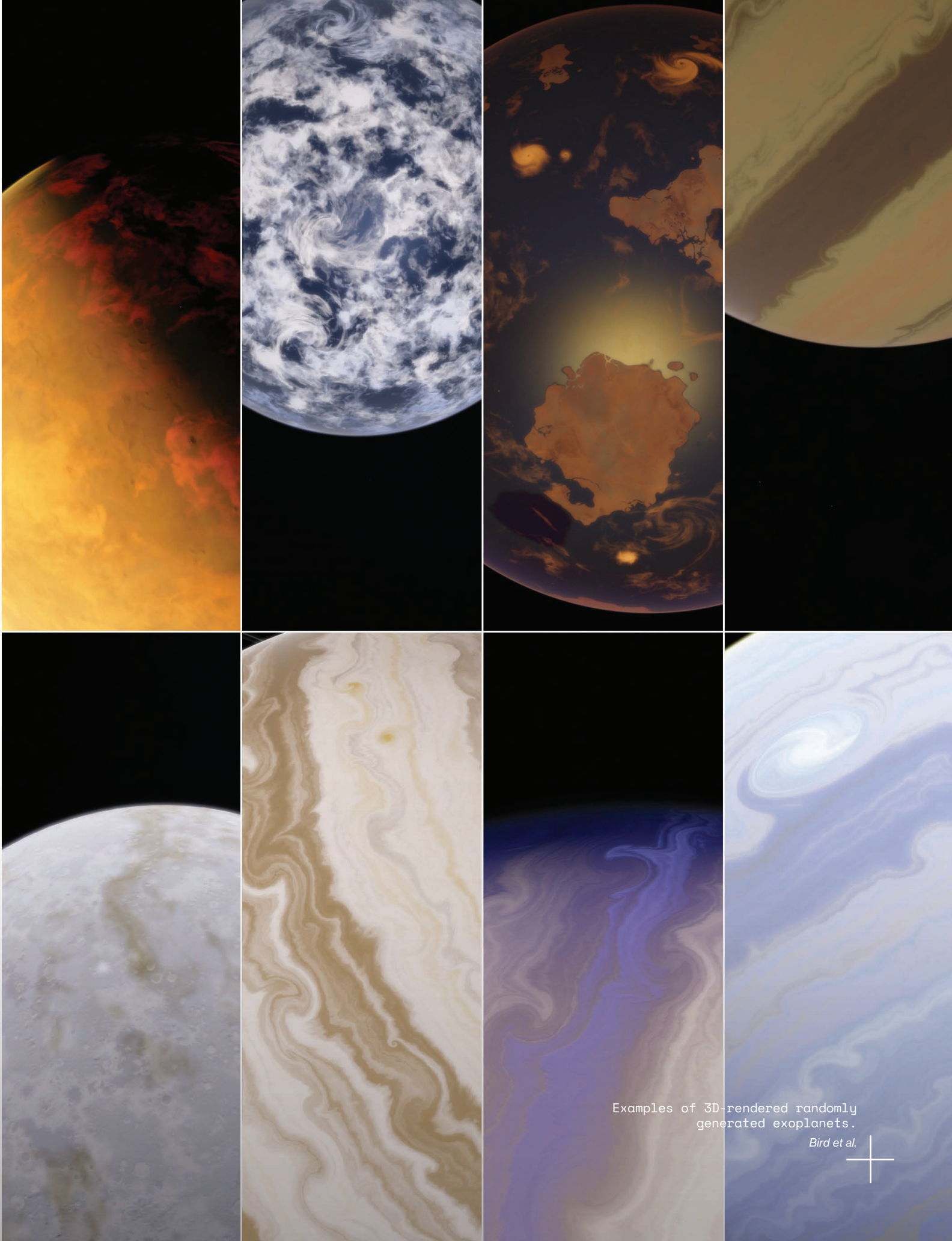
Smarter robots could one day handle all these operations on their own. In simulations, AI-driven spacecraft have planned maneuvers involving aerobraking and gravity assists that minimize fuel and travel time. AI methods can also automatically detect surface features like cave entrances, classify how navigable terrain is, and construct maps for rovers based on orbiter images.

Finally, more intelligent probes might not only understand their surroundings better but also their own workings. Research shows that AI-driven techniques can improve how a spacecraft identifies and adapts to internal problems in real time. This might help missions do things like account for broken instruments and spot software malfunctions caused by intense space radiation. If a wind sensor failed on NASA's InSight Mars lander, for instance, scientists have shown they could use AI to lessen the impact on the spacecraft's data.

I, SPACECRAFT

Put all this together and AI becomes perfect for self-reliant missions to unexplored worlds.

The next generation of robotic Moon rover, ENDURANCE-R, is a prime example. By relying on onboard intelligence, ENDURANCE-R would drive up to 2,000 kilometers (1,200 miles) in just three years, covering ground at over 50 times the rate of NASA's latest Mars rover. Though the mission has yet to be confirmed, the National Academy of Sciences has recommended ENDURANCE-R to become the agency's top priority within one of its lunar science programs.



Examples of 3D-rendered randomly generated exoplanets.

Bird et al.

AI spots a cluster of Mars craters: HiRISE's view
The High-Resolution Imaging Science Experiment (HiRISE) camera aboard NASA's Mars Reconnaissance Orbiter took this image of a crater cluster on Mars, the first ever to be discovered by artificial intelligence.
NASA/JPL-Caltech/University of Arizona

Planetary defense could also draw on AI to go beyond missions like DART. Untested methods, like nudging asteroids with ion beams or pulling them with a spacecraft's gravity, could use AI to keep probes hovering around their targets for long periods. And if there is no time to send a mission to scout out a dangerous asteroid, a spacecraft that uses AI to adapt to unknown bodies could make the difference in averting catastrophe.

Perhaps no missions stand to benefit more from AI, though, than those searching for life on faraway worlds like Europa and Enceladus. Where communication signals take around an hour to travel to Earth and back, missions all but have to govern themselves to achieve anything. AI could also help probes navigate unexplored terrain on these worlds, as the interview later in this issue of The Planetary Report shows.

But getting instructions to a distant lander is only half the problem; the other half is getting data back. Downlink speeds from these missions can be slower than dial-up internet. In a single minute, with just one instrument, a Europa lander mission might collect 40 times more data than it could send back to Earth over its entire lifetime. Though data can be compressed and transmission technology improved, neither is expected to come close to solving this problem soon.

So, upcoming missions will have AI summarize their measurements and decide which should be sent back to scientists. The European Space Agency's Rosalind Franklin rover will use this method to look for organic compounds on Mars, while NASA's Dragonfly mission will apply it to Saturn's moon Titan. Both missions are slated to launch in 2028. If either ends up finding something spectacular, AI will likely have seen it first and passed it along.

DON'T SAY HAL

AI will make robots more capable, but it will not replace human crews. If anything, AI may be essential to expanding humanity's presence farther from Earth. Just as more distant or complex robotic missions can depend on AI to replace mission control, space stations and crewed deep-space missions can use onboard intelligence to rely less on a distant home planet.

Already, AI has acted as a personal assistant to astronauts aboard the International Space Station. A computer powered by IBM's Watson AI made the trip twice in the past few years, taking a first step toward future AI astronaut helpers. Another assistant, this one based on a large language model similar to ChatGPT, will soon be tested by ESA on Earth.

UPDATE IN PROGRESS...

There is still a lot to figure out, though, before AI starts commanding entire missions or helping astronauts in deep space.

For one, AI methods can be hard to trust. Smarter algorithms often function in ways that aren't transparent, and since AI methods are meant to respond to a huge variety of conditions, testing them is difficult. Unlike a self-driving car, an AI-enabled spacecraft can't be crash-tested around a warehouse. Future systems will probably be proven almost entirely through computer simulations. Research shows that these methods could be enough to show that AI systems are ready to fly, but this part of the field is only just getting started.

> **"In one recent test at a Marslike site, a rover with this sort of 'smart' software was able to complete a science campaign a full 80% faster than one using traditional methods."**

Yet the biggest roadblock to adopting AI for space exploration may not be issues with the technology itself but with how it fits into space agencies. This is not new. In 1980, a panel of experts chaired by Planetary Society co-founder Carl Sagan published a report criticizing NASA's attitude toward machine intelligence and robotics, calling it "conservative and unimaginative." Since computer science is so essential to space exploration, the panel argued, NASA should act as an incubator for it. Otherwise, the agency will have to wait for private companies to invent new technology and then adopt it, rather than developing their own systems tailored to the needs of exploration.

Today, NASA is no AI incubator, but it's not stuck in the past. It also has a very different relationship with the private sector. The agency launched an AI research partnership with Nvidia, Google Cloud, and other leading organizations in 2016, well before the recent jump in AI's popularity. NASA has built some AI methods into recent missions, and it established its own chief AI officer in 2024.

Still, NASA and other space agencies have done little to apply AI to spacecraft operations more broadly. Some experts argue that this might require a change in how agencies think about their missions. Officials would have to view AI as a way to improve a mission's reliability instead of just adding risk, spacecraft and instrument teams would have to work together more closely than they do now, and agencies would have to invest in AI on more than a mission-by-mission basis.

As science challenges us to expand where we might boldly go and the discoveries we might boldly make, the impact AI could have on space exploration will only grow — and so will the reasons for agencies to make these kinds of changes.

After all, we don't know whether the first major discovery to depend on AI will come from a moon of Saturn, a nearby star, or somewhere else entirely. But with the right support, AI will provide a way of knowing the Cosmos unlike any we have ever had before.

EELS AND THE FUTURE OF EXPLORATION

How artificial intelligence could traverse other worlds

by Kate Howells

If you want to send a robotic explorer to an unexplored planet or moon, how should you design it to move around its environment? The future of exploration may involve letting the robot decide for itself.

This is one of the core principles of NASA's EELS (Exobiology Extant Life Surveyor) project. This technology demonstration (not yet an approved mission) was first designed with the challenges of exploring Saturn's moon Enceladus in mind. Data from NASA's Cassini spacecraft hinted at a subsurface ocean of liquid water beneath the icy crust, sometimes spewing out into space through cracks around the moon's south pole. In that ocean, conditions may be favorable to life. But sending a spacecraft to probe those icy depths would be challenging. Enceladus is extremely far away, making communication difficult, and we don't have a detailed understanding of its surface environment.

EELS aims to address a challenge like this through artificial intelligence coupled with an innovative design. The robot's snake-like body is made of multiple segments, each capable of moving independently to enable propulsion, traction, and grip. EELS can change its shape and how it moves to adapt to whatever environmental conditions it encounters. Crucially, it doesn't rely on commands from Earth to make those decisions; EELS maps its surroundings using stereo cameras and lidar and then uses artificial intelligence to decide how best to get around.

The team behind EELS believes that its autonomy and adaptability represent a paradigm shift in robotic exploration. Hiro Ono, EELS principal investigator, describes this as "Robotic Exploration 3.0." In November, Ono and graduate student Morgan Cable spoke with Planetary Radio host Sarah Al-Ahmed about the project, the role artificial intelligence plays in it, and how the future of space exploration might evolve.

First of all, the big question: Given the challenges, why explore a distant, unknown environment like Enceladus at all?

This transcript has been edited for length and clarity.

Morgan Cable: Enceladus is just such a fascinating world. Every place in our Solar System is unique and interesting in its own right. But for me, Enceladus holds such magic because it has this liquid water ocean and this tortured surface with cracks in it, and it is the one place where we know that water is coming straight from that ocean into space in a way that we can access it with technology today.

From an astrobiology perspective, this is one of our first real opportunities to test this question: If you have the ingredients for life — water, chemical building blocks, and energy — and you mix them together and wait, does life form? This is a place where we can go and test this. We call this civilization-level science because when you discover life elsewhere for the first time in human history, you only get to do that once. And we have the technology to detect life on another world right now. We just have to get there. We have to go.

Sarah Al-Ahmed: Because the terrain of Enceladus is complicated, if we want to find life, we're going to have to find ways to get down into those cracks and potentially sample things in the water. And that is a colossal challenge to tackle.

MC: Life is not likely to be just sitting out in the open on a planetary surface where it's exposed to the extreme conditions of space. Chances are it's going to be in those hard-to-reach places: under a rock, in a crevasse, down in one of these subsurface liquid water oceans. And developing technology that can tackle those challenges gives us access to these places that previously were so far out of reach.

SAA: That brings us to EELS.

▼ Slithering onto the scene
Version 1.0 of JPL's EELS robot.
NASA/JPL-Caltech

MC: Picture an anaconda-size robot designed to navigate the features on the surface of an icy world and then get down into a vent — a crack in that ice shell. And there, stuff is shooting out at 200-300 kilograms (440-660 pounds) a second. This robot will need to push against the walls of that ice shaft and move down to get into the really exciting environment: that liquid water ocean.

Hiro Ono: There are many reasons that this is challenging, but I would say the greatest challenge is the uncertainty, the unknowns. We've sent 10 spacecraft to Mars, knowing a lot beforehand about the regions where we landed and explored. But the best resolution we have on Enceladus is about 6 meters (20 feet) per pixel and only around very limited regions. We don't know, for example, what the surface topography is or what the geometry of the vents is. We still don't know how strong the jets are. It's really, really hard to design an explorer without knowing what the environment is.

That's why EELS is so different from rovers, in that its snakelike design gives it many ways of moving around. If something unexpected happens, it can change the mode of locomotion and figure out the best way to interact with the environment.

SAA: There are two things going on here. One is the actual physical design of this object, but there's also the brain behind this technology. EELS uses artificial intelligence to figure out how to move around its environment based on the conditions it encounters. Hiro, you've spoken before about the idea of "Space Exploration 3.0." Can you talk a little bit about this framework for understanding space exploration and how this technology represents a new phase forward?

HO: The way we explore planetary surfaces has changed over time. In the '60s, NASA sent a bunch of spacecraft to the Moon as a precursor to Apollo. It was basically trial and error to learn what worked. And that was a reasonable way to learn how to get to the Moon because the Moon is nearby. You can get there in three days. So we could call that "Robotic Space Exploration 1.0": trial and error.

Mars is six to seven months away, and the launch window opens up only every 26 months. Now you cannot do trial and error and wish for the best, right? You need to be sure that what you're going to do will work, so we changed the mode.

We got more cautious; we incrementally learned about the environment and refined our capabilities, starting with flybys, orbiters, landers, and then rovers. Then, we knew enough to build Curiosity and Perseverance — super complex robots — and now we are designing an even more complex Mars Sample Return campaign. That's "Robotic Space Exploration 2.0." And that's how we were so successful on Mars in the past few decades.

But we can't extrapolate that model to the outer Solar System, simply because it takes much too long to get to those destinations. So that's where "Robotic Space Exploration 3.0" comes in. It involves a more intelligent, more adaptive robot capable of diving into a highly unknown environment — a robot that can learn by itself [and] adapt by itself to robustly explore the environment.

SAA: A huge benefit of this kind of technology is that it can be used for many different destinations since it adapts itself to new environments. What could this mean for the future of space exploration? And how has EELS moved us toward this future?

MC: The planets and moons of the outer Solar System are so diverse and fascinating.

And each time we send a spacecraft somewhere new, we learn more than we could have possibly imagined. Just think about if we had dedicated missions for each of the worlds around Jupiter, Saturn, Uranus, Neptune, and beyond, as well as the asteroid belt. There are so many exciting worlds to explore, and each one is deserving of its own mission.

One of the coolest things I've discovered working on the EELS project is that the snake has already grown legs in a certain way. Some of the technologies that we developed, particularly some of the autonomy technologies as well as a few of the others on the engineering side, are being incorporated into other mission concept developments and other engineering and robotics projects at JPL. I definitely hope to see an EELS-like robot on another world in my lifetime. I really think that would be incredible.

SAA: And we should be clear: There is no mission currently planned to go to Enceladus. But if we want that mission to exist, we need to build the technologies to do it.

HO: I think a mission to the subsurface ocean of icy moons will happen. Why? Because there's this fundamental question that we want to answer. This is probably one of the oldest questions of humankind. What I don't know is how soon it is going to happen. And I think it's fair to say that we're making a great leap in the technologies needed for that. Whatever spacecraft actually goes down into an icy moon's ocean may or may not look exactly like EELS. But our contributions will be there.

MC: NASA's mission has always been driven by the science. As long as there is NASA, as long as we are still guided by science and by looking up at the night sky and wondering, as long as that is still our guiding light, our candle in the dark, we will be sending spacecraft out there to these ocean worlds and exploring their watery depths.

SAA: You've just got to dare enough mighty things, one step at a time.

MC: Or one slither at a time if you're a snake.

Enceladus in the infrared
This global map of Enceladus shows the icy moon's surface in infrared wavelengths. Captured by NASA's Cassini spacecraft as it orbited Saturn, this map shows warmer (redder) regions around the south pole, where liquid water sometimes erupts through the thinner ice.

NASA/JPL-Caltech/University of Arizona/LPG/CNRS/ University of Nantes/Space Science Institute

ARE WE ALONE IN THE UNIVERSE? AI MAY HELP US FIND OUT

The field of SETI research (the search for extraterrestrial intelligence) addresses one of the biggest mysteries facing humanity: whether we are alone in the Universe. This question is one that The Planetary Society's science and technology programs try to help solve. As part of that endeavor, our STEP (Science and Technology Empowered by the Public) Grant program has provided funding to "Are We Alone? A Citizen-Science-Enabled Search for Technosignatures," a project led by planetary astronomer Jean-Luc Margot of UCLA.

The project uses the 100-meter Green Bank Telescope in West Virginia to capture radio signals from 100 stars with known planets along with tens of thousands of additional stars and planetary systems. One major challenge in a search like this is to filter potential extraterrestrial signals from the immense volume of radio frequency interference (RFI) generated by earthly sources.

Megan Li, a Ph.D. student on the project, is working on this challenge using artificial intelligence. "To give you a sense of the volume of RFI we're dealing with," says Li, "two hours of observations using the Green Bank Telescope detects about 11 million instances of RFI. Before I joined UCLA SETI, there was already a protocol in place that automatically classifies 99.6% of these signals as RFI. However, that still leaves about 45,000 signals in each two-hour observation that need further analysis. Ideally, we would conduct SETI observations continuously, but manually inspecting those 45,000 signals would take at least 12 hours per two-hour observation."

This is where artificial intelligence comes in. Volunteers on the Zooniverse citizen science platform help categorize known RFI patterns, training a machine learning system to conduct future searches faster and more efficiently. "The machine learning model we're using is a convolutional neural network," says Li, "which relies on iterative calculus to recognize similar patterns across images. This technology is similar to that used in self-driving cars: Just as we want a car to distinguish red from green lights, we want our model to reliably identify one type of radio frequency interference from another. We're training the model to identify distinct RFI types because if its understanding of RFI is too broad, we risk discarding potential extraterrestrial signals. Thanks to the patterns labeled by our volunteers, we're training the network to identify these specific RFI types."

Caution is needed when using AI for SETI research. AI's drive to maximize metrics like speed and efficiency can lead to problems. "AI might quickly 'solve' the question of whether a SETI search found ET by simply answering 'no' each time," Li explains, "and such an answer would go unnoticed. Conversely, if AI leans too far toward identifying everything as ET-related, we face issues with model accuracy." This is why the project uses AI to assist with specific tasks rather than making decisions about potential ET signals on its own.

Although AI research is a complex and growing field, Li emphasizes that it is accessible to everyone. "When I began this project in 2023, I had no prior experience with AI and only three years of basic Python programming under my belt. Starting out, I felt intimidated, and the entire endeavor seemed overwhelming. But today, I no longer feel that way. I am living proof that working with AI isn't reserved for elite programmers; anyone can join in thanks to the plethora of free tools and resources available online."

The potential for AI in SETI research also raises an intriguing possibility: If there are other technologically advanced civilizations out there using AI as a tool for exploration, one artificial intelligence could someday detect another. "One of the things I love about SETI," says Li, "is how our ideas about contact evolve with humanity's own experiences. The Drake Equation, a formula for estimating the probability of contact, has changed with us, sometimes factoring in civilization-ending risks like nuclear war or climate change. I imagine that some may already be advocating for an 'AI-takeover' variable!"

A NEW LOOK FOR THE PLANETARY REPORT

Color theory
Early explorations of "*The Astronaut's Almanac.*"
Ariaï

If this is your first time receiving The Planetary Report, welcome! If not, you'll have noticed that things look a little different now. We have welcomed a new duo of talented designers to reenvision the look and feel of our longstanding member magazine. To create this new vision for the magazine, Aïda Amer and Arielle Wilkins, who together form the design agency Ariaï, delved into the Society's past and learned about our goals for the future. Here are a few words from Aïda about their design inspiration.

The night before Arielle and I presented our very first pitch to work on the redesign of The Planetary Report, we were meticulously building and rebuilding our slides. For days, we had been poring over magazine layouts, typography hierarchies, and NASA image libraries, pulling pieces together to create something sleek and eye-catching without being overly trendy.

Our greatest inspiration, however, ended up coming from, weirdly enough, eBay.

It was just an off chance, but as avid collagers who had bought old magazines before, we thought we might be able to look through some old issues of The Planetary Report for inspiration. Who knew what we might find?

Beacons in the night
The SONEAR Robert C. Byrd Green Bank Telescope at the National Radio Astronomy Observatory (NRAO), Green Bank, West Virginia, as seen on Oct. 26, 2012. (Image has been flipped horizontally.)
Jiuguang Wang/Flickr

A few clicks and we found them: original prints and covers of the magazine, which would serve as a muse for our new concept, dubbed "The Astronaut's Almanac."

Moving from design inspiration to implementation is all about the details. While we have integrated some nods to The Planetary Report's legacy into the Almanac design, we also wanted to bring a feeling of elevation and modernity.

Combining cyber-futuristic and retro-schematic details, we also aimed to evoke the gravitas of an official report. The cover font, Eurostile, is the original font used in The Planetary Report's earliest cover design but is supported by the more modern Nexa in the supplementary text. Inside, Nimbus Sans takes center stage as a font that references the width of Eurostile but remains clear and easy to read. Our two interior headline fonts, Jay URW and Megazoid, help create a balance between serious subject matter and topics where we can have a bit of fun. And with bold use of lines and subtle shadow work, we aim to prioritize readability and clarity.

Throughout the design, we've implemented small flourishes to pull you into a visual narrative that can only be experienced in the Report. If you look closely, you'll see them peppered throughout the magazine as small gifts to our fellow space lovers. We introduced elements inspired by science fiction cinema and gaming, like head-up display markers used as reference points for new sections or to draw your attention to images. You'll also see small minimalist and utilitarian icons inspired by the illustrations on the Voyager Golden Record along the page edges, guiding you through your journey.

All of these touches speak to our love of space. Arielle has six space-themed tattoos at the time of writing (by the time of publication, she may have one more), and I have a too-large collection of books on space and am a hobbyist astrophotographer. (In fact, I took the photo of the night sky that serves as a starfield background on some pages of this issue.)

We designed this magazine for people who love space as much as we do.

We hope you enjoy your journey through this reimagining of The Planetary Report, dear reader. May it bring you closer to the stars.

SPACE FOR EVERYONE

City lights in northern Mexico streak by in this long-exposure photograph taken from the International Space Station on Oct. 24, 2024.
NASA/Don Pettit

The Planetary Society implemented the Space for Everyone five-year strategic planning framework in 2019, which elucidated the organization's big-picture goals and priorities. Now, the Society is preparing to roll out a new framework in late 2025.

Planetary Society Director of Content and Engagement Rae Paoletta caught up with COO Jennifer Vaughn to recap the most recent strategic planning era and preview what's to come.

This interview has been edited for length and clarity.

Rae Paoletta: What is a strategic planning framework, and why is it helpful for The Planetary Society to have one?

Jennifer Vaughn: I think if you asked 1,000 different people, you might get 1,000 different answers that are ever so slightly different from one another. But a strategic framework, or a strategic plan, is a commitment to how you intend to develop your company, your organization, your life — it can apply to anything. And for The Planetary Society, this is very much a deep look at where we are at a given moment and then an aspirational look at where we want to go. The plan helps you develop your pathway for getting there — or your best guess at a pathway for getting there.

RP: Over the last five years or so, how has The Planetary Society advanced our three core enterprises: explore worlds, find life, and defend Earth?

JV: The first thing we did back in 2019 was commit to working on only the core enterprises, and that was a big deal for the organization. Before the 2019 to 2024 plan, there was a bit more uncertainty about where our boundaries were. Space is huge, and so we had to decide: What do we do? What don't we do? Since we are a relatively small nonprofit, we simply can't do it all.

That allowed us to be very bold in our policy principles, which became very well defined during this period. They're on our website so anyone can see how we advocate and how we work to shape decision-making around those three core enterprises.

On the education front, having our core enterprises has allowed us to build out long-term evergreen resources on our website that help our audience truly understand the worlds that we're exploring and how we're exploring them.

And our science and technology grants actively support work in all three core enterprises. With planetary defense, we've been able to give more money to more researchers through our Shoemaker Grants.

RP: What victories from the last five years are you most proud of?

JV: We have a digital community that allows for a deeper connection with our members, and I just love that community so much. If I ever start feeling a little down or like I need a lift, going into the community and watching our members interact with each other makes me feel great. Having a digital community was one of the initiatives of this planning period, and I'm super excited to see it grow.

There's also the Day of Action, which we started back in 2019. Right when we kicked off this current strategic plan, we had our first Day of Action, and it has been so successful on so many fronts. Our members who attend are so committed that they put their own time and money into going to Washington, D.C., getting trained, and really being the face of the public that wants more scientific exploration of our Solar System and beyond. I think it's very refreshing for legislators to hear that and to see it directly.

Our new STEP Grant program provides seed funding for new science and technology projects. We've always done this kind of work of funding smaller or niche projects — things that were maybe struggling to get initial backing — but they're really valuable steps to science and technology. What we didn't have until this most recent strategic period is the framework for an open call for proposals specifically supporting the three core enterprises, a regular cadence of grants, and the beginning of an endowment to provide future support.

It was also during this footprint that LightSail 2 happened. In 2019, we had an active spacecraft, and LightSail 2 was orbiting and sending down data. We were changing the orbits, and we were seeing so many beautiful images. I'm still awed that 50,000 everyday people came together to make that mission a reality. It's truly astounding. The work of LightSail continues to have a

real impact out there, and I will always be very, very proud of the accomplishment.

I hope that our members recognize that these achievements are theirs. It's their support that makes this all possible. Through initiatives like our Beyond the Horizon campaign, it's a victory in itself to see how our space community comes together to create the future of space exploration that we all want to see.

RP: What can we expect to see in the next strategic framework?

JV: I don't have details I can share yet because we're just maybe a third of the way through this process. But there are certain themes that are showing up that I know are going to matter to us. One is international connection. Starting from 1983, the organization committed to being an international group and not a U.S. group. We are based in the U.S. and have mostly U.S. members. So in many ways, there will always be a lot of United States emphasis and perspective, but it's very important to us that the whole world is getting excited about space. It's very important to us that there is a place for the whole world to come together and that we are trying to create a global movement for the scientific exploration of our Solar System and beyond.

RP: What are you most excited about as the Society enters a new strategic planning era in 2025?

JV: The future! I'm excited about new generations getting excited about space exploration and more people from around the world getting involved. The year 2030 will be The Planetary Society's 50th anniversary, so I'm also excited by a new influx of energy, ideas, and perspectives that are being brought into the organization. By 2030, we want to be the best-ever version of The Planetary Society. I'm also excited that Apophis is going to come by Earth during this period. Apophis has been part of our story for two decades, and in 2029, it's finally passing by Earth. That's going to be a big milestone.

And of course, Europa Clipper is going to arrive, NEO Surveyor is scheduled to launch, and the Rosalind Franklin rover will be landing on Mars. It's going to be a great time to be exploring space.

FROM THE CHIEF SCIENTIST

A cosmic roundup from The Planetary Society's chief scientist

by Bruce Betts

IN THE SKY

In March, bright Jupiter is in the western sky in the evening. It gets closer to the horizon as the weeks pass until it is very hard to see in June. Reddish Mars is very high in the sky in the evening. Watch it dim gradually as Mars and Earth grow farther apart in their orbits. Super-bright Venus and yellowish Saturn will start rising in the predawn east in April and grow higher over time. Soon after sunset, Mercury will be visible low to the west from mid-June into July. There is a partial solar eclipse on March 29 visible from eastern Canada and northern and western Europe.

For more night sky tips, you can always check out **planetary.org/night-sky**.

TRIVIA CONTEST

Our September Equinox contest winner is David Lee Summers of Las Cruces, New Mexico, USA. Congratulations!

The question was: *What type of celestial object, when the first one was discovered, was nicknamed LGM-1, standing for Little Green Men-1?*

The answer: The first pulsar, due to the time regularity of the pulsing radio signal coming from it.

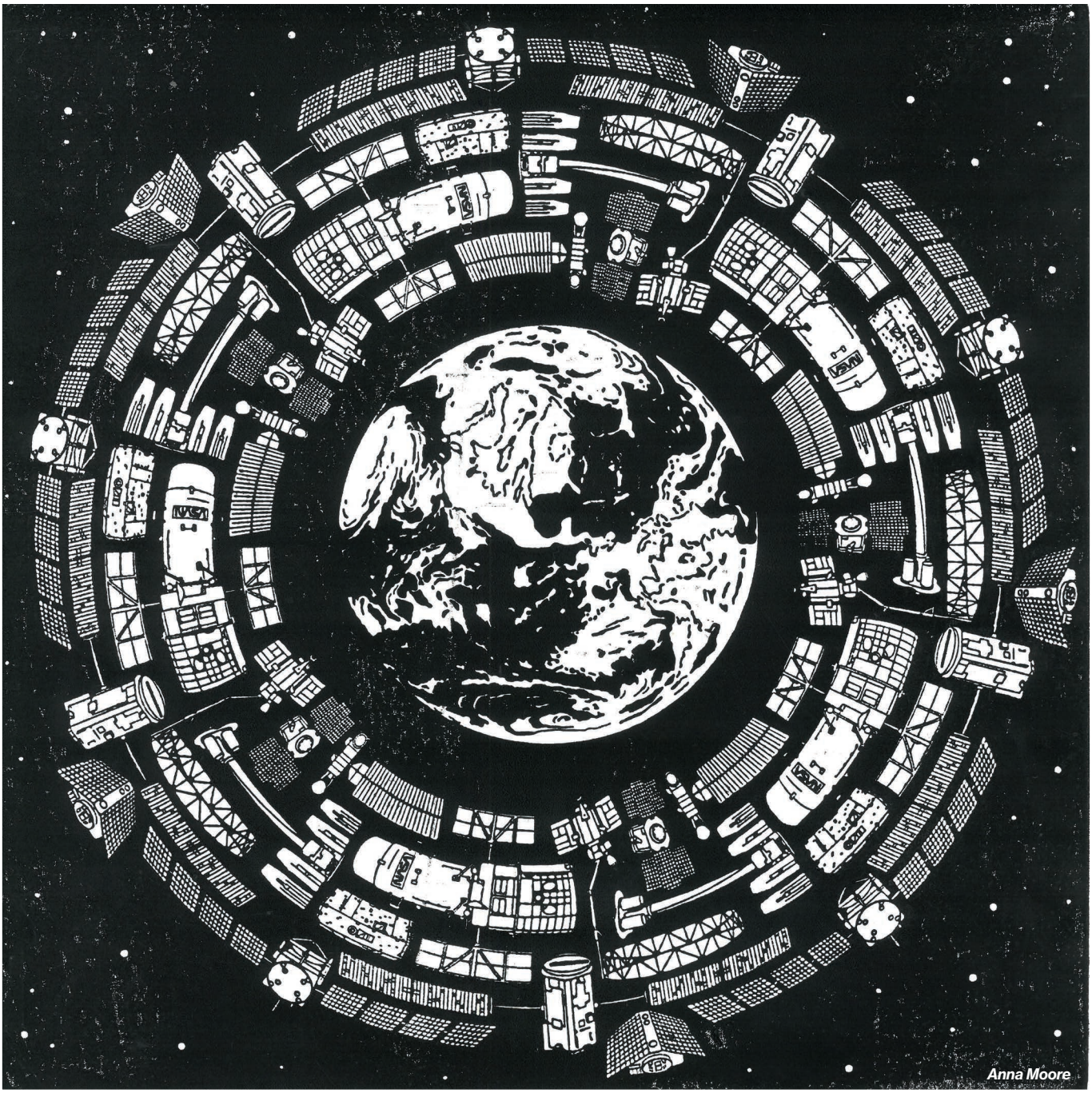
Try to win a copy of the new book "Mars: The Red Planet with The Planetary Society" by Bruce Betts and a Planetary Radio T-shirt by answering this question:

What was the last mission to fly by Jupiter on its way to somewhere else?

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, 2025. One entry per person. The winner will be chosen in a random drawing from among all the correct entries received.

RANDOM SPACE FACT

The surface area of Jupiter's moon Europa is approximately equal to the area of Africa. To equal the surface area of Jupiter's moon Ganymede, the largest moon in the Solar System, you would need not only Africa but all of Asia and Europe in addition.



SPACE ART

This print by artist and Planetary Society supporter Anna Moore, titled "Orbit," shows a repeating pattern of spacecraft around our planet.

"Orbit" captures the role of technology in space science and exploration. From advanced AI to basic nuts and bolts, every element that allows us to reach out into the Cosmos is designed and built by humans. Although exploration is a human endeavor, it is carried out by technologies we create.

This art piece is also a feat of technology. Anna made a digital illustration based on real spacecraft images, then laser-engraved the illustration onto a wood block to make a print.

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.

ADVOCATING FOR PLANETARY EXPLORATION ON CAPITOL HILL

In October 2024, The Planetary Society's director of government relations, Jack Kiraly, organized two targeted advocacy days to connect leading experts in space science with key legislative and committee staff on Capitol Hill.

These visits were part of a concerted effort to demonstrate the importance of space science and exploration to key leaders in Washington, D.C. Between the two advocacy events, we also facilitated 18 meetings between scientists and House and Senate staff.

The first event, held on Oct. 3 and 4, focused on the lunar science community, which is reeling from NASA's abrupt cancellation of the Volatiles Investigating Polar Exploration Rover (VIPER) mission in July. Lunar scientists, including Dr. Clive Neal, Dr. Ben Fernando, and Ruby Patterson, engaged in meetings to underscore VIPER's importance and advocate for reversing recent budget cuts that have fallen predominantly on NASA's Science Mission Directorate.

VIPER, the agency's first robotic lunar rover, is critical to understanding water resources on the Moon and lays the groundwork for long-term human exploration. VIPER was originally slated to land on the Moon under a Commercial Lunar Payload Services contract with Astrobotic. The rover was fully built and had begun environmental testing when NASA proposed canceling it. But thanks to significant public pressure — including a letter signed by nearly 5,000 space advocates — and congressional action, the cancellation was rejected by Congress. NASA has turned to industry and international partners to help get VIPER a ride to the Moon.

Turning to Earth's "evil twin," Venus, NASA currently has two missions on the books: the Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) orbiter and the Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) probe.

The Aurora Borealis is seen over the United States Capitol on Oct. 10, 2024.
Jonah Bryson

When these missions began development in 2021, they were expected to launch sometime in the mid-2020s. However, due to budget constraints, the missions' schedules were upended, and VERITAS was put on an indefinite hold. In early 2023, space advocates successfully called on Congress to restart the development of these missions, which was secured as part of the fiscal year 2024 budget. However, both missions are still facing budget-related delays that would push their launches into the 2030s.

Enter The Planetary Society, which organized a Venusian advocacy day coinciding with the 30th anniversary of the end of the Magellan orbiter — the last American mission to the planet. Independent members of the VERITAS and DAVINCI science teams, Dr. Darby Dyar and Dr. Stephen Kane, respectively, came to Washington, D.C., to advocate for fully funding these missions and ensuring a robust, balanced planetary science program.

These prominent Venus scientists spoke with congressional staff about the critical insights these missions would provide about Venus' geology and climate, their importance in understanding the evolution of terrestrial worlds, and the need for consistent funding to avoid delays that could jeopardize decades of progress in planetary exploration. Primed by the support of space advocates around the country, these meetings helped reignite enthusiasm on Capitol Hill for Venus exploration.

These advocacy days highlight the critical role of public engagement in advancing NASA's science goals. By connecting experts with policymakers, The Planetary Society continues to push for increased investment in space science and exploration, emphasizing the need for consistent support to avoid derailing progress on high-priority missions and diminishing U.S. leadership in space.

YOUR MEMBER COMMUNITY

If you haven't already logged in, be sure to check out The Planetary Society's online member community. This is a virtual environment tailored to the interests of our members, away from the bots and trolls of social media. Here are some highlights of what you'll find when you visit **community.planetary.org**:

- Connect with space enthusiasts from around the world
- Talk to space experts in virtual webinars
- Share artwork and astrophotography
- Join virtual book club meetings
- Take in-depth online courses on topics you'll love, including:
  - → Stargazing
  - → Space policy and advocacy
  - → The search for life

FUNDRAISING SUCCESS!

Thank you to all the members and supporters who took us beyond the horizon with your support for our year-end fundraising appeal, raising over $325,000 to support the Society's mission to advance space science and exploration. We are especially grateful to our board of drectors, an anonymous donor, and CEO Bill Nye for their generous matching gift challenges that inspired support from Giving Tuesday to the last day of the year and beyond.

A 45TH ANNIVERSARY MEMBER EVENT

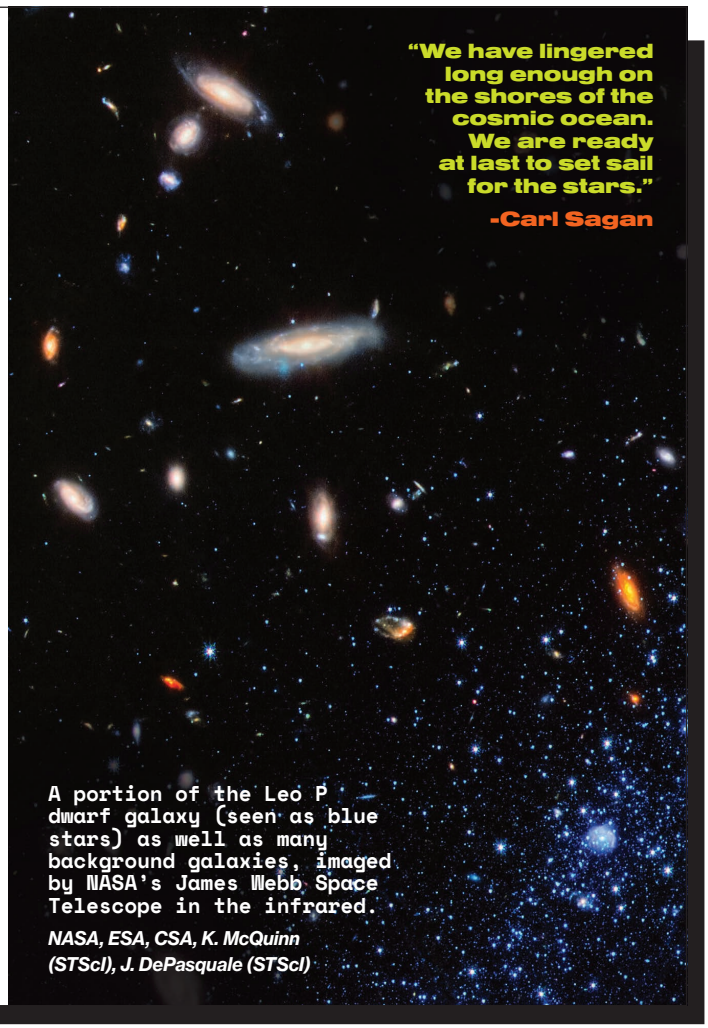
Join us for a cosmic adventure as we set sail for the stars! We're celebrating a very special occasion: The Planetary Society's 45th anniversary.

All members are cordially invited to a special lecture, gala dinner, and awards presentation from 4:00 to 9:00 p.m. PT on Saturday, April 5, 2025, hosted aboard the RMS Queen Mary in Long Beach, California.

Venture beyond the shores of our cosmic ocean for an extraordinary evening celebrating 45 years of pioneering space exploration. Join Master of Ceremonies Robert Picardo and embark on an elegant gathering featuring enlightening talks from distinguished speakers, recognition of outstanding achievements through our prestigious awards ceremony, and an exclusive silent auction offering unique space-related treasures. Immerse yourself in an atmosphere of wonder and discovery, complemented by sophisticated cuisine and celestial melodies as we honor our legacy and envision the fascinating journey ahead.

In the words of one of our founders, Carl Sagan, "Never again will the planets be mere wandering points of light ... they will forever after be worlds crying out for exploration and discovery." See you on board!

Go to **planetary.org/anniversary** to learn more.



A portion of the Leo P dwarf galaxy (seen as blue stars) as well as many background galaxies, imaged by NASA's James Webb Space Telescope in the infrared.

NASA, ESA, CSA, K. McQuinn (STScI), J. DePasquale (STScI)

One for the road

Total lunar eclipse of April 15, 2014.

Max J. Corneau

SOCIETY TRAVEL

We invite you to join other members and friends of The Planetary Society to discover the world on a Betchart Expeditions adventure!

Please contact Terri or Taunya at Betchart Expeditions for brochures and updated information. Call 1-800-252-4910 or email info@betchartexpeditions.com.

Aug. 26 – Sept. 10, 2025

MAGNIFICENT MADAGASCAR & LUNAR ECLIPSE

Explore the unique heritage of Madagascar and see the lunar eclipse and the spectacular southern skies! Isolated from the African continent for over 30 million years, Madagascar is home to fauna and flora found nowhere else!

Sept. 3 – 14, 2025

TANZANIA SAFARI & LUNAR ECLIPSE

Come with us on safari in Tanzania! See the finest wildlife reserves in East Africa and the total lunar eclipse! This is a tremendous experience for travelers to view the Milky Way over spectacular Ngorongoro crater and the Serengeti. With leadership by an excellent astronomer and safari guides, this will be an exceptional experience.

March 15 – 21, 2025

ALASKA AURORA BOREALIS

Come see the greatest light show on Earth! Visit the Kenai peninsula and then take the train to Fairbanks. Delight in the ice festival and the aurora borealis in the night sky!

Aug. 3 – 13, 2026

MAJORCA, SPAIN & TOTAL SOLAR ECLIPSE

We invite you to join our Spain total solar eclipse adventure, including special visits to Madrid's historic Royal Observatory, the Castile La Mancha Science Museum in Cuenca, the remarkable City of Arts and Sciences center in Valencia, and the enchanting Mediterranean island of Majorca to see the total solar eclipse at sunset!

THE PLANETARY SOCIETY
60 SOUTH LOS ROBLES AVE
PASADENA CA 91101-2016 USA

ADVOCACY ACTION ALERT!

Since The Planetary Society's founding 45 years ago, supporters like you have been powerful and effective space advocates as part of the world's largest and most influential nonprofit space organization. Together, we've ensured that space exploration remains a top priority on Capitol Hill.

Today, your support is just as important as it has ever been to keep our advocacy efforts going strong. Please consider making your most generous contribution today and your advocacy gift will be doubled – up to $75,000 – thanks to a generous Planetary Society member.

Visit **planetary.org/takeaction** to put your donation to work right away.