TAKING STOCK OF THE SOLAR SYSTEM

LUNAR AND PLANETARY INFORMATION BULLETIN

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Lori Glaze, NASA Planetary Science Division Director

As we turn over the calendar and start another year, NASA and the National Science Foundation (NSF) are also on the eve of receiving the Planetary Science and Astrobiology Decadal Survey for 2023–2032 from the National Academies of Sciences, Engineering, and Medicine (NASEM). This document, expected to be released in the spring of 2022, will lay out a vision for the next decade of solar system exploration, and help guide many of the activities conducted by the Planetary Science Division at NASA. I am excited to read what the Survey recommends, but before that, I want to take this opportunity to "take stock" and reflect on the current state of planetary science at NASA.

First and foremost, it is important to underline that this is an incredible time to be a planetary scientist — I thank my lucky stars often that I get to lead the Planetary Science Division (PSD) during this era of planetary exploration. Right now, we have 38 missions on our "fleet chart" (Fig. 1). Some of those are in development, some are in primary operations, and others are in their extended missions. More still are missions led by international agencies, on which we are proud to partner and provide mission hardware. These missions span the full breadth of the solar system — from ESA/JAXA's BepiColombo mission currently on its way to Mercury (it performed the first of five Mercury flybys in 2021 and is due to enter Mercury orbit four years from now, in December 2025), all the way to the Kuiper belt with New Horizons, which is continuing its journey after encounters with the Pluto system and Arrokoth.

Some of 2021's biggest PSD highlights included changes and updates to this fleet chart. For instance, we celebrated two flawless launches of planetary missions in

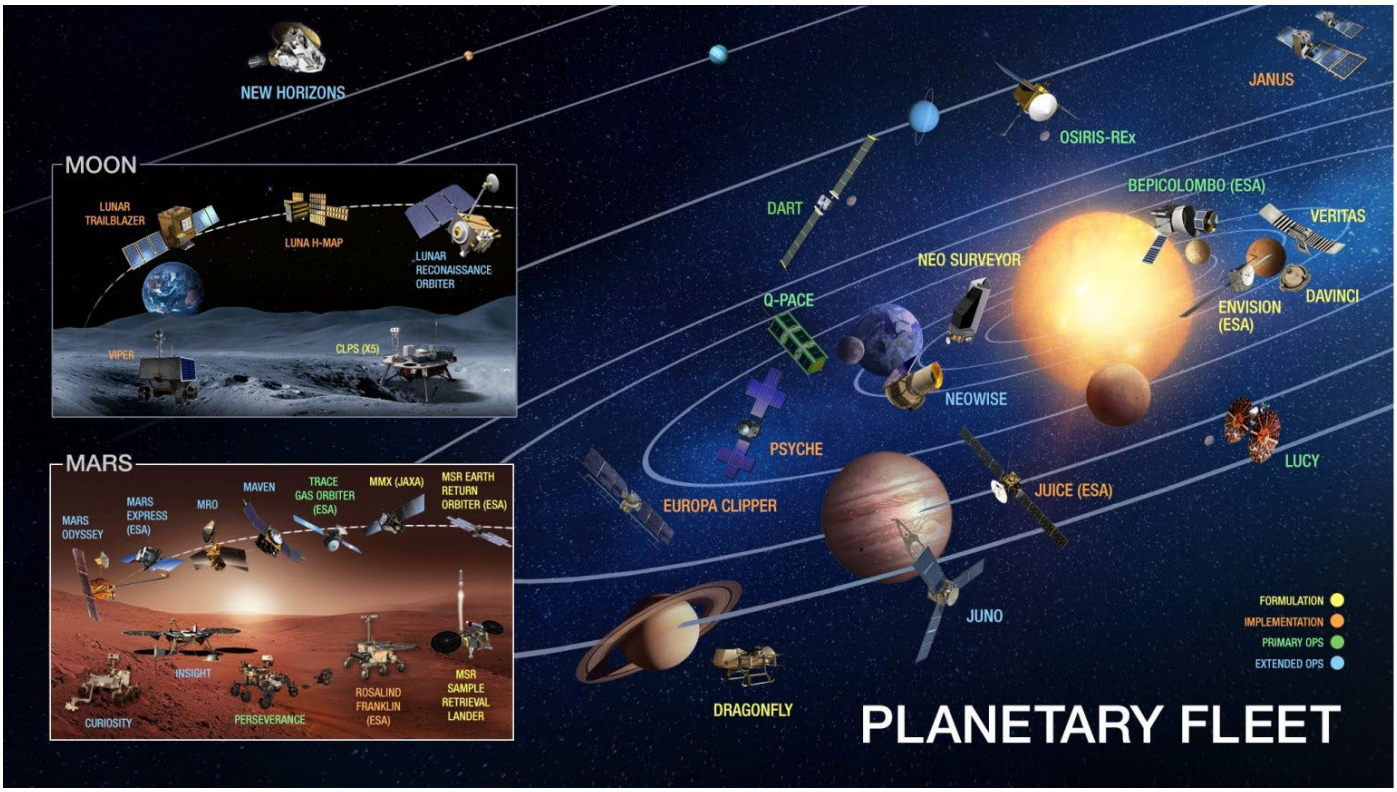


Fig. 1. NASA's Planetary Science Division mission fleet chart, December 2021. Credit: NASA.

> “DART is humanity’s first attempt to perceptibly alter the motion of an asteroid.”

quick succession in the fall (Fig. 2). First, Lucy’s journey to Jupiter’s Trojan asteroids began with an early morning launch from Cape Canaveral in October 2021. Although the Lucy team is still working on an anomaly with one of the spacecraft’s solar arrays, we are confident they will find a good solution to enable Lucy’s 12-year magical mystery tour, during which it will conduct flybys of one main-belt and seven Trojan asteroids. Equipped with a suite of scientific instruments, Lucy will allow us to survey the diversity and gain new insights into the unique, never-before-explored population of asteroids that have been trapped in Jupiter’s orbit for billions of years. Just as Lucy the famous fossilized hominid skeleton (for the which the mission is named) provided fundamental knowledge of the evolution of our species, our Lucy mission is set to revolutionize our understanding of planetary origins and the formation of the solar system.

Our second launch of 2021 was that of the Double Asteroid Redirection Test (DART) mission, which lifted off from Vandenberg Space Force Base right before Thanksgiving. DART is humanity’s first attempt to perceptibly alter the motion of an asteroid, as a test of the proposed planetary defense kinetic impact technique. DART is now headed for the Didymos binary asteroid system, which consists of the larger Didymos asteroid [about 780 meters (2560 feet) in diameter] and its small “moonlet” Dimorphos [about 161 meters (530 feet) in diameter]. On September 26, 2022, the spacecraft will autonomously direct itself to a head-on collision with Dimorphos. In doing so, we expect the speed of Dimorphos’ orbit around Didymos to slow slightly, but by enough that we will be able to detect the change in its orbital period from groundbased measurements (Fig. 3). Models suggest that the period will go from 11 hours and 55 minutes to approximately 11 hours and 45 minutes. Although we are not concerned that Didymos or Dimorphos pose any threat to Earth (nor will they after the DART impact), with this mission we are planning ahead by testing the technique and the technology now, so that we are prepared should we need to employ this kind of planetary defense approach at some point in the future. I will also emphasize that, as of now, no known asteroid is an impact threat to Earth at any time in the next century. Given the current incompleteness of the near-Earth object (NEO) catalog, however, an unpredicted event by an unknown asteroid could be discovered at any time. For this reason, I am pleased that the next planetary defense mission, NEO Surveyor, progressed to the next stage in its formulation in 2021. NEO Surveyor is designed to discover and characterize most of the potentially hazardous NEOs, i.e., those that are larger than 140 meters (459 feet). This mission will be another important piece in our planetary defense efforts.

Another highlight of 2021 was the selection of three new missions that will visit Venus over the next decade. Back in the spring, many in the community were surprised with the dual selection of two Venus missions as the next installments of the Discovery Program. Venus has had to wait a long time for a NASA mission, having not been visited by a targeted Venus probe since Magellan more than 30 years ago. The Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) and Venus Emissivity, Radio science, InSAR, Topography, And Spectroscopy (VERITAS) missions, however, will lead a renaissance in Venus exploration science in the coming years. I am also delighted that these two missions will be joined by the ESA medium-class mission, EnVision, on which NASA will provide the synthetic aperture radar instrument (VenSAR) and will support some U.S. scientist involvement. Venus is compelling as a destination for many reasons, and these missions will allow us specifically to make huge inroads into understanding how the evolutions of Earth and Venus diverged so greatly.

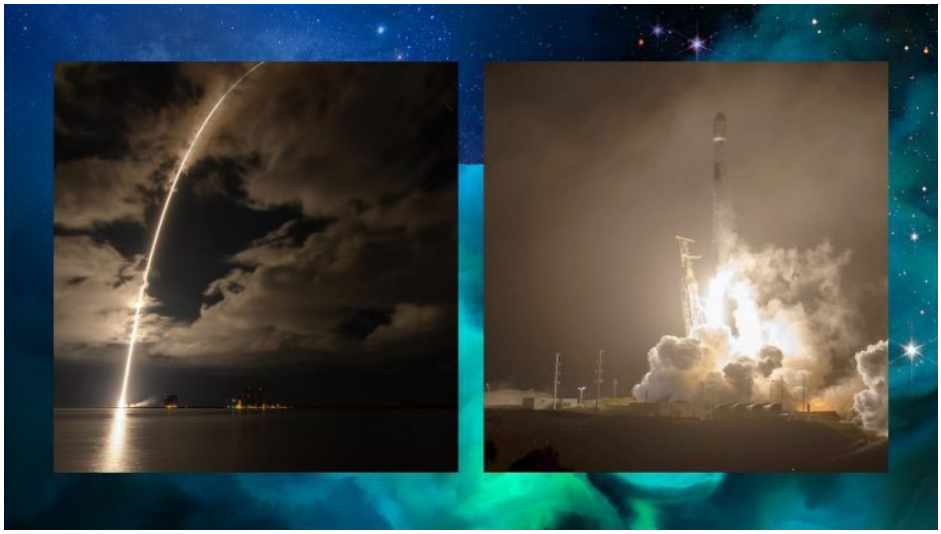


Fig. 2. Launch of Lucy from Cape Canaveral, October 16, 2021 (left), and launch of DART from Vandenberg Space Force Base, November 24, 2021 (right). Credit: NASA/Bill Ingalls.

Of course, 2021 has been another year of perseverance, but also of ingenuity (Fig. 4)! The Mars2020 Perseverance

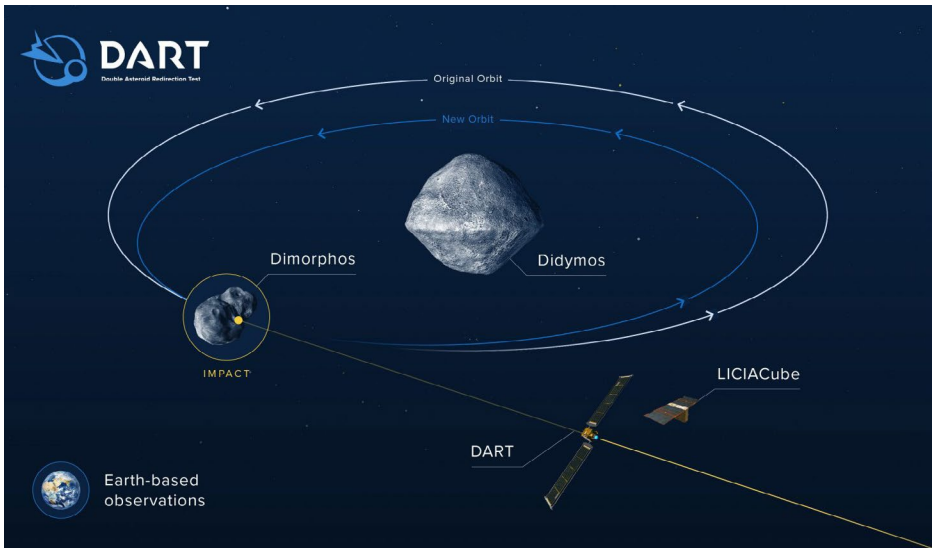


Fig. 3. Illustration of the effect of DART's impact on the orbit of Dimorphos. Credit: NASA/Johns Hopkins APL.

Rover touched down safely in Jezero Crater back in February and has since been working to explore the region for signs of past microbial life. At the time of writing, the rover has collected seven samples (six rock samples and one atmospheric sample). These samples represent the first steps in the international endeavor of Mars sample return, through which the Mars2020 samples will be retrieved and returned to Earth in the coming years. Moreover, after the "Wright Brother's moment" on April 19, 2021, when the Ingenuity helicopter made the first powered, controlled flight on another planet, Ingenuity completed its month-long technology demonstration with flying colors (pun intended). The helicopter continues to fly on a regular cadence and is now in an operational demonstration phase where it supports Perseverance planning and operations.

In addition to Mars sample return, we are excited about the other extraterrestrial materials that are on their way to, or newly arrived on, Earth. After its successful "touch and go" maneuver in 2020, OSIRIS-REx is now on its journey back to Earth, and it will deliver its precious sample of Bennu in September 2023. We are proud that we will be sharing part of the OSIRIS-REx sample with JAXA, and in reciprocation, JAXA has kindly allocated 10% of the Hayabusa-2 sample (from Ryugu) to NASA. We received this allocation of material at the Johnson Space Center in December, where it will be carefully curated and cataloged. We expect to announce sample availability in the coming months, with allocation to scientists in early summer 2022.

Looking ahead, many of our upcoming missions have made great progress in 2021, and I will mention a few (but not all) here. Psyche's assembly, test, and launch operations (ATLO) phase is continuing, and we are excited for the mission's launch in summer 2022. Likewise, the Europa Clipper project continues to make great strides toward its launch on a SpaceX Falcon Heavy in 2024; ATLO is set to begin this spring. For me, one of the most exciting elements in planetary exploration right now is the nascent Commercial Lunar Payload Services program, run out of the Exploration Science and Strategy Integration Office (ESSIO). I am eagerly awaiting the first of these launches in 2022, when Intuitive Machines and Astrobotic will be delivering NASA science and technology demonstration payloads to the lunar surface (at three separate sites: Oceanus Procellarum, Lacus Mortis, and the south pole). Astrobotic will also be delivering our Volatiles Investigating Polar Exploration Rover (VIPER) to the lunar south pole in 2023. We now know that golf-cart-sized VIPER will explore the region close to Nobile Crater (with the precise landing site to be determined) during its 100-day mission. It will prospect for water ice and other potential resources so that we can learn more about the origin and distribution of water on the Moon and determine how to harvest lunar resources for future human exploration.

It is important to recognize that the work of PSD is not entirely focused around our mission activities. Indeed, our Research and Analysis (R&A) programs are the lifeblood that sustains our scientific community. I've therefore been pleased to see significant recent changes to the way we run some of our R&A programs, and I believe these changes will have a positive effect on the community going forward. Starting with ROSES-20, we began implementing a Dual-Anonymous Peer Review (DAPR) process for the review of proposals to some programs. After the success of the pilot year, in which we used DAPR in the Habitable Worlds proposal cycle, the process is

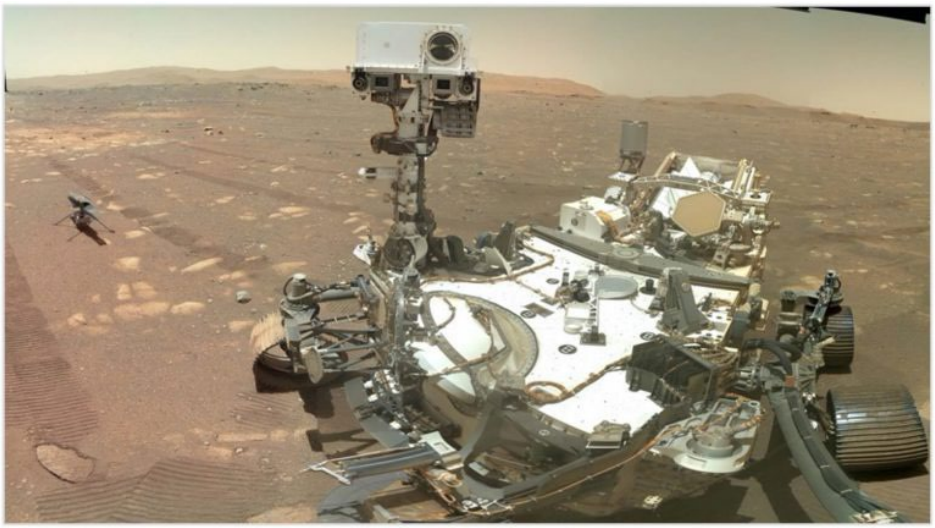


Fig. 4. The Mars2020 Perseverance rover and Ingenuity helicopter on the surface of Mars. Credit: NASA.

Fig. 5. First view of Ganymede in more than 20 years, taken during the Juno flyby on June 7, 2021. Credit: NASA/JPL/SwRI/MSSS.

now being implemented more widely in several of our programs (including the cross-divisional Exoplanets Research Program, all our Data Analysis Programs, and others). Although DAPR does require proposers to change the way they write proposals, feedback so far has been overwhelmingly positive. More than that, it is vitally important that we strive to always maintain a fair review process that is as unbiased as possible — DAPR is a critical part of that endeavor.

Another big change in PSD R&A in 2021 has been the start of a three-year trial of a "no due date" (NoDD), or rolling submission, approach. For many of our core research programs, rather than NASA-imposed deadlines for proposal submissions, we have adapted these programs so that proposals can be submitted on the proposers' desired timeline. This means there does not need to be a rush to complete proposals, nor would proposers be unfairly penalized for accidentally missing a submission deadline. Instead, proposers can submit proposals when they believe they are at their best. Although it is too soon to measure and report the success of this initiative, I hope that it will bring a positive change for all.

In this October 2021 issue of the publication, I outlined some of the inclusion, diversity, equity, and accessibility (IDEA) initiatives we are working on at NASA, and especially within the Science Mission Directorate (SMD) and PSD. Under the remit of the new SMD-wide IDEA Working Group, we are working on a multitude of inward- and outward-facing activities that I know will make a difference, both in-house and in our wider science community. In addition to the plans I discussed previously, we are also starting a new SMD Bridge Program. This initiative is designed to boost diversity, equity, inclusion, and accessibility within the NASA workforce and within the U.S. science and engineering ecosystem. Funding for this program was included in the FY22 President's Budget Request, and it will allow increased engagement and partnering between minority-serving institutions, other Ph.D.-granting universities, and NASA centers. The focus of the program will be on paid research and engineering studentships at participating institutions, to allow students to effectively transition from undergraduate studies into graduate schools and employment by NASA. SMD will be facilitating community-planning workshops that will allow this program to be collaboratively co-created with all stakeholders.

Before completing this stock-taking, I would be remiss if I didn't discuss some of our amazing recent science results. After all, our exploration, our missions, and our curiosities are driven by science first and foremost. Results from InSight were published in a suite of three *Science* papers, which provided details on the depth and composition of Mars' crust, mantle, and core. Specifically, these InSight results confirmed that the planet's center is molten. The results also turned up a surprise — that the most significant "marsquakes" detected by InSight come from one area, known

“You are all a key part of our mission of exploring the unknown and inspiring the world around us.”

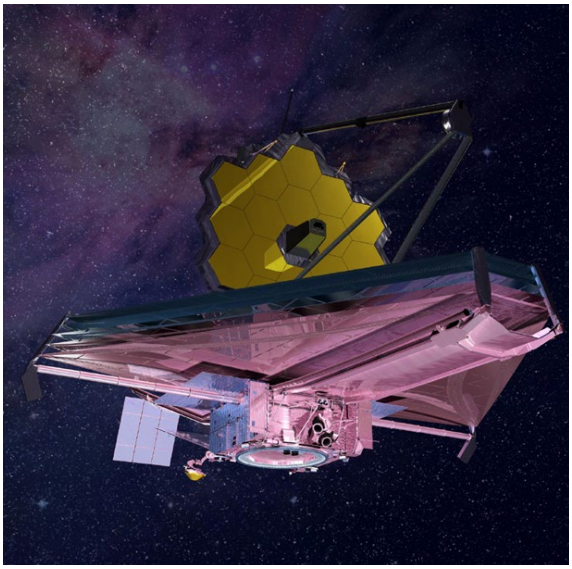
as Cerberus Fossae, which is a region volcanically active enough that lava may have flowed there in the last few million years. Curiously, however, no quakes have been detected from more prominent volcanic regions, like Tharsis.

Juno celebrated 10 years in space in 2021 and marked the occasion by entering its extended mission phase. During this new phase, the spacecraft will make a series of flybys of the jovian moons Ganymede, Io, and Europa — the first flyby of Ganymede occurred in June and was the first visit to this moon by a spacecraft in more than two decades (Fig. 5). The science results from Juno also continue to flow at an astounding speed. For example, a new map of Jupiter's magnetic field is the most detailed ever, providing insights into the gas giant's mysterious Great Blue Spot (a magnetic anomaly) at the planet's equator. The Juno data indicate that a change in Jupiter's magnetic field occurred during the time Juno has been in orbit, and that this spot is moving eastward at a rate of about 5 centimeters (2 inches) per second (meaning it would lap the planet in about 350 years). In contrast, the well-known Great Red Spot is drifting westward at a much more rapid pace (circling the planet in about 4.5 years). The new map also shows that Jupiter's zonal winds (jet streams) are pulling the Great Blue Spot apart, meaning that these winds, which are measured at the surface of the planet, actually reach deep into the planet's interior.

On the astrobiology front, a very successful "Biosignature Standards of Evidence Workshop" was held in July 2021, with the focus on developing a generalized, progressive framework for robust biosignature assessment. This workshop is part of a larger effort to ensure that we, as a science community, are being responsible in our search for life elsewhere in the universe. An article, published in *Nature* in October, is a rallying cry to the community to ensure that we engage in an open dialogue about how to convey information in the diverse, complicated field of astrobiology and biosignature detection — a field that has a great potential to be sensationalized. The July workshop was therefore a direct response to this need. Hundreds of international participants attended the workshop, many of whom contributed to drafting the white paper that was a product of the meeting. This white paper was open for public comment during the fall, and the draft version can be read here. I am eager to read the final version and its findings and to receive the independent review of the white paper that is currently being conducted by NASEM's Committee on Astrobiology and Planetary Sciences (CAPS).

As I close, I want to stress my sincere thanks to the whole planetary science community for their perseverance, passion, and patience as we have traversed these tiresome past two years. More than that, I cannot express enough how thankful we at NASA are for each individual scientist's service to our work and to our community — whether that's serving as a proposal reviewer, volunteering time to work with one of our Analysis/Assessment Groups, working as part of the Decadal Survey efforts, or contributing to another community need. Your time, your energy, and your expertise are truly appreciated. You are all a key part of our mission of exploring the unknown and inspiring the world around us.

NASA'S WEBB TELESCOPE LAUNCHES TO SEE FIRST GALAXIES, DISTANT WORLDS



Artist's concept of the James Webb Space Telescope in space. Credit: NASA.

NASA's James Webb Space Telescope launched at 7:20 a.m. EST on December 25, 2021, on an Ariane 5 rocket from Europe's Spaceport in French Guiana, South America.

A joint effort with the European Space Agency and the Canadian Space Agency, the Webb observatory is NASA's revolutionary flagship mission to seek the light from the first galaxies in the early universe and to explore our own solar system, as well as planets orbiting other stars, called exoplanets.

"The James Webb Space Telescope represents the ambition that NASA and our partners maintain to propel us forward into the future," said NASA Administrator Bill Nelson. "The promise of Webb is not what we know we will discover; it's what we don't yet understand or can't yet fathom about our universe. I can't wait to see what it uncovers!"

Ground teams began receiving telemetry data from Webb about five minutes after launch. The Arianespace Ariane 5 rocket performed as expected, separating from the observatory 27 minutes into the flight. The observatory was released at an altitude of approximately 120 kilometers (75 miles).

"I want to congratulate the team on this incredible achievement — Webb's launch marks a significant moment not only for NASA, but for thousands of people worldwide who dedicated their time and talent to this mission over the years," said Thomas Zurbuchen, associate administrator for the Science Mission Directorate at NASA Headquarters in Washington. "Webb's scientific promise is now closer than it ever has been. We are poised on the edge of a truly exciting time of discovery, of things we've never before seen or imagined."

The world's largest and most complex space science observatory has now begun six months of commissioning in space. At the end of commissioning, Webb will deliver its first images. Webb carries four state-of-the-art science instruments with highly sensitive infrared detectors of unprecedented resolution. Webb will study infrared light from celestial objects with much greater clarity than ever before. The premier mission is the scientific successor to NASA's iconic Hubble and Spitzer space telescopes, built to complement and further the scientific discoveries of these and other missions.

The telescope's revolutionary technology will explore every phase of cosmic history — from within our solar system to the most distant observable galaxies in the early universe, to everything in between. Webb will reveal new and unexpected discoveries and help humanity understand the origins of the universe and our place in it.

For more information, visit webb.nasa.gov.

"The world's largest and most complex space science observatory has now begun six months of commissioning in space."

NASA LAUNCHES LUCY MISSION TO "FOSSILS" OF PLANET FORMATION

A United Launch Alliance Atlas V rocket with the Lucy spacecraft aboard is seen in this 2-minute-and-30-second exposure photograph as it launches from Space Launch Complex 41 on Saturday, October 16, 2021, at Cape Canaveral Space Force Station in Florida. Lucy will be the first spacecraft to study Jupiter's Trojan asteroids. Like the mission's namesake — the fossilized human ancestor "Lucy" whose skeleton provided unique insight into humanity's evolution — Lucy will revolutionize our knowledge of planetary origins and the formation of the solar system. Credit: NASA/Bill Ingalls.

NASA's Lucy mission, the agency's first to Jupiter's Trojan asteroids, launched at 5:34 a.m. EDT on October 16, 2021, on a United Launch Alliance (ULA) Atlas V 401 rocket from Space Launch Complex 41 at Cape Canaveral Space Force Station in Florida.

Over the next 12 years, Lucy will fly by one main-belt asteroid and seven Trojan asteroids, making it the agency's first single spacecraft mission in history to explore so many different asteroids. Lucy will investigate these "fossils" of planetary formation up close during its journey.

"Lucy embodies NASA's enduring quest to push out into the cosmos for the sake of exploration and science to better understand the universe and our place within it," said NASA Administrator Bill Nelson. "I can't wait to see what mysteries the mission uncovers!"

About an hour after launch, Lucy separated from the second stage of the ULA Atlas V 401 rocket. Its two massive solar arrays, each nearly 7.3 meters (24 feet) wide, successfully unfurled about 30 minutes later and began charging the spacecraft's batteries to power its subsystems.

"Today's launch marks a genuine full-circle moment for me as Lucy was the first mission I approved in 2017, just a few months after joining NASA," said Thomas Zurbuchen, associate administrator for the Science Mission Directorate at the agency's headquarters in Washington. "A true mission of discovery, Lucy is rich with opportunity to learn more about these mysterious Trojan asteroids and better understand the formation and evolution of the early solar system."

Lucy sent its first signal to Earth from its own antenna to NASA's Deep Space Network at 6:40 a.m. The spacecraft is now traveling at roughly 108,000 kilometers per hour (67,000 miles per hour) on a trajectory that will orbit the Sun and bring it back toward Earth in October 2022 for a gravity assist.

Named for the fossilized skeleton of one of our earliest known hominin ancestors, the Lucy mission will allow scientists to explore two swarms of Trojan asteroids that share an orbit around the Sun with Jupiter. Scientific evidence indicates that Trojan asteroids are remnants of the material that formed giant planets. Studying them can reveal previously unknown information about their formation and our solar system's evolution in the same way the fossilized skeleton of Lucy revolutionized our understanding of human evolution.

"We started working on the Lucy mission concept early in 2014, so this launch has been long in the making," said Hal Levison, Lucy principal investigator, based out of the Boulder, Colorado, branch of Southwest Research Institute, which is headquartered in San Antonio. "It will still be several years before we get to the first Trojan asteroid, but these objects are worth the wait and all the effort because of their immense scientific value. They are like diamonds in the sky."

Lucy's Trojan destinations are trapped near Jupiter's Lagrange points — gravitationally

stable locations in space associated with a planet's orbit where smaller masses can be trapped. One swarm of Trojans is ahead of the gas giant planet, and another is behind it. The asteroids in Jupiter's Trojan swarms are as far away from Jupiter as they are from the Sun.

The spacecraft's first Earth gravity assist in 2022 will accelerate and direct Lucy's trajectory beyond the orbit of Mars. The spacecraft will then swing back toward Earth for another gravity assist in 2024, which will propel Lucy toward the Donaldjohanson asteroid, located within the solar system's main asteroid belt, in 2025.

Lucy will then journey toward its first Trojan asteroid encounter in the swarm ahead of Jupiter for a 2027 arrival. After completing its first four targeted flybys, the spacecraft will travel back to Earth for a third gravity boost in 2031, which will catapult it to the trailing swarm of Trojans for a 2033 encounter.

"Today we celebrate this incredible milestone and look forward to the new discoveries that Lucy will uncover," said Donya Douglas-Bradshaw, Lucy project manager at NASA's Goddard Space Flight Center in Greenbelt, Maryland.

For more information, visit lucy.swri.edu/.

NASA, SPACEX LAUNCH DART: FIRST TEST MISSION TO DEFEND PLANET EARTH

NASA's Double Asteroid Redirection Test (DART), the world's first full-scale mission to test technology for defending Earth against potential asteroid or comet hazards, launched at 1:21 a.m. U.S. Eastern Standard Time (EST) on November 24, 2021, on a SpaceX Falcon 9 rocket from Space Launch Complex 4 East at Vandenberg Space Force Base in California.

NASA's Double Asteroid Redirection Test (DART) spacecraft sets off to collide with an asteroid in the world's first full-scale planetary defense test mission. Riding atop a SpaceX Falcon 9 rocket, DART took off Wednesday, November 24, 2021, from Space Launch Complex 4 East at Vandenberg Space Force Base in California. Credit: NASA/Bill Ingalls.

Just one part of NASA's larger planetary defense strategy, DART — built and managed by the Johns Hopkins Applied Physics Laboratory (APL) in Laurel, Maryland — will impact Dimorphos, a known asteroid that is not a threat to Earth. Its goal is to slightly change the asteroid's motion in a way that can be accurately measured using groundbased telescopes.

DART will show that a spacecraft can autonomously navigate to a target asteroid and intentionally collide with it — a method of deflection called kinetic impact. The test will provide important data to help better prepare for an asteroid that might pose an impact hazard to Earth, should one ever be discovered. The Light Italian CubeSat for Imaging of Asteroids (LICIACube), a CubeSat riding with DART and provided by the Italian Space Agency (ASI), will be released prior to DART's impact to capture images of the impact and the resulting cloud of ejected matter. Roughly four years after DART's impact, European Space Agency's (ESA's) Hera project will conduct detailed surveys of both asteroid Didymos and its small moonlet Dimorphos, with particular focus on the crater left by DART's collision and a precise determination of Dimorphos' mass.

"DART is turning science fiction into science fact and is a testament to NASA's proactivity and innovation for the benefit of all," said NASA Administrator Bill

> **“It is an indescribable feeling to see something you’ve been involved with since the ‘words on paper’ stage become real and launched into space.”**

Nelson. “In addition to all the ways NASA studies our universe and our home planet, we’re also working to protect that home, and this test will help prove out one viable way to protect our planet from a hazardous asteroid should one ever be discovered that is headed toward Earth.”

At 2:17 a.m., DART separated from the second stage of the rocket. Minutes later, mission operators received the first spacecraft telemetry data and started the process of orienting the spacecraft to a safe position for deploying its solar arrays. About two hours later, the spacecraft completed the successful unfurling of its two 8.5-meter-long (28-foot-long) roll-out solar arrays. They will power both the spacecraft and NASA’s Evolutionary Xenon Thruster–Commercial (NEXT-C) ion engine, one of several technologies being tested on DART for future application on space missions.

“At its core, DART is a mission of preparedness, and it is also a mission of unity,” said Thomas Zurbuchen, associate administrator for the Science Mission Directorate at NASA Headquarters in Washington. “This international collaboration involves DART, ASI’s LICIACube, and ESA’s Hera investigations and science teams, which will follow up on this groundbreaking space mission.”

DART’s one-way trip is to the Didymos asteroid system, which comprises a pair of asteroids. DART’s target is the moonlet Dimorphos, which is approximately 160 meters (530 feet) in diameter. The moonlet orbits Didymos, which is approximately 780 meters (2560 feet) in diameter.

Since Dimorphos orbits Didymos at much a slower relative speed than the pair orbits the Sun, the result of DART’s kinetic impact within the binary system can be measured much more easily than a change in the orbit of a single asteroid around the Sun.

“We have not yet found any significant asteroid impact threat to Earth, but we continue to search for that sizable population we know is still to be found. Our goal is to find any possible impact, years to decades in advance, so it can be deflected with a capability like DART that is possible with the technology we currently have,” said Lindley Johnson, planetary defense officer at NASA Headquarters. “DART is one aspect of NASA’s work to prepare Earth should we ever be faced with an asteroid hazard. In tandem with this test, we are preparing the Near-Earth Object Surveyor Mission, a spacebased infrared telescope scheduled for launch later this decade and designed to expedite our ability to discover and characterize the potentially hazardous asteroids and comets that come within 30 million miles of Earth’s orbit.”

The spacecraft will intercept the Didymos system between September 26 and October 1, 2022, intentionally slamming into Dimorphos at roughly 6 kilometers per second (4 miles per second). Scientists estimate the kinetic impact will shorten Dimorphos’ orbit around Didymos by several minutes. Researchers will precisely measure that change using telescopes on Earth. Their results will validate and improve scientific computer models critical to predicting the effectiveness of the kinetic impact as a reliable method for asteroid deflection.

“It is an indescribable feeling to see something you’ve been involved with since the ‘words on paper’ stage become real and launched into space,” said Andy Cheng, one of the DART investigation leads at Johns Hopkins APL and the individual who came up with the idea of DART. “This is just the end of the first act, and the DART investigation and engineering teams have much work to do over the next year preparing for the main event — DART’s kinetic impact on Dimorphos. But tonight we celebrate!”

DART’s single instrument, the Didymos Reconnaissance and Asteroid Camera for Optical navigation (DRACO), will provide the first images from the spacecraft. DART will continue to travel just outside of Earth’s orbit around the Sun for the next 10 months until Didymos and Dimorphos will be a relatively close 11 million kilometers (6.8 million miles) from Earth.

A sophisticated guidance, navigation, and control system, working together with algorithms called Small-body Maneuvering Autonomous Real Time Navigation (SMART Nav), will enable the DART spacecraft to identify and distinguish between the two asteroids. The system will then direct the spacecraft toward Dimorphos. This process will occur within roughly an hour of impact.

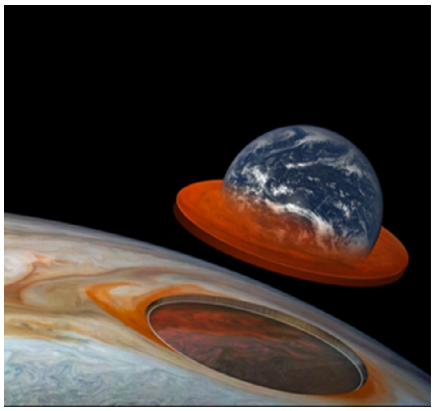
For more information, visit dart.jhuapl.edu/.

NASA'S JUNO SCIENCE RESULTS OFFER FIRST THREE-DIMENSIONAL VIEW OF JUPITER ATMOSPHERE

New findings from NASA's Juno probe orbiting Jupiter provide a fuller picture of how the planet's distinctive and colorful atmospheric features offer clues about the unseen processes below its clouds. The results highlight the inner workings of the belts and zones of clouds encircling Jupiter as well as its polar cyclones and even the Great Red Spot.

Researchers published several papers on Juno's atmospheric discoveries recently in the journal *Science* and *Journal of Geophysical Research: Planets*. Additional papers appeared in two recent issues of *Geophysical Research Letters*.

"These new observations from Juno open up a treasure chest of new information about Jupiter's enigmatic observable features," said Lori Glaze, director of NASA's Planetary Science Division at the agency's headquarters in Washington. "Each paper sheds light on different aspects of the planet's atmospheric processes — a wonderful example of how our internationally-diverse science teams strengthen understanding of our solar system."



This illustration combines an image of Jupiter from the JunoCam instrument onboard NASA's Juno spacecraft with a composite image of Earth to depict the size and depth of Jupiter's Great Red Spot. Credits: JunoCam image data: NASA/JPL-Caltech/SwRI/MSSS; JunoCam image processing by Kevin M. Gill (CC BY); Earth image: NASA.

Juno entered Jupiter's orbit in 2016. During each of the spacecraft's 37 passes of the planet to date, a specialized suite of instruments has peered below its turbulent cloud deck.

"Previously, Juno surprised us with hints that phenomena in Jupiter's atmosphere went deeper than expected," said Scott Bolton, principal investigator of Juno from Southwest Research Institute in San Antonio and lead author of the paper in *Science* on the depth of Jupiter's vortices. "Now, we're starting to put all these individual pieces together and getting our first real understanding of how Jupiter's beautiful and violent atmosphere works – in 3D."

Juno's Microwave Radiometer (MWR) allows mission scientists to peer beneath Jupiter's cloud tops and probe the structure of its numerous vortex storms. The most famous of these storms is the iconic anticyclone known as the Great Red Spot. Wider than Earth, this crimson vortex has intrigued scientists since its discovery almost two centuries ago.

The new results show that the cyclones are warmer on top with lower atmospheric densities, while they are colder at the bottom with higher densities. Anticyclones, which rotate in the opposite direction, are colder at the top but warmer at the bottom.

The findings also indicate these storms are far taller than expected, with some extending 100 kilometers (60 miles) below the cloud tops and others, including the Great Red Spot, extending over 350 kilometers (200 miles). This surprise discovery demonstrates that the vortices cover regions beyond those where water condenses and clouds form, below the depth where sunlight warms the atmosphere.

The height and size of the Great Red Spot means the concentration of atmospheric mass within the storm potentially could be detectable by instruments studying Jupiter's gravity field. Two close Juno flybys over Jupiter's most famous spot provided the opportunity to search for the storm's gravity signature and complement the MWR results on its depth.

With Juno traveling low over Jupiter's cloud deck at about 209,000 kilometers per hour (130,000 miles per hour), Juno scientists were able to measure velocity changes as small 0.01 millimeter per second (0.0004 inches per second) using a Deep Space Network tracking antenna from a distance of more than 650 million kilometers (400 million miles). This enabled the team to constrain the depth of the Great Red Spot to about 500 kilometers (300 miles) below the cloud tops.

"The precision required to get the Great Red Spot's gravity during the July 2019 flyby is staggering," said Marzia Parisi, a Juno scientist from NASA's Jet Propulsion Laboratory in Southern California and lead author of a paper in *Science* on gravity overflights of the Great Red Spot. "Being able to complement MWR's finding on the depth gives us great confidence that future gravity experiments at Jupiter will yield equally intriguing results."

In addition to cyclones and anticyclones, Jupiter is known for its distinctive belts and zones — white and reddish bands of clouds that wrap around the planet.

Strong east-west winds moving in opposite directions separate the bands. Juno previously discovered that these winds, or jet streams, reach depths of about 3200 kilometers (2000 miles). Researchers are still trying to solve the mystery of how the jet streams form. Data collected by Juno's MWR during multiple passes reveal one possible clue: the atmosphere's ammonia gas travels up and down in remarkable alignment with the observed jet streams.

"By following the ammonia, we found circulation cells in both the north and south hemispheres that are similar in nature to 'Ferrel cells,' which control much of our climate here on Earth," said Keren Duer, a graduate student from the Weizmann Institute of Science in Israel and lead author of the paper in *Science* on Ferrel-like cells on Jupiter. "While Earth has one Ferrel cell per hemisphere, Jupiter has eight — each at least 30 times larger."

Juno's MWR data also shows that the belts and zones undergo a transition around 65 kilometers (40 miles) beneath Jupiter's water clouds. At shallow depths, Jupiter's belts are brighter in microwave light than the neighboring zones. But at deeper levels, below the water clouds, the opposite is true, which reveals a similarity to our oceans.

"We are calling this level the 'jovicline' in analogy to a transitional layer seen in Earth's oceans, known as the thermocline — where seawater transitions sharply from being relative warm to relative cold," said Leigh Fletcher, a Juno participating scientist from the University of Leicester in the United Kingdom and lead author of the paper in *Journal of Geophysical Research: Planets* highlighting Juno's microwave observations of Jupiter's temperate belts and zones.

Juno previously discovered polygonal arrangements of giant cyclonic storms at both of Jupiter's poles, eight arranged in an octagonal pattern in the north and five arranged in a pentagonal pattern in the south. Now, five years later, mission scientists using observations by the spacecraft's Jovian Infrared Auroral Mapper (JIRAM) have determined these atmospheric phenomena are extremely resilient, remaining in the same location.

"Jupiter's cyclones affect each other's motion, causing them to oscillate about an equilibrium position," said Alessandro Mura, a Juno co-investigator at the National Institute for Astrophysics in Rome and lead author of a recent paper in *Geophysical Research Letters* on oscillations and stability in Jupiter's polar cyclones. "The behavior of these slow oscillations suggests that they have deep roots."

JIRAM data also indicates that, like hurricanes on Earth, these cyclones want to move poleward, but cyclones located at the center of each pole push them back. This balance explains where the cyclones reside and the different numbers at each pole.

For more information, visit www.missionjuno.swri.edu/.

A CADRE OF MINI-ROVERS NAVIGATE THE LUNAR TERRAIN OF SLOPE

A team of shoebox-sized rover scouts was recently put to the test at a NASA Glenn Research Center lab. The facility, called the Simulated Lunar Operations lab (SLOPE), is designed to mimic lunar and planetary surface operations. The mini-rovers traversed simulated lunar soil — called regolith — to better understand the types of challenges that lunar rovers of this size will face on the Moon's surface. The results of the tests will be used to characterize the performance of small rovers and improve their mobility design.

NASA's Cooperative Autonomous Distributed Robotic Exploration (CADRE) project is developing robots programmed to work as an autonomous team to explore the lunar surface, collect data, and map different areas of the Moon in three dimensions. With each mini-rover free to move independently, together they can perform distributed measurements that would be nearly impossible for a single rover to achieve. The core autonomy technology developed under CADRE could also be used on other planetary bodies such as Mars and beyond.

Mini-rovers designed to autonomously work together recently underwent tests at NASA's Glenn Research Center, navigating obstacles and surfaces that they could encounter on the Moon. Credit: NASA.

CADRE researchers from NASA's Jet Propulsion Laboratory worked with SLOPE engineers to see if the small robots could manage the challenging, fine-grained lunar surface environment.

"We tested the traction of the wheels in different conditions," said Alex Schepelmann, lead roboticist for SLOPE at NASA's Glenn Research Center. "The rover wheels were also tested to see if

they could negotiate large lunar rocks and climb the slopes of our tilt beds that simulate the hills of the Moon's surface."

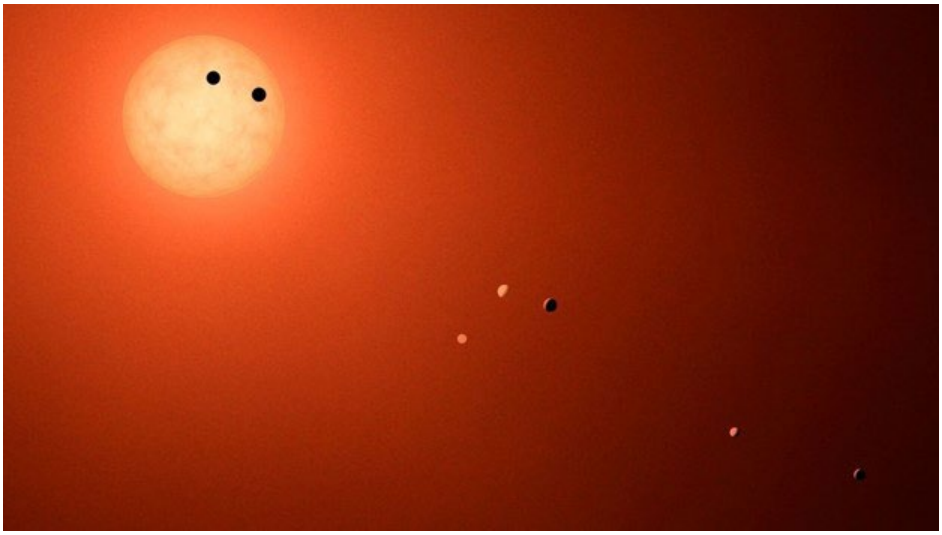
The SLOPE team also used scientific imaging equipment to determine the amount of wheel slip in the simulated lunar soil, which could affect the rovers' ability to determine location accurately using their sensors.

"If the wheel slips, the rover might think it has gone farther than it has actually traveled, since GPS technology isn't yet developed for the Moon," Schepelmann said.

Characterizing this slip is an important input to the rovers' algorithms that determine position. The CADRE software will also use data from an inertial measurement unit, stereo cameras, and a Sun sensor to track the position of each scout as they explore the lunar surface.

According to Schepelmann, the CADRE robots utilize spoked wheels, like the wheels on the VIPER rover, which will be delivered to the Moon in late 2023 to look for ice and other resources.

NEW DEEP LEARNING METHOD ADDS 301 PLANETS TO KEPLER'S TOTAL COUNT



Over 4500 planets have been found around other stars, but scientists expect that our galaxy contains millions of planets. There are multiple methods for detecting these small, faint bodies around much larger, bright stars. Credit: NASA/JPL-Caltech.

Scientists recently added a whopping 301 newly validated exoplanets to the total exoplanet tally. The throng of planets is the latest to join the 4569 validated planets orbiting a multitude of distant stars. How did scientists discover such a huge number of planets seemingly all at once? The answer lies with a new deep neural network called ExoMiner.

Deep neural networks are machine learning methods that automatically learn a task when provided with enough data. ExoMiner is a new deep neural network that leverages NASA's supercomputer, Pleiades, and can distinguish real exoplanets from different types of imposters, or "false positives." Its design is inspired by various tests and properties human experts use to confirm new exoplanets. And it learns by using past confirmed exoplanets and false-positive cases.

ExoMiner supplements people who are pros at combing through data and deciphering what is and isn't a planet, specifically data gathered by NASA's Kepler spacecraft and K2, its follow-on mission. For missions like Kepler, with thousands of stars in its field of view, each holding the possibility to host multiple potential exoplanets, it is a hugely time-consuming task to pore over massive datasets. ExoMiner solves this dilemma.

NASA's Eyes on Exoplanets shows the location of over 4500 planets around other stars outside our solar system. Users can also see information about the physical features of the planets (where known) and the stars they orbit. To view the full interactive experience, visit Eyes on Exoplanets at eyes.nasa.gov/eyes-on-exoplanets.html.

"Unlike other exoplanet-detecting machine learning programs, ExoMiner isn't a black box — there is no mystery as to why it decides something is a planet or not," said Jon Jenkins, exoplanet scientist at NASA's Ames Research Center in California's Silicon Valley. "We can easily explain which features in the data led ExoMiner to reject or confirm a planet."

What is the difference between a confirmed and validated exoplanet? A planet is "confirmed" when different observation techniques reveal features that can only be explained by a planet. A planet is "validated" using statistics, meaning how likely or unlikely it is to be a planet based on the data.

In a paper published in the *Astrophysical Journal*, the team at Ames shows how

ExoMiner discovered the 301 planets using data from the remaining set of possible planets, or candidates, in the Kepler archive. All 301 machine-validated planets were originally detected by the Kepler Science Operations Center pipeline and promoted to planet-candidate status by the Kepler Science Office. But until ExoMiner, no one was able to validate them as planets.

The paper also demonstrates how ExoMiner is more precise and consistent in ruling out false positives and better able to reveal the genuine signatures of planets orbiting their parent stars, all while giving scientists the ability to see in detail what led ExoMiner to its conclusion.

"When ExoMiner says something is a planet, you can be sure it's a planet," added Hamed Valizadegan, ExoMiner project lead and machine learning manager with the Universities Space Research Association at Ames. "ExoMiner is highly accurate and in some ways more reliable than both existing machine classifiers and the human experts it's meant to emulate because of the biases that come with human labeling."

None of the newly confirmed planets are believed to be Earth-like or in the habitable zone of their parent stars, but they do share similar characteristics to the overall population of confirmed exoplanets in our galactic neighborhood.

"These 301 discoveries help us better understand planets and solar systems beyond our own, and what makes ours so unique," said Jenkins.

As the search for more exoplanets continues — with missions using transit photometry such as NASA's Transiting Exoplanet Survey Satellite (TESS) and the European Space Agency's upcoming PLAnetary Transits and Oscillations of stars (PLATO) mission — ExoMiner will have more opportunities to prove it is up to the task.

"Now that we've trained ExoMiner using Kepler data, with a little fine-tuning, we can transfer that learning to other missions, including TESS, which we're currently working on," said Valizadegan. "There's room to grow."

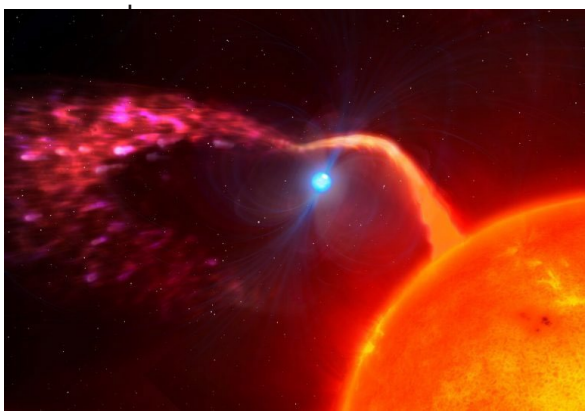
HIGH-SPEED PROPELLER STAR IS FASTEST-SPINNING WHITE DWARF

A white dwarf star that completes a full rotation once every 25 seconds is the fastest-spinning confirmed white dwarf, according to a team of astronomers led by the University of Warwick.

They have established the spin period of the star for the first time, confirming it as an extremely rare example of a magnetic propeller system: the white dwarf is pulling gaseous plasma from a nearby companion star and flinging it into space at around 3000 kilometers per second (1864 miles per second).

Reported on November 22 in *Monthly Notices of the Royal Astronomical Society: Letters*, it is only the second magnetic propeller white dwarf to have been identified in over 70 years thanks to a combination of powerful and sensitive instruments that allowed scientists to catch a glimpse of the speeding star.

A white dwarf is a star that has burned all its fuel and shed its outer layers, undergoing a process of shrinking and cooling over millions of years. The star that the University of Warwick team observed, named LAMOST J024048.51+195226.9 (or J0240+1952 for short), is the size of Earth but is thought to be at least 200,000 times more massive. It is part of a binary star system, and its immense gravity pulls material from its larger companion star in the form of plasma.



Artist's impression of LAMOST J024048.51+195226.9, the fastest-spinning confirmed white dwarf and only second ever magnetic propeller known. Material is being pulled from the companion and flung into space at high speed. A small fraction of it is accreted, gathering in bright spots that rotate in and out of view, which allowed the detection of the rotation period. Credit: University of Warwick/Mark Garlick.

In the past, this plasma fell onto the white dwarf's equator at high speed, providing the energy that has given it this dizzyingly fast spin. Put into context, one rotation of Earth takes 24 hours, while the equivalent on J0240+1952 takes a mere 25 seconds. That's almost 20% faster than the confirmed white dwarf with the most comparable spin rate, which completes a rotation in just over 29 seconds.

However, at some point in its evolutionary history, J0240+1952 developed a strong magnetic field. The magnetic field acts a protective barrier, causing most of the falling plasma to be propelled away from the white dwarf. The remainder flows toward the star's magnetic poles, gathering in bright spots on the surface of the star; as these rotate in and out of view, they cause pulsations in the light that astronomers

> "The rotation is so fast that the white dwarf must have an above-average mass just to stay together and not be torn apart."

observe from Earth, which they then used to measure the rotation of the entire star.

Lead author Ingrid Pelisoli of the University of Warwick's Department of Physics said, "J0240+1952 will have completed several rotations in the short amount of time that people take to read about it. It is really incredible. The rotation is so fast that the white dwarf must have an above-average mass just to stay together and not be torn apart.

"It is pulling material from its companion star due to its gravitational effect, but as that gets closer to the white dwarf, the magnetic field starts to dominate. This type of gas is highly conducting and picks up a lot of speed from this process, which propels it away from the star and out into space."

J0240+1952 is one of only two stars with this magnetic propeller system discovered in over past 70 years. Although material being flung out of the star was first observed in 2020, astronomers had not been able to confirm the presence of a rapid spin, a main ingredient of a magnetic propeller, as the pulsations are too fast and dim for other telescopes to observe.

To visualize the star at that speed for the first time, the University of Warwick team used the highly sensitive HiPERCAM instrument, jointly operated by the University of Warwick and the University of Sheffield with funding from the European Research Council. HiPERCAM was specially mounted on the largest functioning optical telescope in the world, the 10.4-meter-diameter (34-foot-diameter) Gran Telescopio Canarias (GTC) in La Palma, Canary Islands, to capture as much light as possible.

"These kinds of studies are possible thanks to the unique combination of the fast-imaging capability of HiPERCAM, with the largest collecting area in the world provided by GTC," said Antonio Cabrera, head of GTC Science Operations.

Co-author Professor Tom Marsh from the University of Warwick's Department of Physics adds: "It's only the second time that we have found one of these magnetic propeller systems, so we now know it's not a unique occurrence. It establishes that the magnetic propeller mechanism is a generic property that operates in these binaries, if the circumstances are right."

"The second discovery is almost as important as the first as you develop a model for the first, and with the second you can test it to see if that model works. This latest discovery has shown that the model works really well. It predicted that the star had to be spinning fast, and indeed it does."

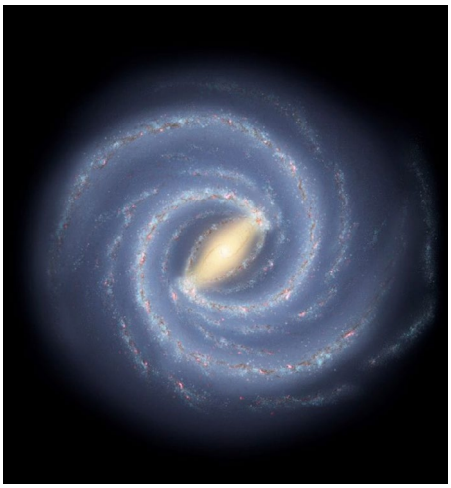
NASA SELECTS GAMMA-RAY TELESCOPE TO CHART MILKY WAY EVOLUTION

NASA has selected a new space telescope proposal that will study the recent history of star birth, star death, and the formation of chemical elements in the Milky Way. The gamma-ray telescope, called the Compton Spectrometer and Imager (COSI), is expected to launch in 2025 as NASA's latest small astrophysics mission.

NASA's Astrophysics Explorers Program received 18 telescope proposals in 2019 and selected four for mission concept studies. After detailed review of these studies by a panel of scientists and engineers, NASA selected COSI to continue into development.

> "For more than 60 years, NASA has provided opportunities for inventive, smaller-scale missions to fill knowledge gaps where we still seek answers."

"For more than 60 years, NASA has provided opportunities for inventive, smaller-scale missions to fill knowledge gaps where we still seek answers," said Thomas Zurbuchen, associate administrator for the agency's Science Mission Directorate in Washington. "COSI will answer questions about the origin of the chemical elements in our own



NASA has selected a new gamma-ray space telescope, the Compton Spectrometer and Imager (COSI), that will chart the evolution of the Milky Way, seen here in this illustration. Credit: NASA/JPL-Caltech/R. Hurt (SSC/Caltech).

Milky Way galaxy, the very ingredients critical to the formation of Earth itself."

COSI will study gamma rays from radioactive atoms produced when massive stars exploded to map where chemical elements were formed in the Milky Way. The mission will also probe the mysterious origin of our galaxy's positrons, also known as antielectrons, subatomic particles that have the same mass as an electron but have a positive charge.

COSI's principal investigator is John Tomsick at the University of California, Berkeley. The mission will cost approximately $145 million, not including launch costs. NASA will select a launch provider later.

The COSI team spent decades developing their technology through flights on scientific balloons. In 2016, they sent a version of the gamma-ray instrument onboard NASA's super pressure balloon, which is designed for long flights and heavy lifts.

NASA's Explorers Program is the agency's oldest continuous program. It provides frequent, low-cost access to space using principal-investigator-led space research relevant to astrophysics and heliophysics programs. Since the 1958 launch of Explorer 1, which discovered Earth's radiation belts, the program has launched more than 90 missions. In 2006, the principal investigators of the Cosmic Background Explorer, another NASA Explorer mission, received the Nobel Prize in Physics for their work on the project.

For more information, visit cosi.ssl.berkeley.edu/.

HOW NASA'S CURIOSITY ROVER IS MAKING MARS SAFER FOR ASTRONAUTS

Could lava tubes, caves, or subsurface habitats offer safe refuge for future astronauts on Mars? Scientists with NASA's Curiosity Mars rover team are helping explore questions like that with the Radiation Assessment Detector (RAD).

Unlike Earth, Mars doesn't have a magnetic field to shield it from the high-energy particles whizzing around in space. That radiation can wreak havoc on human health, and it can seriously compromise the life support systems that Mars astronauts will depend on as well.

Based on data from Curiosity's RAD, researchers are finding that using natural materials, such as the rock and sediment on Mars, could offer some protection from this ever-present space radiation. In a paper published in *Journal of Geophysical Research: Planets*, they detailed how Curiosity remained parked against a cliff at a location called "Murray Buttes" from September 9 to 21, 2016.

While there, RAD measured a 4% decrease in overall radiation. More significantly, the instrument detected a 7.5% decrease in neutral particle radiation, including neutrons that can penetrate rock and are especially harmful to human health. These numbers are statistically high enough to show that the decrease in radiation was due to Curiosity's location at the foot of the cliff rather than normal changes in the background radiation.

"We've been waiting a long time for the right conditions to get these results, which are critical to ensure the accuracy of our computer models," said Bent Ehresmann of Southwest Research Institute, lead author of the paper. "At Murray Buttes, we finally had these conditions and the data to analyze this effect. We're now looking for other locations where RAD can repeat these kinds of measurements."

NASA's Curiosity Mars rover used its Mast Camera (Mastcam) to capture this image of an outcrop with finely layered rocks within the "Murray Buttes" region on lower Mount Sharp on September 8, 2016. Credit: NASA/JPL-Caltech/MSSS.

Most of the radiation measured by RAD comes from galactic cosmic rays, particles

> **"Cosmic rays, solar radiation, solar storms — they are all components of space weather, and RAD is effectively a space weather outpost on the surface of Mars."**

cast out by exploding stars and sent pinballing throughout the universe. This forms a carpet of "background radiation" that can pose health risks for humans.

Far more intense radiation sporadically comes from the Sun in the form of solar storms that throw massive arcs of ionized gas into interplanetary space.

"These structures twist in space, sometimes forming complex croissant-shaped flux tubes larger than Earth, driving shock waves that can efficiently energize particles," said Jingnan Guo, who led a study published in September in *Astronomy and Astrophysics Review*. The study analyzed nine years of RAD data while Guo was at Germany's Christian Albrecht University.

"Cosmic rays, solar radiation, solar storms — they are all components of space weather, and RAD is effectively a space weather outpost on the surface of Mars," said Don Hassler of Southwest Research Institute and principal investigator of the RAD instrument.

Solar storms occur with varying frequency based on 11-year cycles, with certain cycles bearing more frequent and energetic storms than others. Counterintuitively, the periods when solar activity is at its highest may be the safest time for future astronauts on Mars. The increased solar activity shields the Red Planet from cosmic rays by as much as 30% to 50%, compared to periods when solar activity is lower.

"It's a trade-off," Guo said. "These high-intensity periods reduce one source of radiation: the omnipresent, high-energy cosmic-ray background radiation around Mars. But at the same time, astronauts will have to contend with intermittent, more intense radiation from solar storms."

"The observations from RAD are key to developing the ability to predict and measure space weather, the Sun's influence on Earth and other solar system bodies," said Jim Spann, space weather lead for NASA's Heliophysics Division. "As NASA plans for eventual human journeys to Mars, RAD serves as an outpost and part of the Heliophysics System Observatory — a fleet of 27 missions that investigates the Sun and its influence on space — whose research supports our understanding of and exploration of space."

RAD has measured the impact of more than a dozen solar storms to date (five while traveling to Mars in 2012), although these past nine years have marked an especially weak period of solar activity.

Scientists are just now starting to see activity pick up as the Sun comes out of its slumber and becomes more active. RAD observed evidence of the first X-class flare of the new solar cycle on October 28, 2021. X-class flares are the most intense category of solar flares, the largest of which can lead to power outages and communications blackouts on Earth.

"This is an exciting time for us because one of the important objectives of RAD is to characterize the extremes of space weather. Events such as solar flares and storms are one type of space weather that happens most frequently during increased solar activity — the time we are approaching now," Ehresmann said. More observations are needed to assess just how dangerous an extremely powerful solar storm would be to humans on the martian surface.

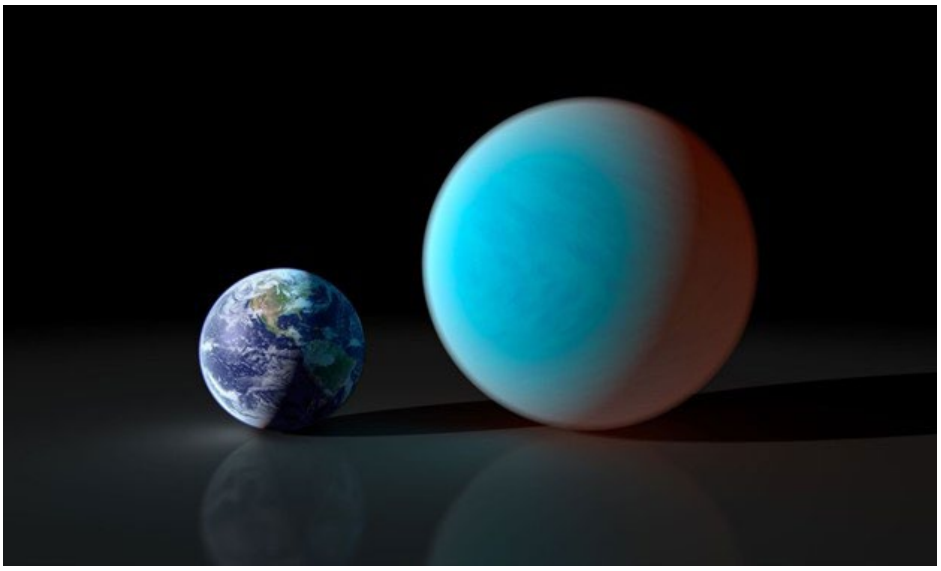
RAD's findings will feed into a much larger body of data being compiled for future crewed missions. In fact, NASA even equipped Curiosity's counterpart, the Perseverance rover, with samples of spacesuit materials to assess how they hold up to radiation over time.

For more information, visit mars.nasa.gov/msl/spacecraft/instruments/rad/.

HOW TO FIND HIDDEN OCEANS ON DISTANT WORLDS? USE CHEMISTRY

In our solar system, planets are either small and rocky (like Earth) or large and gaseous (like Neptune). But around other stars, astronomers have found planets that fall in between, worlds slightly larger than Earth but smaller than Neptune. These planets may have rocky surfaces or liquid-water oceans, but most are likely to be topped with atmospheres that are opaque and many times thicker than Earth's.

In a new paper, accepted in *Astrophysical Journal Letters*, researchers show how the chemistry of those atmospheres could reveal clues about what lies beneath, specifically which planets are too hot to support liquid-water oceans. Since liquid water is a necessary ingredient for life as we know it, this technique could help scientists narrow their search for potentially habitable exoplanets, or planets beyond our solar system. More than 4500



Planets that are between 1.7 and 3.5 times the diameter of Earth are sometimes called "sub-Neptunes." There are no planets in this size range in our solar system. Scientists think many sub-Neptunes have thick atmospheres, potentially cloaking rocky surfaces or liquid oceans. Credit: NASA/JPL-Caltech.

exoplanets have been confirmed in our galaxy, with over 7700 candidates yet to be confirmed, but scientists estimate that hundreds of billions of exoplanets exist in our galaxy.

Some NASA space telescopes equipped with spectrometers can reveal the chemical makeup of an exoplanet's atmosphere. A chemical profile of Earth wouldn't be able to reveal pictures of, say, humans or cows on the planet's surface, but it would show carbon dioxide and methane produced by mammals, and oxygen produced by trees. None of these chemicals alone would be a sign of life, but in combination, they would point to the possibility that our planet is inhabited.

The new paper shows which chemicals might point to hidden oceans on exoplanets between 1.7 and 3.5 times the diameter of Earth. Since Neptune is about four times Earth's diameter, these planets are sometimes called "sub-Neptunes."

A thick atmosphere on a sub-Neptune planet would trap heat on the surface and raise the temperature. If the atmosphere reaches a certain threshold — typically about 770°C (1430°F) — it will undergo a process called thermochemical equilibrium that changes its chemical profile. After thermochemical equilibrium occurs, and assuming the planet's atmosphere is composed mostly of hydrogen, which is typical for gaseous exoplanets, carbon and nitrogen will predominantly be in the form of methane and ammonia.

Those chemicals would largely be missing in a cooler, thinner atmosphere where thermochemical equilibrium has not occurred. In that case, the dominant forms of carbon and nitrogen would be carbon dioxide and molecules of two nitrogen atoms.

A liquid-water ocean underneath the atmosphere would leave additional signs, according to the study, including the absence of nearly all stray ammonia, which would be dissolved in the ocean. Ammonia gas is highly soluble in water, depending on the pH of the ocean (its level of acidity). Over a wide range of plausible ocean pH levels, the researchers found the atmosphere should be virtually free of ammonia when there is a massive ocean underneath.

In addition, there would be more carbon dioxide than carbon monoxide in the atmosphere; by contrast, after thermochemical equilibrium, there should be more carbon monoxide than carbon dioxide. if there are detectable amounts of either.

"If we see the signatures of thermochemical equilibrium, we would conclude that the planet is too hot to be habitable," said Renyu Hu, a researcher at NASA's Jet Propulsion Laboratory, who led the study. "Vice versa, if we do not see the signature of thermochemical equilibrium and also see signatures of gas dissolved in a liquid-water ocean, we would take those as a strong indication of habitability."

NASA's James Webb Space Telescope launched on December 25 and carries a spectrometer capable of studying exoplanet atmospheres. Scientists like Hu are working to anticipate what kinds of chemical profiles Webb will see in those atmospheres and what they could reveal about these distant worlds. The observatory has the capabilities to identify signs of thermochemical equilibrium in sub-Neptune atmospheres — in other words, signs of a hidden ocean — as identified in the paper.

As Webb discovers new planets or does more in-depth studies of known planets, this information could help scientists decide which of them are worthy of additional observations, especially if scientists want to target planets that might harbor life.

"We don't have direct observational evidence to tell us what the common physical characteristics for sub-Neptunes are," said Hu. "Many of them may have massive hydrogen atmospheres, but quite a few could still be 'ocean planets.' I hope this paper will motivate many more observations in the near future to find out."

TWIN OF NASA'S PERSEVERANCE MARS ROVER BEGINS TERRAIN TESTS

On a recent day in November, the car-sized rover rolled slowly forward, then stopped, perched on the threshold of a martian landscape. But this rover, named OPTIMISM, wasn't on the Red Planet. And the landscape was a boulder-strewn mock-up of the real Mars — the Mars Yard at NASA's Jet Propulsion Laboratory in Southern California.

OPTIMISM, a twin of the Perseverance rover that is exploring Jezero Crater on Mars, will perform a crucial job in the weeks ahead: navigating the Mars Yard's slopes and hazards, drilling sample cores from boulders, and storing the samples in metal tubes, just like Perseverance is doing in its hunt for signs of ancient microbial life. Short for Operational Perseverance Twin for Integration of Mechanisms and Instruments Sent to Mars, OPTIMISM is more generically known as a vehicle system test bed, and the recently upgraded rover began testing out new equipment for the first time in November.

The tests help ensure that OPTIMISM's twin on Mars can safely execute the commands sent by controllers on Earth. They also could potentially reveal unexpected problems Perseverance might encounter.

"The size and shape of rocks in the visual field — will they turn into obstacles or not?" said Bryan Martin, the flight software and test bed manager at JPL. "We test a lot of that, figure out what kinds of things to avoid. What we have safely traversed around here has informed rover drivers in planning their traverses on Mars. We've done so much testing on the ground, we can be confident in it. It works."

About as long as a doubles tennis court and twice as wide, the Mars Yard has served as a testing ground for many a fully-engineered rover twin — from the engineering model of the very first, tiny Sojourner that landed on Mars in 1997, to the Spirit and Opportunity missions that began in 2004, to the Curiosity and Perseverance rovers exploring Mars today.

Updated with new features, the twin of NASA's Perseverance Mars rover arrives at JPL's Mars Yard garage on October 29, 2021. Credit: NASA/JPL-Caltech.

In each case, a rover double has scaled slopes, dodged obstacles, or helped rover planners puzzle out new paths on the simulated patch of Mars. OPTIMISM first rolled out into the Mars Yard in September 2020, when it conducted mobility tests.

But it recently received some key updates to match features available on Perseverance, including additional mobility software and the bulk of the exquisitely complex sample caching system. And while the team has already performed tests using the coring drill at the end of OPTIMISM's robotic arm, they'll be testing the newly installed Adaptive Caching Assembly for the first time in the Mars Yard. The assembly on Perseverance is responsible for storing rock and sediment samples. Some or all of these initial samples could be among those returned to Earth by a future mission.

"Now we can do it end-to-end in the test bed," said the Vehicle System Test Bed systems engineering lead, Jose G. Trujillo-Rojas. "Drill into the rock, collect the core sample, and now we have the mechanism responsible to cache that sample in the cylinder."

And if problems arise on Perseverance on Mars, OPTIMISM can be used as a platform to figure out what went wrong and how to fix it.

In November, a heavy-duty vehicle transported OPTIMISM from a JPL test lab to the Mars Yard garage. Recently expanded, the structure also provides shelter to one of Curiosity's Earthly counterparts: the Mars Automated Giant Gizmo for Integrated Engineering (MAGGIE). A second Curiosity double, a skeletal version called "Scarecrow" that lacks a computer brain, is housed in a separate shed in the Mars Yard.

MAGGIE would be joining OPTIMISM in the Mars Yard garage in the days ahead.

But, for now, the test bed crew was focused on OPTIMISM. "Straight 5 meters forward: Ready?" Leann Bowen, a test bed engineer, called out from a computer console inside the garage.

"All right, bring her home, Leann," Trujillo-Rojas said.

With a whine of electric motors, OPTIMISM crept forward on its six metal wheels, stopping right on the mark on the garage's concrete floor as members of the test bed team looked on in their white lab coats. Through a wide-open door ahead of the rover, the Mars Yard beckoned.

Drilling core samples from terrestrial rocks in the Mars Yard and sealing them in metal tubes is not as straightforward as it might sound. JPL's Mars team provides a variety of rock types for OPTIMISM to drill through, since the exact nature of the rock Perseverance will encounter often can't be known in advance. Terrain is a variable, too. One previous test with the robotic arm involved parking the rover on a slope, then instructing it to drill.

"There was a possibility that the rover might slip," Trujillo-Rojas said. "We wanted to test that first here on Earth before sending instructions to the rover on Mars. That was scary because you can imagine if you drill this way, and the rover slightly slipped back, the drill could have gotten stuck."

OPTIMISM drilled the core successfully, suggesting Perseverance also could pull off drilling on a slope if required.

With longer drives in Perseverance's near future, another job for the Earth-bound twin will involve presenting new challenges to the rover's autonomous navigation system (AutoNav). Perseverance uses a powerful computer to make three-dimensional maps based on rover images of the terrain ahead. Those maps help plan its drive with minimal human assistance.

In Mars Yard tests, the twin rover might pause as it "thinks through" several possible choices or even decides, unexpectedly, to avoid obstacles altogether and just go around.

"Seeing the rover autonomously move in the Mars Yard, you kind of get that sense of being connected to the rover on Mars," Trujillo-Rojas said. "It gives you that visual connection."

Of course, OPTIMISM and its human team must contend with environmental factors that are different from those encountered by Perseverance, which is built for freezing temperatures and intense radiation. Earth's stronger gravity required OPTIMISM's metal wheels to be thicker than its martian counterpart's. And its electronics sometimes must be cooled to avoid damage from Southern California's summer temperatures, the opposite of the problem caused by deep cold on Mars.

"On Mars, we try to keep the rover warm," Trujillo-Rojas said. "Here, we're trying to keep it cool."

Deer, bobcats, tarantulas, and even snakes find their way into the Mars Yard. Wildfire in the region can fill the air with smoke. And testing and staffing schedules had to contend with COVID-19.

"We've been through a lot of challenges with this rover," he said. "As soon as we were going to start building it, with hands-on integration, the pandemic happened. And then we had rains, and we got a lot of fire. We had to leave the lab — smoky!"

Now, a revamped OPTIMISM is ready to get back to work.

"It's a big milestone for our team," Trujillo-Rojas said.

ORBITAL HARMONY LIMITS LATE ARRIVAL OF WATER ON TRAPPIST-1 PLANETS

Seven Earth-sized planets orbit the star TRAPPIST-1 in near-perfect harmony, and U.S. and European researchers have used that harmony to determine how much physical abuse the planets could have withstood in their infancy.

"After rocky planets form, things bash into them," said astrophysicist Sean Raymond of the University of Bordeaux in France. "It's called bombardment, or late accretion, and we care about it, in part, because these impacts can be an important source of water and volatile elements that foster life."

In a study available online in *Nature Astronomy*, Raymond and colleagues from Rice University's NASA-funded CLEVER Planets project and seven other institutions used a computer model of the bombardment phase of planetary formation in TRAPPIST-1 to explore the impacts its planets could have withstood without getting knocked out of harmony.

"Deciphering the impact history of planets is difficult in our solar system and might seem like a hopeless task in systems light-years away," Raymond said.

"On Earth, we can measure certain types of elements and compare them with meteorites," Raymond said. "That's what we do to try to figure out how much stuff bashed into the Earth after it was mostly formed."

But those tools don't exist for studying bombardment on exoplanets.

"We'll never get rocks from them," he said. "We're never going to see craters on them. So what can we do? This is where the special orbital configuration of TRAPPIST-1

comes in. It's a kind of a lever we can pull on to put limits on this."

TRAPPIST-1, about 40 light-years away, is far smaller and cooler than our Sun. Its planets are named alphabetically from b to h in order of their distance from the star. The time needed to complete one orbit around the star — equivalent to one year on Earth — is 1.5 days on planet b and 19 days on planet h. Remarkably, their orbital periods form near-perfect ratios, a resonant arrangement reminiscent of harmonious musical notes. For example, for every eight "years" on planet b, five pass on planet c, three on planet d, two on planet e, and so on.

"We can't say exactly how much stuff bashed into any of these planets, but because of this special resonant configuration, we can put an upper limit on it," Raymond said. "We can say, 'It can't have been more than this.' And it turns out that that upper limit is actually fairly small.

"We figured out that after these planets formed, they weren't bombarded by more than a very small amount of stuff," he said. "That's kind of cool. It's interesting information when we're thinking about other aspects of the planets in the system."

Planets grow within protoplanetary disks of gas and dust around newly formed stars. These disks only last a few million years, and Raymond said previous research has shown that resonant chains of planets like TRAPPIST-1's form when young planets migrate closer to their star before the disk disappears. Computer models have shown disks can shepherd planets into resonance. Raymond said it is believed that resonant chains like TRAPPIST-1's must be set before their disks disappear.

The upshot is TRAPPIST-1's planets formed fast, in about one-tenth the time it took Earth to form, said Rice University study co-author Andre Izidoro, an astrophysicist and CLEVER Planets postdoctoral fellow.

CLEVER Planets, led by study co-author Rajdeep Dasgupta, the Maurice Ewing Professor of Earth Systems Science at Rice University, is exploring the ways planets might acquire the necessary elements to support life. In previous studies, Dasgupta and colleagues at CLEVER Planets have shown a significant portion of Earth's volatile elements came from the impact that formed the Moon.

An illustration showing what the TRAPPIST-1 system might look like from a vantage point near planet TRAPPIST-1f (right). Credit: NASA/JPL-Caltech.

"If a planet forms early and it is too small, like the mass of the Moon or Mars, it cannot accrete a lot of gas from the disk," Dasgupta said. "Such a planet also has much less opportunity to gain life-essential volatile elements through late bombardments."

Izidoro said that would have been the case for Earth, which gained most of its mass relatively late, including about 1% from impacts after the Moon-forming collision.

"We know Earth had at least one giant impact after the gas (in the protoplanetary disk) was gone," he said. "That was the Moon-forming event."

"For the TRAPPIST-1 system, we have these Earth-mass planets that formed early," he said. "So one potential difference, compared to the Earth's formation, is that they could have, from the beginning, some hydrogen atmosphere and have never experienced a late giant impact. And this might change a lot of the evolution in terms of the interior of the planet, outgassing, volatile loss, and other things that have implications for habitability."

Raymond said this research has implications not only for the study of other resonant planetary systems, but for far more common exoplanet systems that were believed to have begun as resonant systems.

"Super-Earths and sub-Neptunes are very abundant around other stars, and the predominant idea is that they migrated inward during that gas-disk phase and then possibly had a late phase of collisions," Raymond said. "But during that early phase, where they were migrating inward, we think that they pretty much — universally maybe — had a phase where they were resonant chain structures like TRAPPIST-1. They just didn't survive. They ended up going unstable later on."

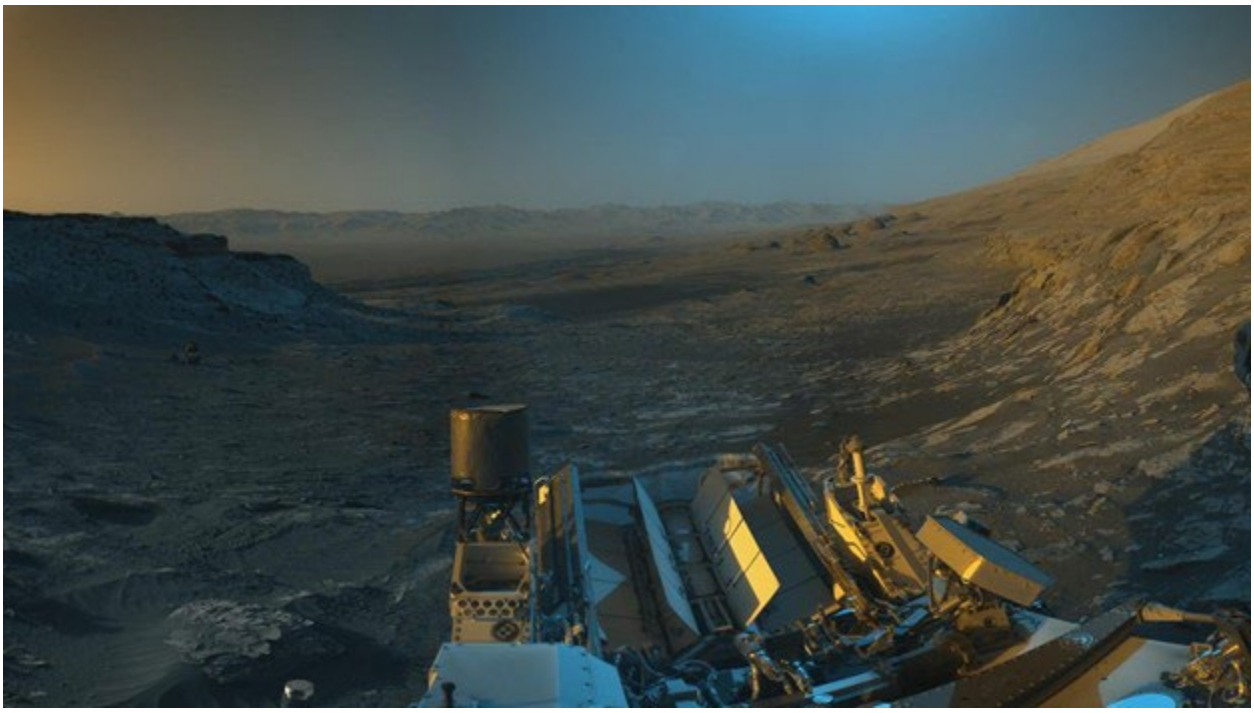
Izidoro said one of the study's major contributions could come years from now, after NASA's James Webb Space Telescope, the European Southern Observatory's Extremely Large Telescope, and other instruments allow astronomers to directly observe exoplanet atmospheres.

"We have some constraints today on the composition of these planets, like how much water they can have," Izidoro said of planets that form in a resonant, migration phase. "But we have very big error bars."

In the future, observations will better constrain the interior composition of exoplanets, and knowing the late bombardment history of resonant planets could be extremely useful.

"For instance, if one of these planets has a lot of water, let's say 20% mass fraction, the water must have been incorporated into the planets early, during the gaseous phase," he said. "So you will have to understand what kind of process could bring this water to this planet."

NASA'S CURIOSITY ROVER SENDS A PICTURE POSTCARD FROM MARS



NASA's Curiosity Mars rover used its navigation cameras to capture panoramas of this scene. Blue, orange, and green color was added to a combination of the panoramas for an artistic interpretation of the scene. Credit: NASA/JPL-Caltech.

NASA's Curiosity rover captured a remarkable image from its most recent perch on the side of Mars' Mount Sharp. The mission team was so inspired by the beauty of the landscape that they combined two versions of the black-and-white images from different times of the day and added colors, creating a rare postcard from the Red Planet.

Curiosity captures a 360° view of its surroundings with its black-and-white navigation cameras each time it completes a drive. To make the resulting panorama easier to send to Earth, the rover keeps it in a compressed, low-quality format. But when the rover team saw the view from Curiosity's most recent stopping point, the scene was too pretty not to capture it in the highest quality that the navigation cameras are capable of.

Many of the rover's most stunning panoramas are from the color Mastcam instrument, which has far higher resolution than the navigation cameras. That is why the team added colors of their own to this latest image. The blue, orange, and green tints are not what the human eye would see; instead, they represent the scene as viewed at different times of day.

On November 16, 2021 (the 3299th martian day, or sol, of the mission), engineers commanded Curiosity to take two sets of mosaics, or composite images, capturing the scene at 8:30 a.m. and again at 4:10 p.m. local Mars time. The two times of day provided contrasting lighting conditions that brought out a variety of landscape details. The team then combined the two scenes in an artistic re-creation that includes elements from the morning scene in blue, the afternoon scene in orange, and a combination of both in green.

At the center of the image is the view back down Mount Sharp, the 5-kilometer-tall (3-mile-tall) mountain that Curiosity has been driving up since 2014. Rounded hills can be seen in the distance at center-right; Curiosity got a closer view of these hills in July when the rover started to see intriguing changes in the landscape. A field of sand ripples known as the "Sands of Forvie" stretches 400 to 800 meters (1300 to 2600 feet).

At the far right of the panorama is the craggy "Rafael Navarro Mountain," named after a Curiosity team scientist who passed away in 2021. Poking up behind it is the upper part of Mount Sharp, far above the area Curiosity is exploring. Mount Sharp lies inside Gale Crater, a 154-kilometer-wide (96-mile-wide) basin formed by an ancient impact. Gale Crater's distant rim stands 2.3 kilometers (1.4 miles) tall and is visible on the horizon about 30 to 40 kilometers (18 to 25 miles) away.

For more information, visit mars.nasa.gov/msl/home/.

OPPORTUNITIES FOR STUDENTS

2022 INTERNSHIPS

2022 SPACE ASTRONOMY SUMMER PROGRAM (SASP) INTERN POSITIONS

Each summer, the Space Telescope Science Institute (STScI) hires highly motivated college students for the Space Astronomy Summer Program (SASP) to work individually with STScI researchers and staff on projects that include Science Research, Science Instrumentation + Calibration, Science Software Development, and Science Public Outreach. Applications must be submitted by 10:59 p.m. CST on January 31, 2022, to receive consideration.

Click here to learn more and apply.

SETI INSTITUTE REU PROGRAM

The SETI Institute invites motivated students who are interested in research related to astronomy, astrobiology, and planetary science to apply for their 10-week summer Research Experience Undergraduates program. Students will work with scientists at the SETI Institute and NASA Ames Research Center. Research topics span the field of astrobiology, from microbiology to planetary geology to observational astronomy. The deadline to apply is February 1, 2022.

Click here to learn more and apply.

NATIONAL AIR AND SPACE MUSEUM SUMMER INTERNSHIP PROGRAM

The Smithsonian's 10-week summer internship program provides firsthand experience working at the National Air and Space Museum. It's a great introduction to museum work or an opportunity to expand on previous experience. Each year, positions are available in areas such as aviation or space history, planetary science, exhibits, communications, museum management, and education. Students from all fields of study are encouraged to apply. The deadline to apply is February 17, 2022.

Click here to learn more and apply.

STEM ENHANCEMENT IN EARTH SCIENCE (SEES) SUMMER HIGH SCHOOL INTERN PROGRAM

SEES is a nationally competitive STEM program for high school students. The program provides selected students with exposure to Earth and space research. Interns will learn how to interpret NASA satellite data while working with scientists and engineers in their chosen area of work. Applications are due on February 21, 2022.

Click here to learn more and apply.

JPL SUMMER INTERNSHIP PROGRAM 2022

The JPL Summer Internship Program (SIP) offers 10-week, full-time, summer internship opportunities at JPL to undergraduate and graduate students pursuing degrees in STEM. As part of their internships, students are partnered with JPL scientists or engineers, who serve as the students' mentors. Students complete designated projects outlined by their mentors, gaining educational experience in their fields of study while also contributing to NASA and JPL missions and science. Applications must be submitted by 6:00 p.m. CDT on March 31, 2022, to receive consideration.

Click here to learn more and apply.

SCHOLARSHIPS AND FELLOWSHIPS

HARRIET EVELYN WALLACE SCHOLARSHIP FOR WOMEN GEOSCIENCE GRADUATE STUDENTS

The Harriet Evelyn Wallace Scholarship is available to all women pursuing a Master's or Doctoral degree in the geosciences at an accredited U.S. institution of higher education in a recognized geoscience program. Applications will be accepted until February 6, 2022.

Click here to learn more and apply.

AGI SCHOLARSHIP FOR ADVANCING DIVERSITY IN THE GEOSCIENCE PROFESSION

The scholarship is a one-time $5000 award paid upon confirmation of active enrollment in a geoscience graduate program. The scholarship is open to geoscience students who self-identify as Black, Indigenous, or Person of Color and are within two semesters of completing their bachelor's degree in a geoscience. Student must be a U.S. citizen or permanent resident. Applications will be accepted until February 13, 2022.

Click here to learn more and apply.

THE EUGENE M. SHOEMAKER IMPACT CRATERING AWARD

The Eugene M. Shoemaker Impact Cratering Award is for undergraduate or graduate students, of any nationality, working in any country, in the disciplines of geology, geophysics, geochemistry, astronomy, or biology. The award, which will include $3000, is to be applied for the study of impact craters, either on Earth or on the other solid bodies in the solar system. Applications will be accepted starting in April 2022.

Click here to learn more.

POSTDOCTORAL POSITIONS

Opportunities for recent Ph.D. graduates can be found in industry, national labs, nonprofit institutions, and government. Here is a selection of postdoctoral fellowship opportunities for a range of disciplines and backgrounds.

NASA Postdoctoral Program

LPI Postdoctoral Positions

JPL Postdoctoral Positions

U.S. National Labs — Postdoctoral Positions

AGU Job Board — Postdoctoral Positions

PROFESSIONAL DEVELOPMENT AND PUBLIC ENGAGEMENT EVENTS AT THE 53RD LUNAR AND PLANETARY SCIENCE CONFERENCE

The 53rd Lunar and Planetary Science Conference (LPSC) will be a hybrid conference on March 7–11, 2022. With in-person and global virtual participation, attendees will have the opportunity to share their research and network with colleagues. Engagement opportunities for scientists, students, and the public will take place during the 2022 conference. For more information, visit www.hou.usra.edu/meetings/lpsc2022/education/ or contact education@lpi.usra.edu.

LPSC EARLY-CAREER PRESENTERS HELP DESK

February 2022

Students, postdoctoral fellows, and other early-career scientists are invited to stop by a virtual Help Desk for assistance in planning their oral or poster presentations. Participants will receive feedback on presentation content before the submission deadline. Registration and details will be posted in January 2022. To volunteer as a reviewer or to request more information, please email education@lpi.usra.edu.

LPSC EARLY-CAREER NETWORKING EVENT

Sunday, March 6, 2022, Time TBD

This new event is an opportunity for students and other early-career scientists to meet with planetary scientists, learn about career paths, and develop personal connections. This event will support both in-person and virtual attendees. Details for this event will be announced in January 2022.

LPSC INSIGHTS: GET CONNECTED, STAY CONNECTED

Monday, March 7, 2022, Time TBD

Are you a student attending LPSC for the first time? Are you unsure how to navigate the conference? Are you nervous about networking? This mentoring program is for you! First-time student attendees who register for this program will be paired with a mentor. Registration is required and will open in January 2022. If you are an experienced LPSC attendee and would like to mentor a first-time attendee, please email education@lpi.usra.edu.

PUBLIC EVENT: LIVE FROM LPSC

Thursday, March 10, 2022, Time TBD

The public is invited to hear from planetary scientists in this webinar event about the latest research and discussions occurring during this annual conference. More details will be available in February 2022.

LPSC DAILY WRAP-UP: LPSC NETWORKING EVENTS

March 7–10, 2022, Time TBD

Conference attendees and the public are invited to join this daily evening discussion of conference presentations. Conference attendees can join in person or online; the public is welcome to join online. More details will be available in February 2022.

UPCOMING EDUCATION AND PUBLIC ENGAGEMENT OPPORTUNITIES

Are you interested in sharing your science and expertise with the public? Education and public engagement opportunities may be available online or in your community. Explore ways to get involved by contacting your local museums and planetariums, libraries, Solar System Ambassadors, or amateur astronomy clubs.

LAUNCH OF ARTEMIS I

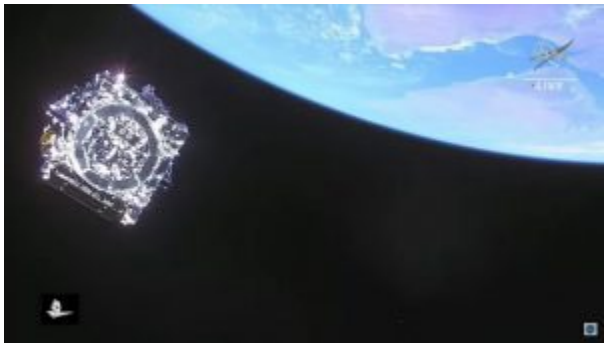
The launch of NASA's uncrewed Artemis I mission will be the first integrated test of the SLS and Orion spacecraft. The Artemis missions will land the first woman and the first person of color on the Moon and establish long-term exploration in preparation for missions to Mars. With the March/April launch date nearing, you can help build excitement and awareness for the next generation of human space exploration. Check out stem.nasa.gov/artemis/ for resources.

WEBB HAS LAUNCHED!

Following a near-perfect launch, the James Webb Space Telescope continues to undergo its historic journey to L2. Keep track of Webb's progress at jwst.nasa.gov/content/webbLaunch/whereIsWebb.html. And take advantage of the amazing resources (including FAQs, PPT and PDF presentations, virtual backgrounds, images and animations, educational activities, and more) available to scientists at jwst.nasa.gov/content/forScientists/index.html.

CELEBRATING ONE YEAR ON MARS

On February 18, 2021, NASA's Perseverance Rover landed on the Red Planet. You can help celebrate the anniversary by sharing the latest advances in planetary science with diverse audiences. The Jet Propulsion Laboratory has an excellent compilation of Mars resources at https://www.jpl.nasa.gov/edu/teach/activity/mission-to-mars-unit/.



Credit: Arianespace, ESA, NASA, CSA, CNES.

LYRIDS METEOR SHOWER: APRIL 22–23, 2022

The Lyrids Meteor Shower is produced by dust particles left behind by Comet C/1861 G1Thatcher. The shower peaks this year on the night of April 21 and the morning of April 22. Meteors will radiate from the constellation Lyra but can appear anywhere in the sky. Meteor showers provide an excellent opportunity to discuss comets with your audiences. For more information, visit www.amsmeteors.org/meteor-showers/meteor-shower-calendar/#Lyrids.

NEW OPPORTUNITIES AND RESOURCES IN STEM EDUCATION

CALL FOR VOLUNTEERS: AGU EDUCATION SECTION LEADERSHIP OPENINGS

The AGU Education Section seeks candidates for several roles on their Executive Committee. These leadership positions require a manageable commitment of time, energy, and skills. The efforts of this committee benefit the geoscience community and the mission of the AGU.

JOIN THE AAS EDUCATION COMMITTEE

The AAS Education Committee invites expressions of interest from potential new members for a three-year term beginning in March 2022. The committee consists of a team of roughly 10 AAS members involved in formal and informal astronomy education at various levels and types of institutions, astronomy education research, professional development, and mentoring. For more information, visit aas.org/posts/news/2021/12/join-aas-education-committee.

PROFESSIONAL DEVELOPMENT WEBINAR: DE-JARGONING YOUR TALKS

The Lunar and Planetary Institute's education and public engagement team assist planetary scientists in their communication and public engagement activities. In this

Credit: NASA.

session of Sharing Planetary Science, we will discuss ways to identify and avoid jargon. Join us on February 15, 2022, at 3:00 p.m. CST. For more information, visit www.lpi.usra.edu/education/scientist-engagement/.

REPORT: FUTURE OF UNDERGRADUATE GEOSCIENCE EDUCATION

The Future of Undergraduate Geoscience Education initiative, sponsored by the NSF, addresses the critical questions facing undergraduate geoscience education. During the last six years, over 1,000 members of the geoscience community have helped shape a vision for the future of undergraduate geoscience education. This report articulates that vision and identifies strategies for transformative change in undergraduate geoscience education. Access the full report at https://www.americangeosciences.org/change/.

NASA SELECTS EDUCATION PROJECTS TO HELP BROADEN STEM PARTICIPATION

NASA has selected a diverse group of projects from museums, science centers, library systems, and other informal education organizations across the country. These projects will bring space exploration to traditionally underserved areas and broaden student participation in STEM. Read the full press release at www.nasa.gov/press-release/nasa-selects-education-projects-to-help-broaden-stem-participation.

NASA'S EYES ON THE EARTH PUTS THE WORLD AT YOUR FINGERTIPS

The 3D real-time visualization tool lets users track NASA satellites and the vital Earth science data they provide. Recent upgrades to the tool make for an even more fascinating experience for learners of all ages. For more information, visit eyes.nasa.gov/apps/earth/#/.

NEW ACTIVITY PUTS STUDENTS IN THE DRIVER'S SEAT ON MARS

In this activity, participants will plan their path for the rover to see just how challenging it can be to get from one place to another on Mars. For more information, visit www.jpl.nasa.gov/edu/learn/project/map-a-mars-rover-driving-route/.

NEW SEASON OF "ON A MISSION" AVAILABLE NOW

"On a Mission" is the JPL's podcast series that shares thrilling stories about NASA missions, told through the lives of those who make space exploration possible. In the fourth season, we're transported to the Red Planet with all five of NASA's Mars rovers. For more information, visit www.jpl.nasa.gov/podcasts/on-a-mission-season-1/season-4-mars-rovers.

Credit: NASA/JPL-Caltech.

"Spotlight on Education" highlights events and programs that provide opportunities for planetary scientists to become involved in education and public engagement. If you know of space science educational programs or events that should be included, please contact the Lunar and Planetary Institute's Education Department at education@lpi.usra.edu.

IN MEMORIAM

Mark Geyer. Credit: NASA.

MARK GEYER

1958–2021

Mark Stephen Geyer, 63, senior advisor to NASA's associate administrator and former director of NASA Johnson Space Center (JSC), passed away on December 7, 2021, after an 18-month battle with pancreatic cancer.

Born in Indianapolis, Indiana, Geyer earned both his Bachelor of Science and Master of Science degrees in Aeronautical and Astronautical Engineering from Purdue University. He began his NASA career in 1990 at JSC in the new business directorate. He joined the International Space Station Program in 1994 where he served in a variety of roles until 2005, including chair of the space station Mission Management Team, manager of the ISS Program Integration Office, and NASA lead negotiator with Russia on space station requirements, plans, and strategies.

From 2005 to 2007, Geyer served as deputy program manager of the Constellation Program before transitioning to manager of the Orion Program, a position he held until 2015. Under Geyer's direction, Orion was successfully tested in space in 2014 for the first time, bringing NASA another step closer to sending astronauts to deep space destinations. After supporting Orion, Geyer served as deputy center director at NASA Johnson until September 2017. In this role, he helped the center director manage a broad range of human spaceflight activities, including the center's annual budget of approximately $5.1 billion. From October 2017 to May 2018, Geyer served as the acting deputy associate administrator for the Human Exploration and Operations Mission Directorate at NASA Headquarters in Washington. In this position, he was responsible for assisting the associate administrator in providing strategic direction for all aspects of NASA's human spaceflight exploration mission. He then served as the 12th center director at JSC, where he led the agency to places it had not been before and fought for several new initiatives to improve the overall diversity and inclusion in the space industry.

Geyer is the recipient of the NASA Distinguished Service Medal, Meritorious Executive Rank Award, and Distinguished Executive Rank Award.

NASA Administrator Bill Nelson issued the following statement following Geyer's passing:

"Today, we mourn the loss of a giant for human spaceflight and a beloved member of the NASA family: former Johnson Space Center Director Mark Geyer.

"Like so many Americans, Mark spent his childhood watching the Gemini and Apollo missions. It inspired him to join NASA. It is difficult to overstate the difference he made. Under Mark's leadership, Johnson Space Center moved the United States into a new era of human space exploration. In fact, more human spaceflight programs were led from Houston during his tenure than ever before.

"That's because Mark personified the American character, believing we should constantly venture farther into the cosmos for the benefit of humanity. It's not an exaggeration to say Mark's legacy will be realized for generations to come at the agency he loved so dearly. When NASA astronauts return to the Moon under Artemis, and ultimately prepares for human missions to Mars, this new generation of explorers and adventurers will be guided by Mark's spirit.

"Mark Geyer shaped history. He strengthened this agency and the bonds of our NASA family. We will miss this champion for exploration and forever be grateful for his service."

— Portions of text courtesy of NASA

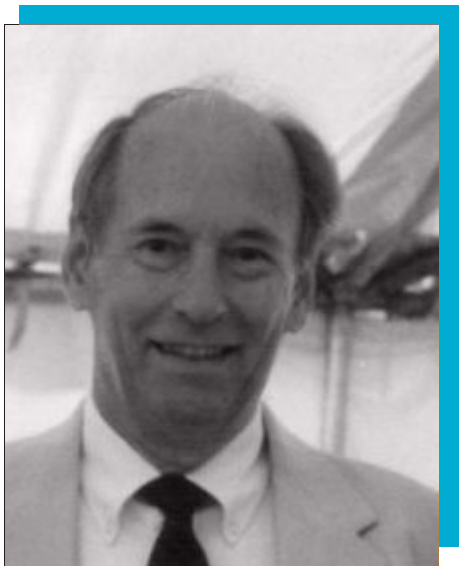
WALTER F. HUEBNER

1928–2021

Walter F. Huebner, world-renowned astrophysicist and planetary scientist specializing in comets, passed away peacefully at his home in Norman, Oklahoma, on June 1, 2021.
Huebner received his Ph.D. in Physics from Yale University. After graduating, he worked at the Los Alamos National Laboratory from 1957 to 1987 in various capacities, from staff scientist to group leader. In 1987, he moved to San Antonio, Texas, and worked at the Southwest Research Institute as an institute scientist until 2018.

Huebner held many professional leadership and service positions, such as President of IAU Commission 15 (Small Bodies of the Solar System), President of the Permanent Monitoring Panel for Cosmic Objects (at international seminars on Nuclear War and Planetary Emergencies), program manager at NASA Headquarters, and visiting scientist at the Jet Propulsion Laboratory, the University of Sao Paulo, and the Max Planck Institute for Astrophysics.

Huebner was awarded a Fulbright Fellowship and was a participant in Operation Dominic at Christmas Island. He was known not only for his invaluable scientific work and insights, but also for his kind, gentle, and generous nature. He had a wonderful sense of humor, a lifelong passion for travel, and was loved by all who knew him.

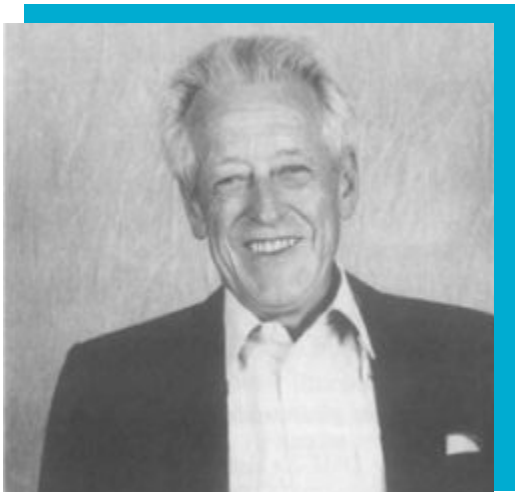


Walter Huebner. Credit: Division for Planetary Sciences.

— Portions of text courtesy of D. Boice/Division of Planetary Sciences

PETER SIGNER

1929–2021



Peter Signer. Credit: ETH Zurich.

Peter Signer, an eminent pioneer of noble gas geochemistry, died on December 10, 2021, following a lengthy illness. He was 92 years old.

Signer graduated from the Physical Institute of the University of Bern under the directorship of Friedrich Houtermans. One of Signer's pioneering studies was his first mass spectrometric investigation of the decay constant of lutetium-176. In 1958, he went to the University of Minnesota to work with Alfred Nier, who was known as the father of modern mass spectrometry.

Over the next seven years, Signer developed his affection for both noble gases and meteorites. One of his widely known contributions was the development, together with Nier, of the "Signer-Nier model" for the production of cosmogenic nuclides in iron meteorites. Some of his other contributions included working with Hans Suess in 1963 to compile a complete dataset of meteorites containing primordial noble gases. Signer pointed out that solar gases in meteorites might be trapped particles of solar corpuscular radiation, a conclusion that was drawn independently at the same time by Heinrich Wänke.

Solar gases in meteorites and lunar material occupied a considerable part of Signer's research activities for the next 30 years. In 1965, Signer returned to Switzerland to join Marc Grunenfelder in the newly established Laboratory for Isotope Geochemistry at the ETH Zurich. While there, Signer created a noble gas laboratory devoted mainly to studies of extraterrestrial materials. The backbone of that lab was two Nier-type mass spectrometers imported from Minneapolis. Those machines went on to devour thousands of lunar, meteorite, and terrestrial samples.

Signer, a Fellow of the Meteoritical Society since 1967, was an enthusiastic lecturer who reminded generations of Earth science students about the importance of understanding the other planets to understand Earth. He was a good friend and teacher, and we mourn his loss.

— Portions of text courtesy of Rainer Wieler, Ludolf Schultz, and the Meteoritical Society

DOBSON NAMED 2021 EUGENE M. SHOEMAKER IMPACT CRATERING AWARD RECIPIENT

Michaela Dobson of the University of Auckland, New Zealand, has been named the 2021 Eugene M. Shoemaker Impact Cratering Award recipient. Dobson will study a potential impact ejecta horizon in a 3.5 Ga sequence of sedimentary rocks. If an impact origin is confirmed, it will be the oldest known ejecta layer on Earth. The Eugene M. Shoemaker Impact Cratering Award is for undergraduate or graduate students of any nationality, working in any country, in the disciplines of geology, geophysics, geochemistry, astronomy, or biology. The award, which includes $3,000, is to be applied for the study of impact craters, either on Earth or on the other solid bodies in the solar system, which areas of study may include but shall not necessarily be limited to impact cratering processes, the bodies (asteroidal or cometary) that make the impacts, or the geological, chemical or biological results of impact cratering.

NASA DEPUTY ADMINISTRATOR AMONG U.S. ASTRONAUT HALL OF FAME INDUCTEES

NASA Deputy Administrator Pam Melroy, along with fellow veteran astronauts Michael Lopez-Alegria and Scott Kelly, were inducted into the U.S. Astronaut Hall of Fame class of 2021 on November 13, 2021. Their induction ceremony, held at NASA's Kennedy Space Center Visitor Complex in Florida, brings the Hall of Fame's membership to 102.

Melroy, Lopez-Alegria, and Kelly have spent a combined total of more than 635 days in space. They were honored for demonstrating outstanding accomplishments in furthering NASA's mission of exploration and discovery.

NASA Administrator Bill Nelson provided keynote remarks at the ceremony and former CNN space correspondent John Zarrella served as host. Both praised the inductees for their contributions to NASA's space program.

"These three pioneers propelled upward and explored the heavens. They broke barriers and set records. They pushed the boundaries of humanity's reach," Nelson said. "Pam, Michael, and Scott, congratulations on this well-earned recognition. And thank you for daring us to keep looking upward and pushing outward into the unknown."

NASA Deputy Administrator Pamela Melroy was one of three former astronauts inducted into the U.S. Astronaut Hall of Fame on Saturday, November 13, 2021, during a ceremony at the Kennedy Space Center Visitor Complex in Florida. Melroy received an official medal and became a member of the 19th class of space shuttle astronauts to be inducted. Credit: NASA/Kim Shiflett.

Melroy was selected as a NASA astronaut in 1994. A veteran of three space shuttle missions, she served as pilot for two flights and commander for her third, making her one of only two women to command a space shuttle. Melroy logged more than 924 hours in space. She retired from NASA in 2007 and was sworn in as the agency's deputy administrator on June 21, 2021.

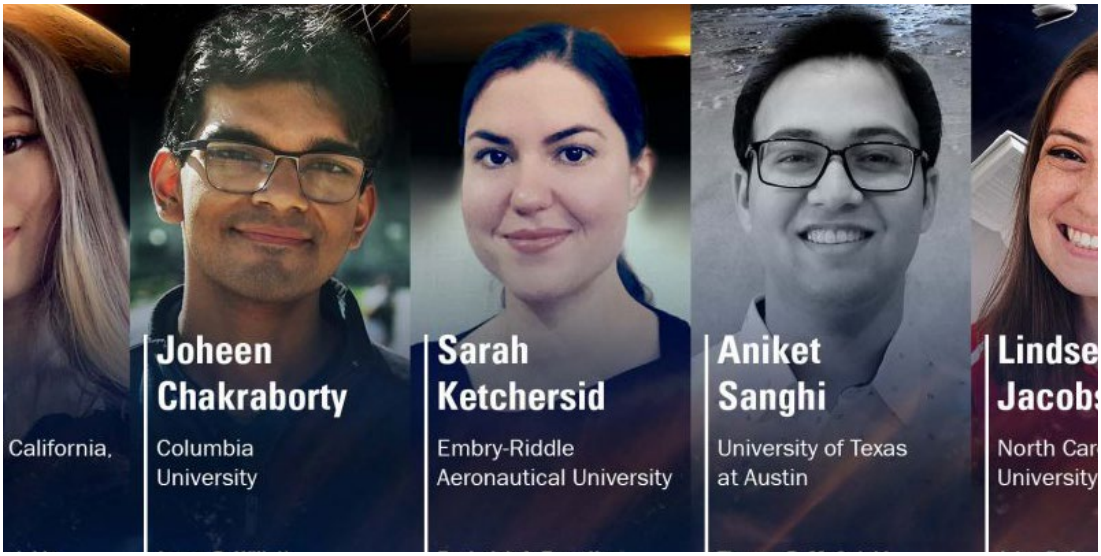
"It is a great honor to be inducted into the U.S. Astronaut Hall of Fame together with my distinguished colleagues," said Melroy. "Now we are building a program to achieve a series of objectives that will provide the blueprint to how we maintain a human presence in deep space as we explore the solar system, and then the universe. Those of us who had the incredible good fortune to go to space know that all of humanity is the crew of spaceship Earth, and it is our duty to care for each other and our home planet."

NASA selected Kelly as an astronaut in 1996. He served as pilot on his first space shuttle mission and commander on his second. In October 2010, Kelly launched onboard the Soyuz TMA-A spacecraft to serve a tour of duty onboard the International Space Station and commander of Expedition 26. In March 2015, Kelly returned to the space station for a one-year mission, serving as a flight engineer and then commander. During the mission, almost 400 experiments were conducted on the station.

The agency selected Lopez-Alegria as an astronaut in 1992. He was a mission specialist for three flights aboard the space shuttle and served as commander of Expedition 14 onboard the space station from September 2006 to April 2007. Lopez-Alegria logged more than 257 days in space and performed 10 spacewalks, totaling 67 hours and 40 minutes.

The 2021 inductees were selected by a committee of Hall of Fame astronauts, former NASA officials, flight directors, historians, and journalists. The process is administered by the Astronaut Selection Foundation, which was founded by the original seven Mercury astronauts in 1984. To be eligible, an astronaut must have made his or her first flight at least 17 years before the induction and have been retired from NASA for at least five years. Each candidate must be a U.S. citizen and a NASA-trained commander, pilot, or mission specialist who has orbited Earth at least once.

USRA ANNOUNCES 2021 DISTINGUISHED UNDERGRADUATE AWARD RECIPIENTS



2021 Distinguished Undergraduate Award Winners

Universities Space Research Association (USRA) proudly announced today the winners of the prestigious 2021 USRA Distinguished Undergraduate Awards.

In keeping with its goal to recognize and develop promising future scientists in space-related disciplines, USRA bestows these awards to honor outstanding undergraduate students in a variety of majors through a competitive process. These awards are granted to students who tackle challenging problems in aerospace engineering, space science research and exploration, demonstrate leadership, promote diversity in science and engineering, and are poised to make significant contributions to their fields.

The following students are the winners of the USRA 2021 Distinguished Undergraduate Awards:

Megan Li, University of California, San Diego,
Physics with Astrophysics concentration
— **Thomas R. McGetchin Memorial Scholarship Award**

Joheen Chakraborty, Columbia University, Astrophysics and Computer Science
— **James B. Willett Education Memorial Scholarship**

Lindsey Jacobson, North Carolina State University, Aerospace Engineering
— **John. R. Sevier Memorial Scholarship**

Sarah Ketchersid, Embry-Riddle Aeronautical University, Aerospace Engineering
— **Frederick A. Tarantino Memorial Scholarship**

Aniket Sanghi, University of Texas at Austin, Astronomy and Physics
— **Thomas R. McGetchin Memorial Scholarship**

"It is our distinct privilege at USRA to honor these 2021 Distinguished Undergraduate Award winners," says Dr. Jeffrey A. Isaacson, President and CEO, Universities Space Research Association. "Their scholastic achievements and leadership potential set them apart from their peers, and we wish them continued success throughout their promising careers."

Six other students received an Honorable Mention:

Rocky An, Cornell University, Mechanical Engineering and Biological Engineering

Pedro Salazar Garcia, Iowa State University, Aerospace Engineering

Asher Hancock, University of Pittsburgh, Mechanical Engineering

Evan Imata, University of California, Berkeley, Astrophysics

Allison Liu, University of Colorado, Boulder, Applied Mathematics

Emma Rogers, Purdue University, Geology and Geophysics/Planetary Science

Established to honor the service and memory of individuals who made significant contributions to their fields and to USRA, these awards are made possible by financial contributions, including those made by USRA employees.

Faculty from USRA Member Universities review the applications for the awards. Through a rigorous process, they evaluate the students based on stated career goals and accomplishments, leadership qualities, outreach to their communities, and strengths such as initiative, creativity, and perseverance. Recommendation letters from their professors and intern advisors also play an important role in the review.

In 2021, USRA received 96 eligible applications from 48 different universities (including one non-U.S. USRA member university). From this pool of applicants, the four review committees — two for science applicants and two for engineering applicants — reviewed the students' dossiers and recommended the finalists. The USRA President and CEO selected the winners of the awards from among the finalists.

NEW ROLES, COMBINED OFFICES FOR NASA ADMINISTRATOR LEADERSHIP TEAM

NASA Administrator Bill Nelson announced new leadership roles and the merging of two offices into the Office of Technology, Policy, and Strategy (OTPS) in support of Biden-Harris Administration priorities and the focus on space strategy.

- Bhavya Lal will serve as the associate administrator for OTPS
- Melanie Saunders will serve as the agency's new chief resilience officer
- Casey Swails will serve as the deputy associate administrator for business operations
- Tom Cremins will serve as the associate administrator for space security interests
- Douglas Terrier, the agency's current chief technologist, will serve in a new position as the associate director for vision and strategy at NASA's Johnson Space Center (JSC) in Houston (in the interim, Lal will serve as acting chief technologist)

All appointments are effective immediately.

OTPS is being established to provide data- and evidence-driven technology, policy, and strategy advice to NASA leadership. The office is a merger of the Office of Strategic Engagements and Assessments and the Office of the Chief Technologist. OTPS will support NASA leadership in developing and guiding the agency's activities across its six mission directorates. As the lead for the organization, Lal, who previously served as NASA's acting chief of staff during the presidential transition and senior advisor for budget and finance, brings her extensive experience and background in space technology, exploration, science, and policy to the role. She will report to NASA Deputy Administrator Pam Melroy.

Because of the ongoing COVID-19 pandemic and unprecedented scope of work that Saunders has been leading, she will move into a new, dedicated role focused

on the agency's coronavirus response and implementation of requirements related to it. In addition, she will oversee and integrate NASA's Future of Work program as it specifically ties to the pandemic, such as the agency's return to more onsite work. Saunders also will be responsible for the continued development and implementation of NASA's pilots, policies, and strategies, enabling a hybrid workforce and innovation in the workplace. Saunders will report to Melroy.

Swails, who most recently served as senior advisor and chief of staff to the associate administrator, as well as the agency's acting deputy chief of staff during the presidential transition, will lead and facilitate the integration of mission support functions across the agency, build and advance NASA's industry partnerships, and act as the principal advisor to NASA Associate Administrator Bob Cabana. Swails will report to Cabana.

In his new role, Cremins will report to the administrator and provide a broad security focus on NASA's civil space efforts within the larger national and global environment. Cremins also will support enterprise protection and assessment efforts, representing NASA and working with our federal agency partners to secure and advance our national posture.

In his new role as the associate director for vision and strategy at Johnson, Terrier will be responsible for leading the strategy, creation, integration, and overall execution of Johnson's ongoing transformation initiatives revolutionizing the center's policies, plans, and processes around workforce, facilities, and products to advance human spaceflight. Terrier also will provide executive and functional leadership to expand the center's collaboration across the agency, industry, academia, and international community, to ensure alignment with NASA's strategic plan and missions.

For more information about NASA programs and missions, visit www.nasa.gov.

NASA SELECTS NEW ASTRONAUT RECRUITS TO TRAIN FOR FUTURE MISSIONS

NASA has chosen 10 new astronaut candidates from a field of more than 12,000 applicants to represent the United States and work for humanity's benefit in space.

NASA Administrator Bill Nelson introduced the members of the 2021 astronaut class, the first new class in four years, during an event at Ellington Field near NASA's Johnson Space Center in Houston.

"Today we welcome 10 new explorers, 10 members of the Artemis generation, NASA's 2021 astronaut candidate class," Nelson said. "Alone, each candidate has 'the right stuff,' but together they represent the creed of our country: E pluribus unum — out of many, one."

The astronaut candidates will report for duty at Johnson in January 2022 to begin two years of training. Astronaut candidate training falls into five major categories: operating and maintaining the International Space Station's complex systems, training for spacewalks, developing complex robotics skills, safely operating a T-38 training jet, and Russian language skills.

Upon completion, they could be assigned to missions that involve performing research onboard the space station, launching from American soil on spacecraft built by commercial companies, as well as deep space missions to destinations including the Moon on NASA's Orion spacecraft and Space Launch System rocket.

"Each of you has amazing backgrounds," Pam Melroy, former NASA astronaut and NASA's deputy administrator, told the candidates. "You bring diversity in so many forms to our astronaut corps and you stepped up to one of the highest and most exciting forms of public service."

Applicants included U.S. citizens from all 50 states, the District of Columbia, and U.S. territories Puerto Rico, Guam, the Virgin Islands, and Northern Mariana Islands. For the first time ever, NASA required candidates to hold a master's degree in a STEM field and used an online assessment tool. The women and men selected for the new astronaut class represent the diversity of America and the career paths that can lead to a place in America's astronaut corps.

2021 Astronaut Candidates

Nichole Ayers, 32, major, U.S. Air Force, is a native of Colorado who graduated from the U.S. Air Force Academy in Colorado Springs, Colorado, in 2011 with a bachelor's degree in mathematics with a minor in Russian. She later earned a master's degree in computational and applied

NASA announced its 2021 Astronaut Candidate Class on December 6, 2021. The 10 candidates, pictured here at NASA's Johnson Space Center in Houston, are U.S. Air Force Maj. Nichole Ayers, Christopher Williams, U.S. Marine Corps Maj. (retired) Luke Delaney, U.S. Navy Lt. Cmdr. Jessica Wittner, U.S. Air Force Lt. Col. Anil Menon, U.S. Air Force Maj. Marcos Berríos, U.S. Navy Cmdr. Jack Hathaway, Christina Birch, U.S. Navy Lt. Deniz Burnham, and Andre Douglas. Credit: NASA.

mathematics from Rice University. Ayers is an experienced combat aviator with more than 200 combat hours and more than 1,150 hours of total flight time in the T-38 and the F-22 Raptor fighter jet. One of the few women currently flying the F-22, in 2019 Ayers led the first ever all-woman formation of the aircraft in combat.

Marcos Berríos, 37, major, U.S. Air Force, grew up in Guaynabo, Puerto Rico. While a reservist in the Air National Guard, he worked as an aerospace engineer for the U.S. Army Aviation Development Directorate at Moffett Federal Airfield in California. He is a test pilot who holds a bachelor's degree in mechanical engineering from the Massachusetts Institute of Technology and a master's degree in mechanical engineering as well as a doctorate in aeronautics and astronautics from Stanford University. A distinguished pilot, Berríos has accumulated more than 110 combat missions and 1,300 hours of flight time in more than 21 different aircraft.

Christina Birch, 35, grew up in Gilbert, Arizona, and graduated from the University of Arizona with a bachelor's degree in mathematics and a bachelor's degree in biochemistry and molecular biophysics. After earning a doctorate in biological engineering from MIT, she taught bioengineering at the University of California, Riverside, and scientific writing and communication at the California Institute of Technology. She became a decorated track cyclist on the U.S. National Team.

Deniz Burnham, 36, lieutenant, U.S. Navy, calls Wasilla, Alaska, home. A former intern at NASA's Ames Research Center in Silicon Valley, California, Burnham serves in the U.S. Navy Reserves. She earned a bachelor's degree in chemical engineering from the University of California, San Diego, and a master's degree in mechanical engineering from the University of Southern California in Los Angeles. Burnham is an experienced leader in the energy industry, managing onsite drilling projects throughout North America, including in Alaska, Canada, and Texas.

Luke Delaney, 42, major, retired, U.S. Marine Corps, grew up in Debary, Florida. He holds a degree in mechanical engineering from University of North Florida and a master's degree in aerospace engineering from the Naval Postgraduate School. He is a distinguished naval aviator who participated in exercises throughout the Asia Pacific region and conducted combat missions in support of Operation Enduring Freedom. As a test pilot, he executed numerous flights evaluating weapon systems integration, and he served as a test pilot instructor. Delaney most recently worked as a research pilot at NASA's Langley Research Center, in Hampton, Virginia, where he supported airborne science missions. Including his NASA career, Delaney logged more than 3,700 flight hours on 48 models of jet, propeller, and rotary-wing aircraft.

Andre Douglas, 35, is a Virginia native. He earned a bachelor's degree in mechanical engineering from the U.S. Coast Guard Academy, a master's degree in mechanical engineering from the University of Michigan, a master's degree in naval architecture and marine engineering from the University of Michigan, a master's degree in electrical and computer engineering from Johns Hopkins University, and a doctorate in systems engineering from the George Washington University. Douglas served in the U.S. Coast Guard as a naval architect, salvage engineer, damage control assistant, and officer of the deck. He most recently was a senior staff member at the Johns Hopkins University Applied Physics Lab, working on maritime robotics, planetary defense, and space exploration missions for NASA.

Jack Hathaway, 39, commander, U.S. Navy, is a native of Connecticut. He earned bachelors' degrees in physics and history from the U.S. Naval Academy and completed graduate studies at Cranfield University in England and the U.S. Naval War College. A distinguished naval aviator, Hathaway flew and deployed with Navy's Strike Fighter Squadron 14 aboard the USS Nimitz and Strike Fighter Squadron 136 aboard the USS Truman. He graduated from Empire Test Pilots' School, supported the Joint Chiefs of Staff at the Pentagon, and was most recently assigned as the prospective executive officer for Strike Fighter Squadron 81. He has more than 2,500 flight hours in 30 types of aircraft, more than 500 carrier arrested landings, and flew 39 combat missions.

Anil Menon, 45, lieutenant colonel, U.S. Air Force, was born and raised in Minneapolis, Minnesota. He was SpaceX's first flight surgeon, helping to launch the company's first humans to space during NASA's SpaceX Demo-2 mission and building a medical organization to support the human system during future missions. Prior to that, he served NASA as the crew

flight surgeon for various expeditions taking astronauts to the International Space Station. Menon is an actively practicing emergency medicine physician with fellowship training in wilderness and aerospace medicine. As a physician, he was a first responder during the 2010 earthquake in Haiti, 2015 earthquake in Nepal, and the 2011 Reno Air Show accident. In the Air Force, Menon supported the 45th Space Wing as a flight surgeon and the 173rd Fighter Wing, where he logged over 100 sorties in the F-15 fighter jet and transported over 100 patients as part of the critical care air transport team.

Christopher Williams, 38, grew up in Potomac, Maryland. He graduated from Stanford University in 2005 with a bachelor's degree in physics and a doctorate in physics from MIT in 2012, where his research was in astrophysics. Williams is a board-certified medical physicist, completing his residency training at Harvard Medical School before joining the faculty as a clinical physicist and researcher. He most recently worked as a medical physicist in the Radiation Oncology Department at the Brigham and Women's Hospital and Dana-Farber Cancer Institute in Boston. He was the lead physicist for the Institute's MRI-guided adaptive radiation therapy program. His research focused on developing image guidance techniques for cancer treatments.

Jessica Wittner, 38, lieutenant commander, U.S. Navy, is a native of California with a distinguished career serving on active duty as a naval aviator and test pilot. She holds a Bachelor of Science in aerospace engineering from the University of Arizona, and a Master of Science in aerospace engineering from the U.S. Naval Postgraduate School. Wittner was commissioned as a naval officer through an enlisted-to-officer program and has served operationally flying F/A-18 fighter jets with Strike Fighter Squadron 34 in Virginia Beach, Virginia, and Strike Fighter Squadron 151 in Lemoore, California. A graduate of U.S. Naval Test Pilot School, she also worked as a test pilot and project officer with Air Test and Evaluation Squadron 31 in China Lake, California.

Find photos and additional information about the new astronaut candidates at www.nasa.gov/astronauts.

NASA AWARDS ARTEMIS CONTRACT FOR FUTURE MEGA MOON ROCKET BOOSTERS

NASA has awarded the Booster Production and Operations Contract (BPOC) to Northrop Grumman of Brigham City, Utah, to build boosters for the agency's Space Launch System (SLS) rocket to support nine SLS flights. Northrop Grumman, the lead booster contractor, has produced booster motors for the first three Artemis missions and is casting the motors for the fourth lunar mission.

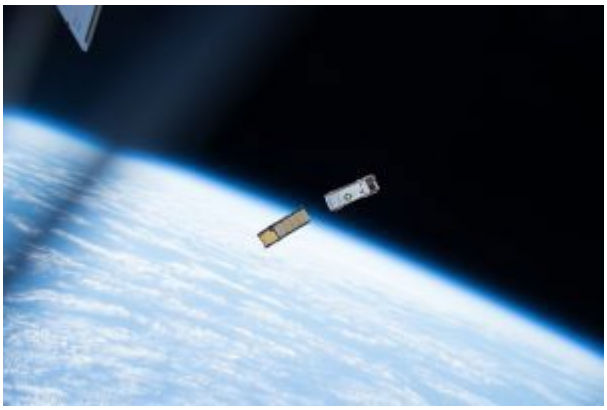
This contract, with a value of $3.19 billion, definitizes a letter contract awarded in June 2020 that authorized Northrop Grumman to order long-lead items and build twin boosters for the next six SLS flights. The period of performance extends through December 31, 2031. This includes production and operations for boosters for Artemis IV-VIII and design, development, test, and evaluation of a booster as part of Booster Obsolescence and Life Extension (BOLE) for Artemis IX.

The twin solid rocket boosters, which are mounted on the side of the SLS core stage, will produce more than 75% of the thrust for each SLS launch. The boosters were based on the design of the space shuttle solid rocket boosters but include a fifth segment to produce the extra power needed to send the larger SLS rocket to space. As part of this contract, the team also will design and test evolved boosters needed for flights starting with the ninth SLS mission. The new BOLE boosters will replace the steel cases currently used from the space shuttle with a stronger composite case and upgraded structures, electronic thrust vector control systems and propellant materials.

The SLS rocket and Orion spacecraft are part of NASA's backbone for deep space exploration. Through Artemis missions, NASA will land the first woman and the first person of color on the surface of the Moon and establish a long-term lunar presence that serves as a steppingstone on the way to Mars.

For more information on SLS, visit www.nasa.gov/sls/.

NASA AWARDS CHALLENGE PRIZES TO STARTUP COMPANIES



Credit: NASA.

NASA has awarded $90,000 each to seven entrepreneurial startup companies under its Entrepreneur's Challenge program. The awards will advance new technology concepts ranging from novel materials with properties not found in nature to innovative technologies that will enable small satellite (SmallSat) science missions.

The following companies were selected as winners of the Entrepreneur's Challenge:

- Morpheus Space of Los Angeles, California
- Multiscale Systems of Worcester, Massachusetts
- Nebula Compute of San Diego, California
- Niobium Microsystems of Dayton, Ohio
- OAM Photonics of San Diego, California
- Resilient Computing of Bozeman, Montana
- Zephyr Computing of Oakland, California

"We face audacious technical challenges to accomplish our NASA science goals," said Florence Tan, acting Science Mission Directorate chief technologist at NASA Headquarters in Washington. "Entrepreneurs can bring a diversity of groundbreaking ideas, concepts, and innovations that are relevant to our science goals. We want to invest in breakthrough technologies that will lead to revolutionary scientific discoveries. This program is a wonderful way to keep those ideas coming into our technology development programs."

NASA partnered with Starburst Aerospace in San Francisco, California, to launch the Entrepreneur's Challenge, which aims to engage U.S.-based entrepreneurs. The program seeks fresh ideas in technology that could advance the agency's science goals to explore and understand the solar system and beyond. The challenge also seeks to increase the number of entrepreneurial companies participating in the agency's technology portfolio.

The technical focus areas for the 2021 Entrepreneur's Challenge were:

- SmallSat technologies including advanced sensors, high-speed electronic systems, and the capability to autonomously recognize science phenomena in space and respond as needed
- Sensors made of metamaterials — manufactured materials with properties not found in nature — to detect and observe their surroundings at dramatically reduced size, weight, power, and cost
- Instruments to detect biomarkers or that can determine evidence of habitability on ocean worlds

Administered by NASA's Science Mission Directorate, the competition was conducted in two rounds. In the first, companies nationwide submitted 44 submissions. A NASA judging panel selected 10 companies from the three focus areas to each receive a $10,000 award. In the second, the participants refined their concepts, developed detailed white papers, and gave presentations to the same panel of judges. The panel selected seven of the companies from two of the focus areas to receive an additional $80,000 in prize funding.

To learn more about the Entrepreneur''s Challenge, visit nasa-science-challenge.com.

NASA SELECTS COMPANIES TO DEVELOP COMMERCIAL DESTINATIONS IN SPACE

NASA has signed agreements with three U.S. companies to develop designs of space stations and other commercial destinations in space. The agreements are part of the agency's efforts to enable a robust, U.S.-led commercial economy in low-Earth orbit.

The total estimated award amount for all three funded Space Act Agreements is $415.6 million. The companies that received awards are:

- Blue Origin of Kent, Washington, for $130 million

- Nanoracks LLC of Houston, Texas, for $160 million
- Northrop Grumman Systems Corporation of Dulles, Virginia, for $125.6 million

NASA seeks to maintain an uninterrupted U.S. presence in low-Earth orbit by transitioning from the International Space Station to other platforms. These awards will stimulate U.S. private sector development of commercial, independent space stations that will be available to both government and private-sector customers.

"Building on our successful initiatives to partner with private industry to deliver cargo, and now our NASA astronauts, to the International Space Station, NASA is once again leading the way to commercialize space activities," said NASA Administrator Bill Nelson. "With commercial companies now providing transportation to low-Earth orbit in place, we are partnering with U.S. companies to develop the space destinations where people can visit, live, and work, enabling NASA to continue forging a path in space for the benefit of humanity while fostering commercial activity in space."

The awards are the first in a two-phase approach to ensure a seamless transition of activity from the International Space Station to commercial destinations. During this first phase, private industry, in coordination with NASA, will formulate and design commercial low-Earth orbit destination capabilities suitable for potential government and private sector needs. The first phase is expected to continue through 2025.

For the second phase of NASA's approach to a transition toward commercial low-Earth orbit destinations, the agency intends to certify for NASA crew member use commercial low-Earth orbit destinations from these and potential other entrants and ultimately purchase services from destination providers for crew to use when available. This strategy will provide services the government needs at a lower cost, enabling NASA to focus on its Artemis missions to the Moon and on to Mars while continuing to use low-Earth orbit as a training and proving ground.

NASA estimates the agency's future needs in low-Earth orbit will require continuous accommodations and training for at least two crew members, as well as the ability to support a national orbiting laboratory and the performance of approximately 200 investigations annually to support human research, technology demonstrations, and biological and physical science.

Developing commercial destinations in low-Earth orbit is part of NASA's broader efforts to build a robust low-Earth orbit economy, including supporting commercial activity and enabling the first private astronaut mission to the space station. In addition to these new awards, NASA selected Axiom Space in January 2020 to design and develop commercial modules to attach to the station. NASA and Axiom recently completed the preliminary design review of two modules as well as the critical design review of the module's primary structure.

By transitioning to a model where commercial industry owns and operates the assets in low-Earth orbit and where NASA is one of many customers, the agency can save on costs to live and work in low-Earth orbit and focus on pushing innovation and exploration of the Moon and Mars through NASA's Artemis missions.

Find more information about NASA's efforts to bolster a low-Earth orbit economy at www.nasa.gov/leo-economy.

NASA ANNOUNCES WINNERS OF DEEP SPACE FOOD CHALLENGE

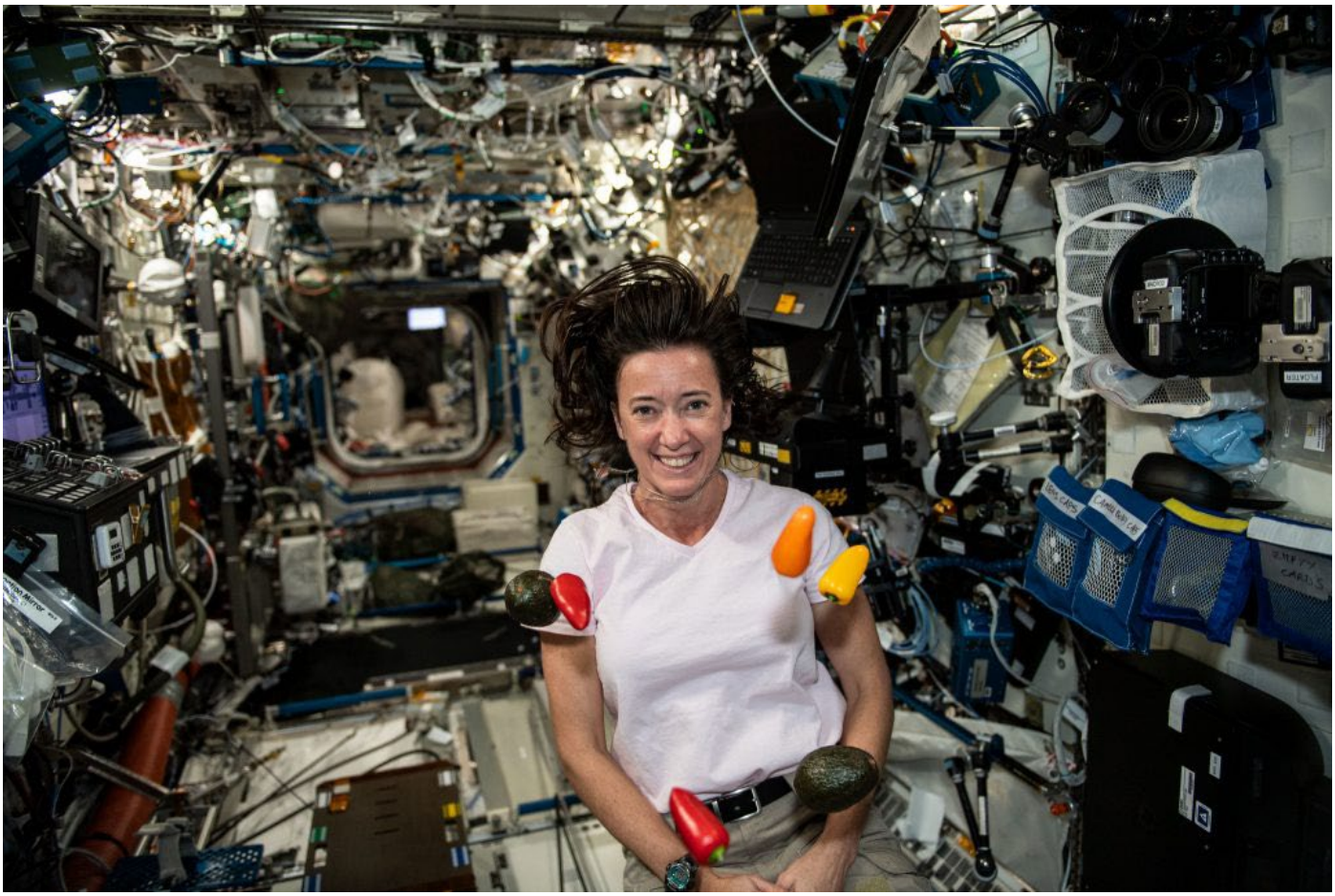
Variety, nutrition, and taste are some considerations when developing food for astronauts. For NASA's Deep Space Food Challenge, students, chefs, small businesses, and others whipped up novel food technology designs to bring new solutions to the table.

NASA has selected 18 U.S. teams to receive a total of $450,000 for ideas that could feed astronauts on future missions. Each team will receive $25,000. Additionally, NASA and the Canadian Space Agency (CSA) jointly recognized 10 international submissions.

NASA Television aired the Deep Space Food Challenge in November 2021 and shared details about the competition, winning solutions, and what could be next for the teams.

Special guests during the show included celebrity chef Martha Stewart and retired NASA astronaut Scott Kelly, announced the winners of two awards honoring international teams that demonstrated exceptional innovation. Other participants will include retired CSA astronaut Chris Hadfield and celebrity chef Lynn Crawford.

"NASA is excited to engage the public in developing technologies that could fuel our deep space explorers," said Jim Reuter, associate administrator for NASA's Space



NASA astronaut Megan McArthur enjoys fresh food on the International Space Station. Credit: NASA.

Technology Mission Directorate at the agency's headquarters in Washington. "Our approach to deep space human exploration is strengthened by new technological advances and diverse community input. This challenge helps us push the boundaries of exploration capabilities in ways we may not recognize on our own."

NASA, in coordination with CSA, opened the Deep Space Food Challenge in January 2021. The competition asked innovators to design food production technologies or systems that met specific requirements: They would need to use minimal resources and produce minimal waste. The meals they produced would have to be safe, nutritious, and delicious for long-duration human exploration missions.

For the U.S. teams, NASA's judges grouped submissions based on the food they envisioned producing. Among the designs were systems that used ingredients to create ready-to-eat foods such as bread, as well as dehydrated powders that could be processed into more complex food products. Others involved cultivated plants and fungi or engineered or cultured food such as cultured meat cells.

The winning U.S. teams, in alphabetical order, are:

- Astra Gastronomy of San Francisco, California
- BeeHex of Columbus, Ohio
- BigRedBites of Ithaca, New York
- Biostromathic of Austin, Texas
- Cosmic Eats of Cary, North Carolina
- Deep Space Entomoculture of Somerville, Massachusetts
- Far Out Foods of St. Paul, Minnesota
- Hefvin of Bethesda, Maryland
- Interstellar Lab of Los Angeles
- Kemel Deltech USA of Cape Canaveral, Florida
- Mission: Space Food of Mountain View, California
- Nolux of Riverside, California
- Project MIDGE of La Crescenta-Montrose, California
- RADICLE-X of Brooklyn, New York
- SIRONA NOMs of Golden, Colorado
- Space Bread of Hawthorne, Florida
- Space Lab Café of Boulder, Colorado
- µBites of Carbondale, Illinois

CSA ran a parallel competition with a separate application, judging process, and prize for participating Canadian teams. The agency will announce its winners at a later date.

Teams from outside the U.S. and Canada qualified for recognition but were not eligible for monetary prizes. The 10 international submissions NASA and CSA recognized are:

- ALSEC Alimentos Secos SAS of Antioquia, Colombia
- Ambar of Bucaramanga, Colombia

- Electric Cow of Germany
- Enigma of the Cosmos of Écully, France, and Brunswick, Australia
- JPWORKS SRL of Milan, Italy
- KEETA of Bangkok, Thailand
- LTCOP of Piracicaba, Brazil
- Natufia X Edama of Thuwal, Saudi Arabia
- Solar Foods of Lappeenranta, Finland
- π of Ghaziabad, India

The Deep Space Food Challenge is a NASA Centennial Challenge. Centennial Challenges are part of the Prizes, Challenges, and Crowdsourcing program within NASA's Space Technology Mission Directorate at the agency's Headquarters in Washington and are managed at NASA's Marshall Space Flight Center in Huntsville, Alabama. Subject matter experts at NASA's Johnson Space Center in Houston and NASA's Kennedy Space Center in Florida support the competition. NASA, in partnership with the Methuselah Foundation, manages the U.S. and international Deep Space Food Challenge competition.

For more information about NASA's prizes and challenges, visit www.nasa.gov/solve.

NASA OUTLINES CHALLENGES, PROGRESS FOR ARTEMIS MOON MISSIONS

In the first major Artemis update provided under the Biden-Harris Administration, NASA leadership discussed the challenges and progress of America's lunar exploration plans and reiterated a long-term commitment to exploring the Moon and sending astronauts to Mars.

The update follows a judge's recent decision to uphold NASA's selection of SpaceX to develop and demonstrate a modern human lunar lander for returning astronauts to the Moon for the first time in more than 50 years.

NASA Administrator Bill Nelson spearheaded the conversation, laying out the path forward for early Artemis missions that will pave the way for lunar surface missions.

"We're pleased with the U.S. Court of Federal Claims' thorough evaluation of NASA's source selection process for the human landing system (HLS), and we have already resumed conversations with SpaceX. It's clear we're both eager to get back to work together and establish a new timeline for our initial lunar demonstration missions," Nelson said. "Returning to the Moon as quickly and safely as possible is an agency priority. However, with the recent lawsuit and other factors, the first human landing under Artemis is likely no earlier than 2025."

Prior to that surface mission, NASA is focused on the Artemis I uncrewed and Artemis II crewed flight tests around the Moon. Nelson announced the Orion spacecraft development cost now is $9.3 billion from fiscal year 2012 through the first crewed flight test no later than May 2024. The Artemis

II mission includes sending astronauts onboard Orion farther into space than any humans have ever traveled before, roughly 64,000 kilometers (40,000 miles) past the Moon, before returning home.

Those missions, as well as a future uncrewed lander demonstration mission with SpaceX, will precede the Artemis III crewed lunar landing mission. NASA also plans to issue a formal solicitation next spring for recurring human landing systems services.

Among the challenges the agency and its partners have addressed in deep space exploration development, Nelson noted a delayed lunar landing is due, in part, to first-time development challenges, an almost seven-month delay due to the HLS lawsuit, Congress not appropriating sufficient funds for the HLS competition, the COVID-19 pandemic, and the Trump Administration's landing goal of 2024 not being technically feasible.

"Going forward, NASA is planning for at least 10 Moon landings in the future, and the agency needs significant increases in funding for future lander competition, starting with the 2023 budget," said Nelson.

In the meantime, there are efforts to reduce costs and streamline operations underway. The agency has issued a request for information to the industry to maximize efficiencies in the Space Launch System (SLS) enterprise and also has asked industry partners to build spacesuits and provide spacewalk services for International Space Station and Artemis program missions.

Recently NASA announced it was reorganizing its human spaceflight programs into two key mission directorates: the Exploration Systems Development Mission Directorate (ESDMD) and Space Operations Mission Directorate (SOMD). That change is helping the agency put focused oversight in place to support and execute missions in low-Earth orbit and at the Moon and Mars.

The agency's update does not affect later Artemis mission schedules and lunar surface plans, including Gateway development and other activities later in the decade. NASA and its international and commercial partners also are building Gateway, a lunar orbiting outpost that will provide critical infrastructure and functionality for long-term exploration of the Moon and Mars, as well as other enabling technologies. NASA encourages our partners to continue research and development activities for lunar science and exploration as planned as we move closer than ever before to establishing a long-term human presence at the Moon.

NASA Deputy Administrator Pam Melroy said, "What we're doing is one of the great undertakings of humanity – the scope of it from SLS to Orion to Gateway, human landing systems, ground systems, communications, spacesuits and more — it's staggering. First at the Moon, and then at Mars. But we're NASA, and we're rising to the challenge."

Learn more about the agency's Artemis program at www.nasa.gov/artemis.

NASA, NATIONAL GEOGRAPHIC PARTNER TO SHOW INSIDE ARTEMIS MOON MISSION

NASA has selected National Geographic to help tell the story of Artemis II, the first Artemis flight that will carry astronauts around the Moon and back to Earth onboard the agency's Orion spacecraft.

Following a competitive selection process, NASA and National Geographic entered into a non-reimbursable (no exchange of funds) Space Act Agreement to collaborate on compact, lightweight audiovisual hardware to fly inside Orion and related support for the project.

"Returning humans to the Moon with Artemis II will inspire the next generation of explorers," said Kathy Lueders, associate administrator for the Space Operations Mission Directorate at NASA Headquarters in Washington, who served as the selection official. "This time, we are bringing partners and technologies that will create additional opportunities for the world to share in the experience along with our astronauts."

National Geographic plans to leverage its portfolio of media assets, including magazines, social and digital content, and television programming, for engagement opportunities. Those would include capabilities for creating an immersive experience onboard Orion to share the story of human exploration of the Moon.

An illustration of the Orion spacecraft. Credit: NASA.

In November 2020, NASA called for proposals to collaborate on unique public engagement, starting with Artemis II. National Geographic media company responded with a proposal to use content

captured during the mission to create a multi-platform story-telling campaign aimed at a global audience.

Artemis mission activities will include Artemis I, an uncrewed flight test that will launch Orion on NASA's Space Launch System rocket to orbit the Moon and return to Earth. Artemis II will carry a crew onboard Orion, paving the way for future missions to send the first woman and first person of color to the surface of the Moon. Subsequent missions will explore more of the Moon and test the technologies and procedures needed for human exploration of Mars.

Learn more about NASA's Artemis program at www.nasa.gov/artemis.

NASA COMMITS $28 MILLION TO UNDERFUNDED U.S. JURISDICTIONS

NASA has awarded $28 million to fund the next five years of research infrastructure development across 28 jurisdictions. The Established Program to Stimulate Competitive Research (EPSCoR), a part of NASA's Office of Stem Engagement and based out of the agency's Kennedy Space Center in Florida, supports science and technology research and development at colleges and universities while also funding studies in Earth science, aeronautics, and human and robotic deep space exploration — all of which are disciplines critical to the NASA mission.

Started almost 30 years ago, EPSCoR focuses on 25 states and three territories, and seeks to lessen the disparity in funding between states across the nation to create an equitable competition in aerospace and aerospace-related research activities. While California receives 12% of all federal research funding, all 28 EPSCoR jurisdictions combined receive less than 10%, so participating states and territories depend heavily on these research investments. NASA funds these areas so they remain competitive in the aerospace research and development field.

The EPSCoR Research Infrastructure Development award further strengthens long-term research capabilities by pledging $200,000 a year to each of the 28 jurisdictions for the next half-decade, increasing and diversifying technology and research development, higher education, and economic development on both a state and national level.

EPSCoR also solicits proposals for Rapid Response Research, which awards funding to researchers as they work with NASA on issues impacting the agency's mission and programs, as well as International Space Station collaborations and suborbital flight opportunities, which provide researchers the opportunity to fly mature research projects in low-Earth orbit.

Dr. Maria Katzarova (left), associate scientist in the chemical and biomolecular engineering department at University of Delaware, and Jennifer Mills, a fourth-year Ph.D. chemical engineering student, perform compression testing of cast martian regolith cubes. Funded through NASA's EPSCoR, the project assessed the capabilities of lunar and martian regolith simulants when mixed with geopolymer binders. Credit: University of Delaware.

Jurisdictions receiving the RID awards are Alabama, Alaska, Arkansas, Delaware, Guam, Hawaii, Idaho, Iowa, Kansas, Kentucky, Louisiana, Maine, Mississippi, Montana, Nebraska, Nevada, New Hampshire, New Mexico, North Dakota, Oklahoma, Puerto Rico, Rhode Island, South Carolina, South Dakota, Vermont, the U.S. Virgin Islands, West Virginia, and Wyoming.

To learn more about EPSCoR, visit www.nasa.gov/stem/epscor/home/index.html.

NASA CHALLENGES STUDENTS TO DESIGN MOON-DIGGING ROBOTS

NASA seeks young engineers to help design a new robot concept for an excavation mission on the Moon. The Lunabotics Junior Contest is open to K–12 students in U.S. public and private schools and home-schoolers.

The competition, which is a collaboration between NASA and Future Engineers, asks students to design a robot that digs and moves lunar soil, called regolith, from an area of the lunar south pole to a holding container near where Artemis astronauts may explore in the future.

As part of the Artemis program, NASA will land the first woman and first person of color on the Moon and establish long-term lunar science and exploration capabilities that will serve as a springboard for future exploration of Mars. Lunar regolith is instrumental in this development and could be used to create lunar concrete, reducing the amount and cost of materials that need to be transported from Earth.

To enter the contest, students must submit entries that must include an image of the robot design and a written summary explaining how the design is intended to operate on the Moon by January 25, 2022.

"Extracting resources in deep space will require innovation and creativity, and students are some of the most creative thinkers," said Mike Kincaid, NASA's associate administrator for the Office of STEM Engagement. "The next generation always brings new perspectives, inventive ideas, and a sense of optimism to the challenges NASA puts in front of them. I'm really looking forward to seeing the designs they submit to Lunabotics Junior."

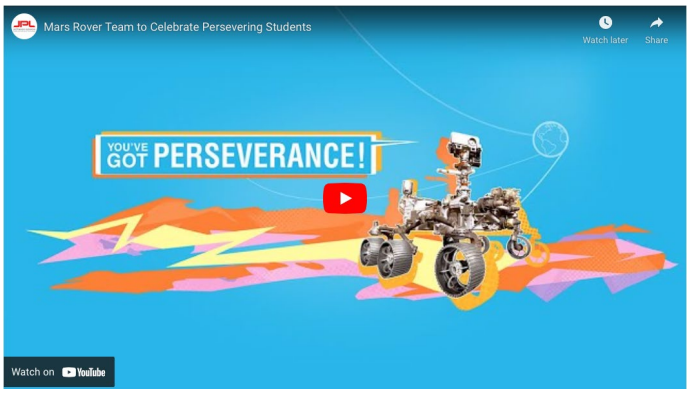
While students are not tasked to build a robot, they are asked to envision a robot design that is no larger than 1.1 meters by 0.6 meters by 0.6 meters (3.5 feet by 2 feet by 2 feet) and that addresses three main design features: how the physical design of the robot will enable it to scoop/dig and move the lunar regolith; whether the robot will operate by moving large amounts of dirt per trip or by transporting less dirt over more trips; and how the design and operation of the robot will meet the big challenge of lunar dust that is stirred up and can "stick" to surfaces when lunar regolith is moved.

Students can sign up individually or teachers can register their entire class. Entries will be split into grades K–5 and grades 6–12. Ten semifinalists will receive a Lunabotics Junior prize pack and four finalists from each category will win a virtual session with a NASA subject matter expert. The winner from each category will be announced on March 29, 2022, and will be awarded a virtual chat for their class with Janet Petro, director of NASA's Kennedy Space Center in Florida.

NASA and Future Engineers also are seeking volunteers to help judge the entries from around the country. U.S. residents interested in offering approximately five hours of their time over a 10-day period can register to be a judge at www.futureengineers.org/registration/judge/lunaboticsjunior.

Artemis Student Challenges create unique opportunities for a diverse group of students to contribute to NASA's work in exploration and discovery while celebrating their creativity and innovation.

TEAM BEHIND NASA'S NEWEST MARS ROVER TO HONOR PERSEVERING STUDENTS



NASA's "You've Got Perseverance" awards opportunity invites U.S. teachers, educators, and community members to nominate students in grades 6–8 who have demonstrated that they have the right stuff to move past obstacles and reach their academic goals. The program will reward that dedication with recognition all the way from Mars.

Events over these many months have taught us all about what it takes to persevere. Students have had to adapt and push forward through tough challenges — not unlike the team behind NASA's Perseverance rover, which has overcome many obstacles to build, launch, and operate the mission on Mars. The rover team now seeks to honor students who have demonstrated perseverance, sending them personal messages beamed by the rover from the Red Planet's Jezero Crater, which it has been exploring since landing in February 2021.

There will be four opportunities to nominate students. Nomination information is available at go.nasa.gov/gotperseverance.

"Getting NASA's heaviest, most sophisticated rover yet onto the surface of a planet hundreds of millions of miles away is a remarkable feat unto itself," said Thomas Zurbuchen, associate administrator of the agency's Science Mission Directorate. "But to do so in spite of the safety restrictions during the early days of the COVID-19 pandemic required extraordinary perseverance. And so does forging ahead as a student when the pandemic dramatically altered so much of your day-to-day life."

Throughout the rover's development, journey to Mars, white-knuckle landing, and ambitious surface mission so far, the Perseverance team has risen to meet new challenges. "It's the most complex robotic system we've ever sent to another planet," said Perseverance Project Manager Jennifer Trosper of NASA's Jet Propulsion Laboratory (JPL). "It has to autonomously drive five times faster than any other Mars rover and use its science instruments to carefully select and then collect over 30 samples for pickup by a future mission."

Perseverance brought to Mars seven new science instruments, including a technology demonstration to generate oxygen from the martian atmosphere, plus the Ingenuity Mars Helicopter.

What's more, "after all the planning, designing, and most of the spacecraft building, we had to dramatically change how we worked because of the COVID-19 pandemic," Trosper said. To stay safe, most team members (including Trosper) teleworked. "We had to finish the development and testing, as well as operate this complex rover, with much of the team working remotely. It was almost to the point where you wondered, 'Is this really doable?' But we just kept moving forward, faced head-on whatever issue came up, and overcame each challenge, one by one," she said.

Now the team wants to encourage the next generation to persevere in the same way – to embrace the idea of overcoming seemingly impossible challenges. As part of "You've Got Perseverance," the rover will congratulate students for persevering in their academic pursuits by using its "Seq. Echo" capability.

When sending instructions to Perseverance, engineers can command the rover to echo a message back to Earth. NASA's Curiosity rover, on Mars since 2012, used the method to "welcome" Perseverance when it landed. "We also wanted to give some young students the opportunity to talk to our team and ask questions," said Trosper.

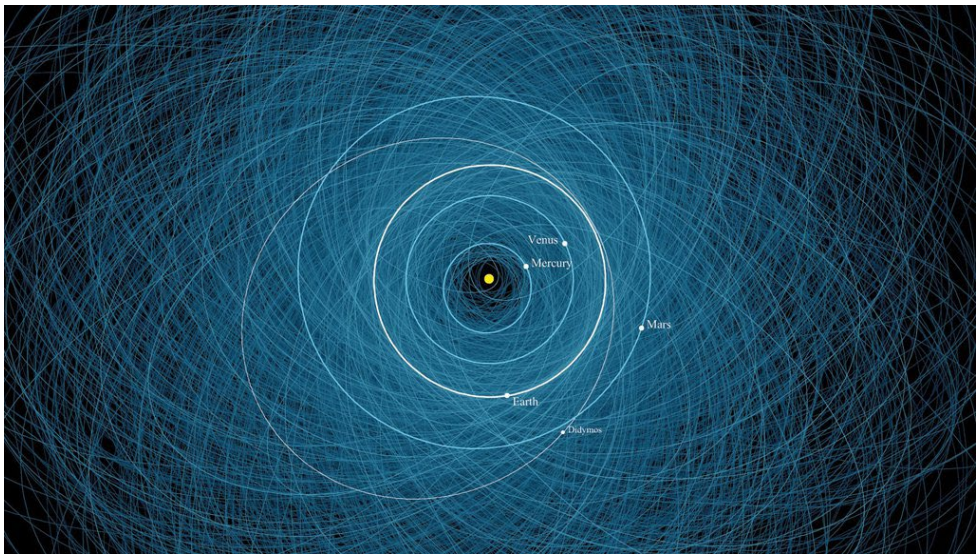
When the personalized messages are transmitted from Mars, the students will have a chance to share the experience with family and their classrooms via a live video chat with Perseverance rover team members in mission control at JPL. Trosper hopes that connecting students with her team will help them see how the scientists and engineers also face challenging situations and succeed through perseverance.

Nomination windows for the "You've Got Perseverance" award are planned throughout the 2021–2022 school year. Selection will be made through a lottery, with entries screened to ensure they meet the criteria. All nominated students can receive a certificate to acknowledge their perseverance.

NASA'S NEXT-GENERATION ASTEROID IMPACT MONITORING SYSTEM GOES ONLINE

The new system improves the capabilities of NASA Jet Propulsion Laboratory's (JPL's) Center for Near Earth Object Studies (CNEOS) to assess the impact risk of asteroids that can come close to our planet.

To date, nearly 28,000 near-Earth asteroids (NEAs) have been found by survey telescopes that continually scan the night sky, adding new discoveries at a rate of about 3,000 per year. But as larger and more advanced survey telescopes turbocharge the search over the next few years, a rapid uptick in discoveries is expected. In anticipation of this increase, NASA astronomers have developed a next-generation impact monitoring algorithm called Sentry-II to better evaluate NEA impact probabilities.



This diagram shows the orbits of 2,200 potentially hazardous objects as calculated by JPL's Center for Near Earth Object Studies (CNEOS). Highlighted is the orbit of the double asteroid Didymos, the target of NASA's Double Asteroid Redirect Test (DART) mission. Credit: NASA/JPL-Caltech.

Popular culture often depicts asteroids as chaotic objects that zoom haphazardly around our solar system, changing course unpredictably and threatening our planet without a moment's notice. This is not the reality. Asteroids are extremely predictable celestial bodies that obey the laws of physics and follow knowable orbital paths around the Sun.

But sometimes, those paths can come very close to Earth's future position and, because of small uncertainties in the asteroids' positions, a future Earth impact cannot be completely ruled out. So, astronomers use sophisticated impact monitoring software to automatically calculate the impact risk.

Managed by JPL, CNEOS calculates every known NEA orbit to improve impact hazard assessments in support of NASA's Planetary Defense Coordination Office (PDCO). CNEOS has monitored the impact risk posed by NEAs with software called Sentry, developed by JPL in 2002.

"The first version of Sentry was a very capable system that was in operation for almost 20 years," said Javier Roa Vicens, who led the development of Sentry-II while working at JPL as a navigation engineer and recently moved to SpaceX. "It was based on some very smart mathematics: In under an hour, you could reliably get the impact probability for a newly discovered asteroid over the next 100 years — an incredible feat."

But with Sentry-II, NASA has a tool that can rapidly calculate impact probabilities for all known NEAs, including some special cases not captured by the original Sentry. Sentry-II reports the objects of most risk in the CNEOS Sentry Table.

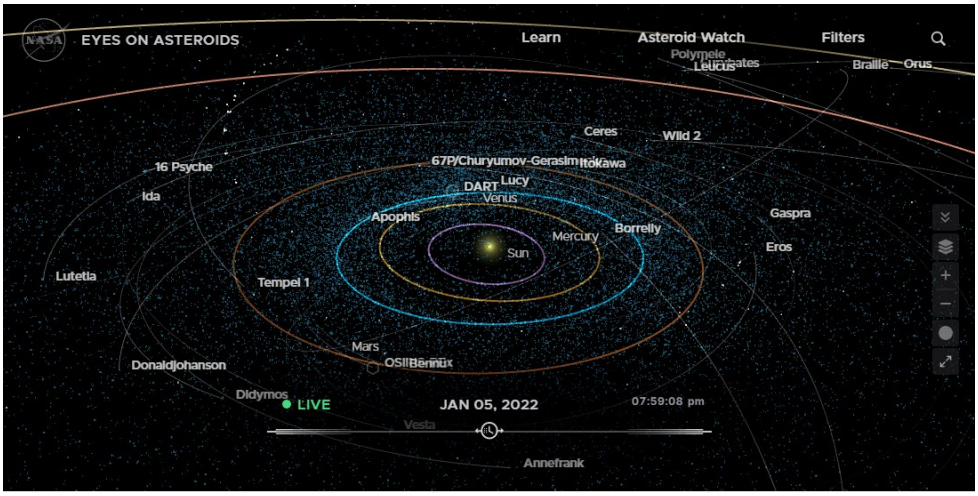
By systematically calculating impact probabilities in this new way, the researchers have made the impact monitoring system more robust, enabling NASA to confidently assess all potential impacts with odds as low as a few chances in 10 million.

A study describing Sentry-II was published in the Astronomical Journal on December 1, 2021.

More information about CNEOS, asteroids, and near-Earth objects can be found at cneos.jpl.nasa.gov.

For more information about PDCO, visit www.nasa.gov/planetarydefense.

NASA'S 'EYES ON ASTEROIDS' REVEALS OUR NEAR-EARTH OBJECT NEIGHBORHOOD



Through a new 3D real-time visualization tool, you can now explore the asteroids and comets that approach Earth's orbital neighborhood — and the spacecraft that visit these objects — with a click or a swipe. NASA's Eyes on Asteroids brings this data to any smartphone, tablet, or computer with an internet connection — no download required.

Thousands of asteroids and dozens of comets are discovered every single year, some of which — called near-Earth objects (NEOs) — follow orbits that pass through the inner solar system. Now totaling about 28,000, their numbers rising daily, these objects are tracked carefully by NASA-funded astronomers in case any might pose an impact threat to our planet.

The new web-based app depicts the orbits of every known NEO, providing detailed information on those objects. Using the slider at the bottom of the screen, you can travel quickly forward and backward through time to see their orbital motions. The visualization receives twice-daily updates with the latest data, so as soon as a new object is discovered and its orbit is calculated, it's added to the app.

The profiles for many NEO missions can also be explored. Select the "events" tab to view detailed animated models of those spacecraft and their asteroid or comet encounters. For example, search for NASA's OSIRIS-REx (short for Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer) spacecraft to view an animated recreation of the mission's October 20, 2020, Touch-And-Go (TAG) sample collection event. Or view NASA's Double Asteroid Redirect Test (DART) mission, which recently launched as NASA's first planetary defense demonstration, and even fast-forward to September 26, 2022, when it will impact the asteroid Dimorphos, the small moonlet of the Didymos binary asteroid system.

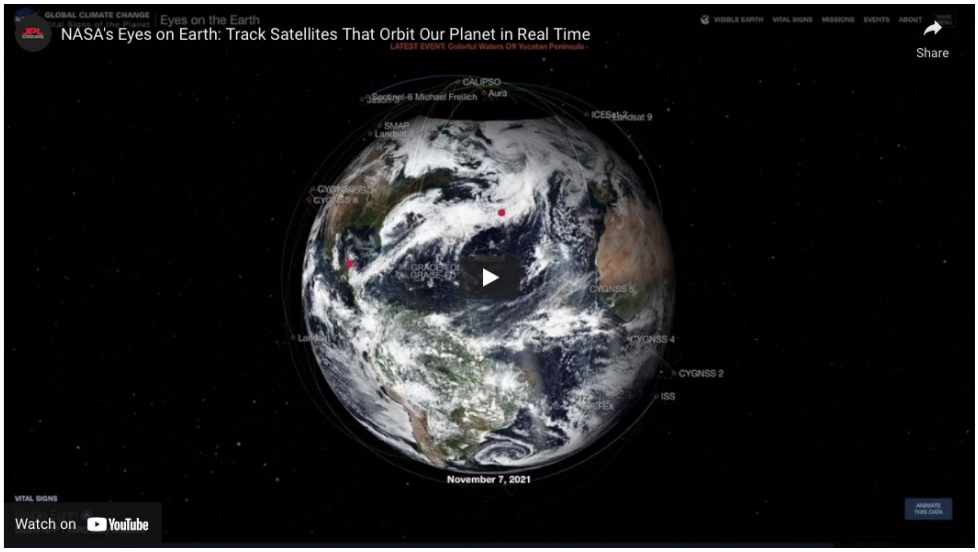
"We wanted Eyes on Asteroids to be as user-friendly as possible while telling the stories about humanity's exploration of these fascinating objects," said Jason Craig, technical producer of the Visualization Technology Applications and Development team at NASA's Jet Propulsion Laboratory in Southern California, which developed Eyes. "Every NEO can be found inside the app, as can most of the spacecraft that have visited these objects."

There's also plenty of detail on the fascinating science behind NEOs and the importance of tracking potentially hazardous objects. Just select "Learn" for details on topics like asteroid close approaches to Earth or to fly along with the dramatic close approach of asteroid Apophis on April 13, 2029.

While you're on the topic, choose the "Asteroid Watch" tab to see the next five asteroid close approaches. "We were keen to include this feature, as asteroid close approaches often generate a lot of interest," said Craig. "The headlines often depict these close approaches as 'dangerously' close, but users will see by using Eyes just how distant most of these encounters really are."

Eyes on Asteroids was developed with support from NASA's Planetary Defense Coordination Office at the agency's headquarters in Washington and from JPL's Center for Near-Earth Object Studies. Eyes gathers its data from JPL's Solar System Dynamics database, which provides real-time data for the orbits, characteristics, and discovery of most known natural bodies (including NEOs) in our solar system.

NASA'S 'EYES ON THE EARTH' PUTS THE WORLD AT YOUR FINGERTIPS



NASA's real-time 3D visualization tool Eyes on the Earth got a recent upgrade to include more datasets, putting the world at your fingertips. Using the tool, you can track the planet's vital signs — everything from carbon dioxide and carbon monoxide to sea level and soil moisture levels — as well as follow the fleet of Earth satellites providing those measurements.

Eyes on the Earth offers an engaging, interactive resource to learn more about environmental phenomena and their impacts.

For instance, to see measurements of the greenhouse gas carbon dioxide in a particular part of the globe, navigate to the Vital Signs menu and click the carbon dioxide button. Eyes on the Earth will show a visualization of data from NASA's Orbiting Carbon Observatory 2 (OCO-2) satellite, which measures the gas from the ground to the top of the atmosphere. (To ensure the greatest accuracy, the mission reprocesses the data in the months prior to it appearing in Eyes.) Click "animate data," specify a date range, and see how levels shift over time.

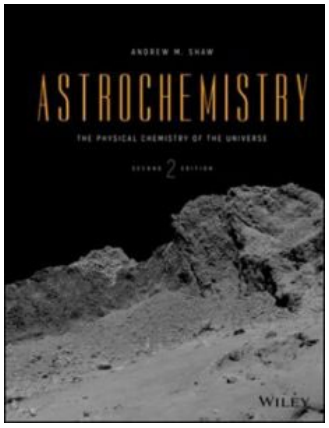
There are eight vital signs to choose from, with background information on the role each plays.

The newest version of Eyes on the Earth also provides snapshots of significant events in the natural world. For instance, you can see details about the maximum wind speeds of a tropical storm, the impacts of a northern California fire, even see the scale of a phytoplankton bloom off of New Zealand and why it matters.

The improvements also include upgrades for a more seamless user experience.

The graphics are as rich as the data, making for fascinating deep dives as you learn about the science, get to know the planet better, and learn about some of the many NASA missions that track the globe's health. And while no downloads are required, the web-based application makes a great addition to any device with a browser and an internet connection including your smartphone.

NEW AND NOTEWORTHY

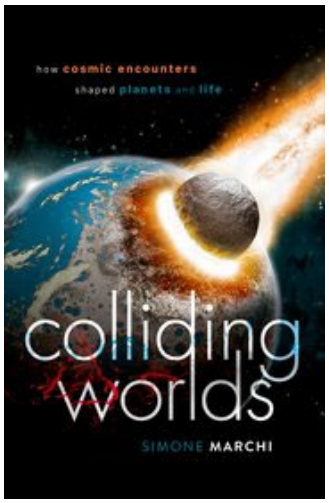


ASTROCHEMISTRY: The Physical Chemistry of the Universe, Second Edition

By Andrew M. Shaw

Wiley, 2021, 480 pp., Hardcover. $90.00. www.wiley.com

Since the first edition in 2006 of *Astrochemistry*, the Mars rovers have driven 31.18 miles, there has been fly-by of Pluto changing it from a 4-pixel world on the Hubble Space Telescope into a mysterious non-planet. There have been visits to asteroids, revisiting Mercury, discovery of the Higgs Boson, discovery of over 2000 extrasolar planets and landing on the comet 67P/Churyumov–Gerasimenko by Rosetta mission, hence the timely publication of this new edition. This core textbook now includes more detailed information on the kinetic modelling of chemistry in the interstellar medium, extending the same principles of physical chemistry to meteor ablation and finally atmospheres and oceans. The increase in density from near emptiness to 1.35 × 1021 L of water in the world's oceans is used to take single collision kinetics into ensemble thermodynamics. A new introduction of thermodynamic using meteor ablation replaces traditional bomb calorimetry and per-biotic chemistry leads to spontaneous reactions. Written for undergraduate and postgraduate students in astrochemistry or more generally physical chemistry, the new edition of *Astrochemistry* is an important introductory text to the topic, the latest developments in the field and the ubiquity of physical chemistry.



COLLIDING WORLDS: How Cosmic Encounters Shaped Planets and Life

By Simone Marchi

Oxford University Press, 2021, 224 pp., Hardcover. $25.95. www.global.oup.com

Simone Marchi presents the emerging story of how cosmic collisions shaped both the solar system and our own planet, from the creation of the Moon to influencing the evolution of life on Earth. The Earth emerged out of the upheaval and chaos of massive collisions in the infancy of the solar system more than four billion years ago. The largest of these events sent into orbit a spray of molten rocks out of which the Moon coalesced. As in ancient mythological tales, this giant catastrophe marks the birth of our planet as we know it. Space exploration has shown that signs of ancient collisions are widespread in the solar system, from the barren and once-habitable Mars to the rugged asteroids. On Earth these signs are more subtle, but still cataclysmic, such as the massive asteroid strike which likely sparked the demise of the dinosaurs and many other forms of life some 66 million years ago. Signatures of even more dramatic catastrophes are concealed in ancient rocks. These events wreaked havoc on our planet's surface, influencing global climate and topography, while also enriching the Earth with gold and other rare elements. And recently, modern science is finding that they could even have contributed to developing the conditions conducive to life. In *Colliding Worlds*, Simone Marchi explores the key role that collisions in space have played in the formation and evolution of our solar system, the development of planets, and possibly even the origin of life on Earth. Analyzing our latest understanding of the surfaces of Mars and Venus, gleaned from recent space missions, Marchi presents the dramatic story of cosmic collisions and their legacies.

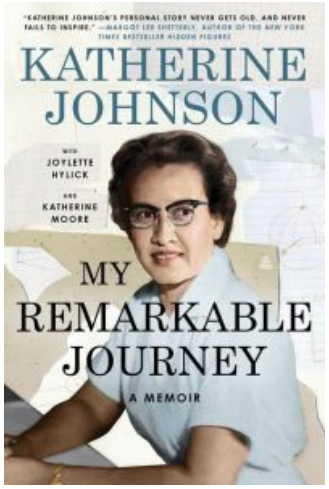
Note: Product descriptions are taken from publishers' websites. LPI is not responsible for factual content.

ROBOTS IN SPACE: The Secret Lives of Our Planetary Explorers

By Ezzy Pearson

The History Press, 2020, 288 pp., Hardcover. $34.95. www.thehistorypress.co.uk

Space sparks the imagination in fantastic ways, but nothing quite captures people's attention more than when we actually reach out and touch another world. Whether it's missions to the Moon, transporting rovers to Mars or landing Philae on a comet, the idea that we can not only picture these worlds from afar, but to touch them is wonderfully inspiring, and it is through cutting-edge robotic technology that it is made possible. In *Robots in Space*, expert space journalist Dr. Ezzy Pearson delves into the fascinating robotic history of space exploration, from distant times when stars were an unreachable godly mystery, through the intense Space Race following the Second World War to the Mars missions of the twenty-first century. As we find ourselves on the cusp of a new and exciting space age, Pearson explores how and why humanity turns its best minds to travelling to the stars, and exactly how far we could go.



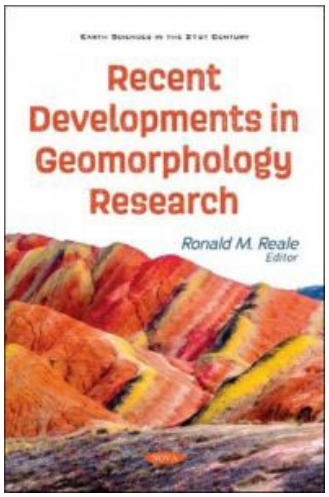
MY REMARKABLE JOURNEY: A Memoir

By Katherine Johnson with Joylette Hylick and Katherine Moore

Amistad, 2021, 256 pp., Hardcover. $25.99. www.harpercollins.com

In 2015, at the age of 97, Katherine Johnson became a global celebrity. President Barack Obama awarded her the prestigious Presidential Medal of Freedom — the nation's highest civilian honor — for her pioneering work as a mathematician on NASA's first flights into space. Her contributions to America's space program were celebrated in a blockbuster and Academy-award nominated movie. In this memoir, Katherine shares her personal journey from child prodigy in the Allegheny Mountains of West Virginia to NASA human computer. In her life after retirement, she served as a beacon of light for her family and community alike. Her story is centered around the basic tenets of her life — no one is better than you, education is paramount, and asking questions can break barriers. The memoir captures the many facets of this unique woman: the curious "daddy's girl," pioneering professional, and sage elder. This multidimensional portrait is also the record of a century of racial history that reveals the influential role educators at segregated schools and Historically Black Colleges and Universities played in nurturing the dreams of trailblazers like Katherine. The author pays homage to her mentor, the African American professor who inspired her to become a research mathematician despite having his own dream crushed by racism. Infused with the uplifting wisdom of a woman who handled great fame with genuine humility and great tragedy with enduring hope, *My Remarkable Journey* ultimately brings into focus a determined woman who navigated tough racial terrain with soft-spoken grace — and the unrelenting grit required to make history and inspire future generations.

Note: Product descriptions are taken from publishers' websites. LPI is not responsible for factual content.

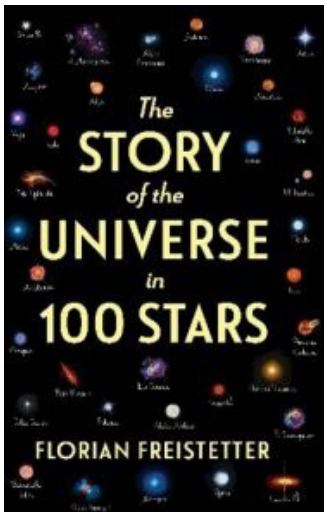


RECENT DEVELOPMENTS IN GEOMORPHOLOGY RESEARCH

Edited by Ronald M. Reale

Nova Science Publishers, 2021, 90 pp., Paperback. $82.00. www.novapublishers.com

Geomorphology is defined as the study of the physical features of the surface of the earth and their relation to its geological structures. Geomorphology is useful not only for understanding the surface evolution of Earth, but of other solid planetary bodies as well. This monograph comprises three chapters, each detailing a specific recent development in geomorphology research. Chapter 1 describes the geomorphology of the Campo de Calatrava Volcanic Field in Central Spain, focusing on its volcanoes and the interference that any volcanic activity has produced in other forms of modeling and quaternary deposits. Chapter 2 analyzes the triggering of snow avalanches in the middle mountains of the Asturian Central Massif and their morphogenetic role in the dynamics and modeling of its slopes, a phenomenon that is impacted by the changing global climate. Chapter 3 analyzes the former fluvial erosion on Mars, adopting a model called SIMWE (SIMulated Water Erosion) to recreate the geomorphological features observed on the planet today in an effort to understand its ancient climatic conditions.



THE STORY OF THE UNIVERSE IN 100 STARS

By Florian Freistetter

The Experiment/Workman Publishing, 2021, 304 pp., Hardcover. $21.95. www.workman.com

With roughly 100 billion stars in the Milky Way alone, the cosmos is simply too vast for an unabridged tell-all. But here's the next best thing: 100 stars – bright and faint, near and far, famous and obscure, long dead and as-yet unborn, red, yellow, blue, and white (but, as you'll learn, never green) – handpicked by astronomer Florian Freistetter because they have the very best stories to tell, including GRB 080319B, the farthest we've seen into space with the naked eye; Gamma Draconis, the star that proved Earth rotates on its axis; V1364 CYGNI, pivotal in the discovery of dark matter; 72 Tauri, definitive evidence for Einstein's theory of relativity; V1, which revealed horizons beyond the Milky Way; Algol, called the Demon Star for its mysterious blinking; and many more. The short, easy-to-read profiles not only invite you to gaze into the past and future of the universe, but they also introduce a stellar cast of scientists who came before, from Annie Jump Cannon, who revolutionized how we classify the stars, to Dorrit Hoffleit, who first counted them. Enjoy your journey through the cosmos!

Note: Product descriptions are taken from publishers' websites. LPI is not responsible for factual content.

THROUGH THE GLASS CEILING TO THE STARS: The Story of the First American Woman to Command a Space Mission

By Col. Eileen M. Collins, USAF (Retired) and Jonathan H. Ward

Arcade Publishing, 2021, 368 pp., Hardcover. $27.99. www.skyhorsepublishing.com

Eileen Collins was an aviation pioneer her entire career, from her crowning achievements as the first woman to command an American space mission, as well as the first to pilot the space shuttle, to her early years as one of the Air Force's first female pilots. She was in the first class of women to earn pilot's wings at Vance Air Force Base and was their first female instructor pilot. She was only the second woman pilot admitted to the Air Force's elite Test Pilot Program at Edwards Air Force Base. NASA had such confidence in her skills as a leader and pilot that she was entrusted to command the first shuttle mission after the *Columbia* disaster, returning the U.S. to spaceflight after a two-year hiatus. Since retiring from the Air Force and NASA, she has served on numerous corporate boards and is an inspirational speaker about space exploration and leadership. Collins is among the most recognized and admired women in the world, yet this is the first time she has told her story in a book. It is a story not only of achievement and overcoming obstacles, but of profound personal transformation. The shy, quiet child of an alcoholic father and struggling single mother, who grew up in modest circumstances and was an unremarkable student, she had few prospects when she graduated from high school, but she changed her life to pursue her secret dream of becoming an astronaut. She shares her leadership and life lessons throughout the book with the aim of inspiring and passing on her legacy to a new generation.

MARS 100-PIECE PUZZLE

Produced by Chronicle Books

$19.99. www.chronicle books.com

Your adventure to Mars starts as you assemble this beautiful and unique oversized circular floor puzzle that features photography from the archives of NASA. The completed puzzle measures 2.5 feet in diameter. It's challenging yet fun to complete and is a great family puzzle suitable for ages 6 and up.

BARBIE® SIGNATURE ROLE MODELS: ESA Astronaut Samantha Cristoforetti

Produced by Mattel

$30.00. www.barbie.mattel.com

Samantha Cristoforetti is honored as a Barbie® role model. As an aviator, engineer, and astronaut of ESA (the European Space Agency), Samantha is proof that hard work can lead to great heights. The Samantha Cristoforetti Barbie® doll is ready for liftoff in a helmet and spacesuit with patches representing the ESA emblem and the Italian flag. Created in her likeness and featuring articulation for dynamic poses, the Samantha Cristoforetti Barbie® doll makes a great gift for collectors and kids, especially those interested in Science, Technology, Engineering, and Mathematics (STEM) fields. Girls need more role models like Samantha, because imagining they can be anything is just the beginning. Seeing it can make all the difference. (Doll cannot stand alone.) For ages 6 and up.

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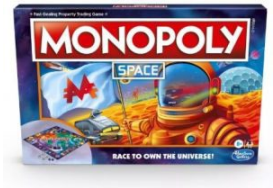
PLUTO GLOBE

Produced by the Astronomy team and Ross A. Beyer

Kalmbach Media. $29.95. myscienceshop.com

Custom-produced by the *Astronomy* team and Ross A. Beyer of NASA's New Horizons team, this highly detailed globe is perfect for exploring Pluto. NASA's New Horizons spacecraft launched in 2006 and reached Pluto in 2015. As soon as it began to send data – especially photographs – back to Earth, the editorial team at *Astronomy* knew this would be the perfect candidate for a globe of this distant world. Scientists had expected a frozen, cratered, and long-dead world with an equally old-looking system of moons. Instead, Pluto's surface is young, with smooth frozen plains, icy mountains as high as the U.S. Rockies, topography that resembles dunes, a glacial lake, and ice that has recently flowed around other features in the same way that glaciers move on Earth's surface. Now you can explore Pluto using imagery from the New Horizons spacecraft's fly-by in July 2015; over 45 planetary features are identified and labeled. Each globe is made of long-lasting durable plastic with just a single seam between hemispheres and comes with a clear acrylic display base and informational flyer.

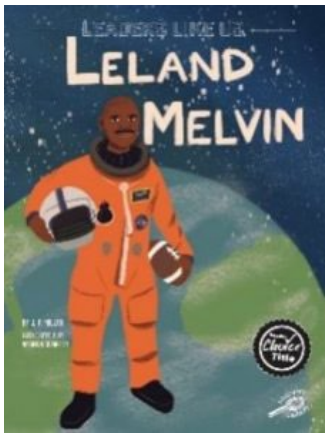


MONOPOLY SPACE GAME

Produced by Hasbro Gaming

$19.99. Available on Target.com

It's a race to own the universe in this Monopoly board game with an outer space twist. Move around the board buying planets, mining resources, and building colonies. Players need to acquire and then "burn" resources so they can buy four small and one large dome to complete their colony. Collect color sets to make it harder for opponents to gather resources. Along with Planet Properties, the gameboard features spaces such as Gravity Loss, Warp Run, and Wild Times that can advance a player's luck or set them back. This game is for two to four players. For ages 8 and up.



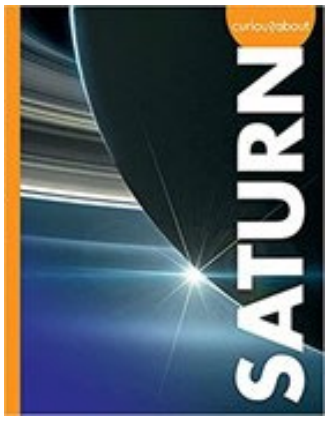
LEADERS LIKE US: Leland Melvin

By J. P. Miller

Rourke Educational Media, 2021, 24 pp., Hardcover. $29.93. www.rourkeeducationalmedia.com

In this biography, you'll meet an important leader in both sports and science — Leland Melvin. Leland was great at both football and science. When he had to stop playing sports, he worked on a new goal. He traded his football helmet for a space suit. He flew two missions into space and taught others the importance of science. With simple, easy-to-read pages and full-color illustrations that bring the story to life, you'll learn about Melvin's dedication, talent, and impact as he went from being a professional football player to an influential NASA astronaut. For ages 6 to 10.

Note: Product descriptions are taken from publishers' websites. LPI is not responsible for factual content.

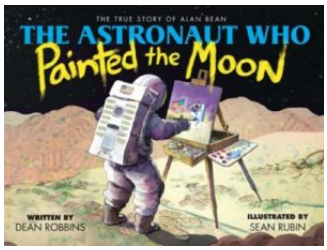


CURIOUS ABOUT SATURN

By Gillia M. Olsen

Amicus Ink, 2022, 24 pp., Paperback. $9.99. www.amicuspublishing.us

What's with those huge rings? Everyone loves Saturn's amazing rings. But did you know the planet has a storm at its north pole shaped like a giant stop sign? Or that one of its moons looks suspiciously like the Death Star from Star Wars? This question-and-answer book covers Saturn's appearance and features, plus missions to the planet. A *Quick Facts* chart provides fast facts while simple infographics support visual learners. A *VV* feature encourages kids to keep asking questions while doubling as a mini media literacy lesson on research skills. This book includes glossary and index. Spark early readers' natural curiosity about planets with this inquiry-based nonfiction approach to Saturn. For ages 6 to 8.



THE ASTRONAUT WHO PAINTED THE MOON:

The True Story of Alan Bean

By Dean Robbins

Scholastic, 2019, 40 pp., Hardcover. $17.99. www.scholastic.com

As a boy, Alan wanted to fly planes. As a young navy pilot, Alan wished he could paint the view from the cockpit. So, he took an art class to learn patterns and forms. But no class could prepare him for the beauty of the lunar surface some 240,000 miles from Earth. In 1969, Alan became the fourth man and first artist on the Moon. He took dozens of pictures, but none compared to what he saw through his artistic eyes. When he returned to Earth, he began to paint what he saw. Alan's paintings allowed humanity to experience what it truly felt like to walk on the Moon. Journalist and storyteller Dean Robbins' tale of this extraordinary astronaut is masterful, and artist Sean Rubin's illustrations are whimsical and unexpected. With back matter that includes photos of the NASA mission, images of Alan's paintings, and a timeline of lunar space travel, this is one adventure readers won't want to miss. For ages 4 to 8.

CALENDAR

2022 Upcoming Events

February | March | April | May | June | July | August | September | October | November

February

MExAG Annual Meeting 2022

February 1–3
Virtual
www.lpi.usra.edu/mexag/meetings/2022/

SOFIA School

February 2–4
Virtual
sofia-school-2022.constantcontactsites.com/

I Heart Pluto Festival

February 12–21
Flagstaff, Arizona
iheartpluto.org/

Lunar Surface Science Workshop — Virtual Session 14: Heliophysics Applications Enabling and Enabled by Human Exploration of the Lunar Surface

February 17
Virtual
www.hou.usra.edu/meetings/lunarsurface2020/

25th Microlensing Conference: The Dawn of Astrometric Microlensing, From Cold Exoplanets to Black-Holes

February 21–23
Paris, France
www.cold-worlds.com/nouvelles-scientifiques/workshops-2022

PERC International Symposium on Dust and Parent Bodies 2022 (IDP2022)

February 21–23
Virtual
www.perc.it-chiba.ac.jp/meetings/IDP2022/IDP2022/Welcome.html

Solar and Space Physics Decadal Survey White Papers Workshop: Solar Ground-Based Projects

February 22–23

Virtual

www.hou.usra.edu/meetings/decadalsurvey2021/

Heliophysics 2050 Workshop: Measurement Techniques and Technologies

February 23–25

Virtual

www.hou.usra.edu/meetings/heliotech2022/

ASLO Ocean Sciences Meeting

February 27 – March 4

Virtual

www.aslo.org/osm2022/

Our Galactic Ecosystem: Opportunities and Diagnostics in the Infrared and Beyond

February 28 – March 4

Lake Arrowhead, California

arrowhead-2022.constantcontactsites.com/

March

Cloud Academy II

March 6–11

Les Houches, France

leap2010.wp.st-andrews.ac.uk/the-project/cloud-academy-ii/

53rd Lunar and Planetary Science Conference

March 7–11

The Woodlands, Texas/Virtual

www.hou.usra.edu/meetings/lpsc2022/

Geological Society of America 2022 Northeastern Section Meeting

March 20–22

Lancaster, Pennsylvania

www.geosociety.org/GSA/Events/Section_Meetings/GSA/Sections/ne/2022mtg/home.aspx

Low-Cost Science Mission Concepts for Mars Exploration

March 29–31

Pasadena, California

www.hou.usra.edu/meetings/lowcostmars2022/

April

16th Spacecraft Charging and Technology Conference (SCTC)

April 4–8

Virtual

www.hou.usra.edu/meetings/sctc2022/

Handling and Manipulation of Small Extraterrestrial Samples

April 13–15

Purdue University, West Lafayette, Indiana

www.lpi.usra.edu/LPI-JSC-JWG/fifth-training-session/index.cfm

Outer Planets Assessment Group

April 19–21

Washington D.C. Area

www.lpi.usra.edu/opag/meetings/upcoming/

Advancing IDEA in Planetary Science

April 25–29

Virtual

www.hou.usra.edu/meetings/advancingidea2022/

May

Exoplanets IV

May 1–6

Las Vegas, Nevada

aas.org/meetings/aastcs9/exoplanets

Science Objectives for Human Exploration of Mars

May 4–6

Denver, Colorado/Virtual

www.hou.usra.edu/meetings/marsexploration2022/

Apophis T-7 Years: Knowledge Opportunities for the Science of Planetary Defense

May 11–13

Virtual

www.hou.usra.edu/meetings/apophis2022/

Origins and Exploration: From Stars to Cells (AbSciCon)

May 15–20

Atlanta, Georgia/Virtual

www.agu.org/abscicon

2022 Humans to Mars Summit

May 17–19

Washington, DC

www.exploremars.org/

7th International Planetary Dunes Workshop

May 17–20

Alamosa, Colorado

www.hou.usra.edu/meetings/dunes2022/

Applications of Statistical Methods and Machine Learning in the Space Sciences

May 17–21

Virtual

spacescience.org/workshops/mlconference2021.php

Japan Geoscience Union Meeting 2022

May 22–27

Makuhari Messe, Chiba, Japan/Virtual

www.jpgu.org/meeting_e2022/

EGU General Assembly 2022

May 23–27

Vienna, Austria/Virtual

www.egu22.eu

June

Mercury: Current and Future Science of the Innermost Planet

June 7–10

Orléans, France

mercury2020.ias.u-psud.fr/main_1st.php

Planet Formation: From Dust Coagulation to Final Orbit Assembly

June 7 –July 1

Garching, Germany

www.munich-iapp.de/final-orbit-assembly22

19th International Conference on Ground Penetrating Radar (GPR 2022)

June 12–17

Golden, Colorado

learn.mines.edu/gpr2022/

Meteoroids 2022

June 13–17

Virtual

www.hou.usra.edu/meetings/meteoroids2022/

7th Mars Atmosphere Modelling and Observations Workshop

June 14–17

Paris, France

www-mars.lmd.jussieu.fr/paris2022/

Planetary Science Informatics and Data Analytics Conference 2022

June 21–23

Villanueva de la Cañada, Spain

www.cosmos.esa.int/web/psida-2022/home

Optimizing Planetary In Situ Surface-Atmosphere Interaction Investigations

June 28 – July 1

Boise, Idaho/Virtual

www.hou.usra.edu/meetings/planetinsitu2022/

July

Rocky Worlds II

July 4–8

Oxford, United Kingdom

www.rockyworlds.org/

Workshop on In Situ Exploration of the Giant Planets II

July 12–14

Laurel, Maryland

www.hou.usra.edu/meetings/giantplanets2022/

44th COSPAR Scientific Assembly and Associated Events (COSPAR 2022)

July 16–24

Athens, Greece

www.cospar-assembly.org

International Conference on Aeolian Research (ICAR XI)

July 17–23

Swakopmund, Namibia

www.geog.ox.ac.uk/events/icar2022/index.html

22nd International Mineralogical Association Meeting

July 18–22

Lyon, France

www.ima2022.fr/

2022 Sagan Summer Workshop: Exoplanet Science in the Gaia Era

July 25–29

Pasadena, California/Virtual

nexsci.caltech.edu/workshop/2022/

August

19th Annual Meeting of the Asia Oceania Geosciences Society (AOGS)

August 1–5

Virtual

www.asiaoceania.org/aogs2022/public.asp?page=home.asp

Winds of Stars and Exoplanets

August 2–11

Busan, Republic of Korea

local.strw.leidenuniv.nl/iaus370

13th Meeting on Cosmic Dust

August 22–26

Kitakyushu, Japan

www.cps-jp.org/~dust/Welcome.html

September

Brines Across the Solar System: Ancient Brines

September 12–15

Reno, Nevada

www.hou.usra.edu/meetings/ancientbrines2022/

Europlanet Science Congress

September 18–23

Granada, Spain

www.europlanet-society.org/european-planetary-science-congress/

Distributed Volcanism and Distributed Volcanic Hazards

September 19–23

Flagstaff, Arizona

www.agu.org/Chapmans-Distributed-Volcanism

October

Ultraviolet Astronomy in the XXI Century: 5th Workshop of the Network for Ultraviolet Astronomy — Face-to-Face

October 3–7

Vitoria, Spain

www.nuva.eu/workshop2020

Apollo 17 ANGSA Workshop

October 26–28

Houston, Texas

www.hou.usra.edu/meetings/ANGSAApollo17_2022/

November

Forming and Exploring Habitable Worlds

November 7–13

Edinburgh, United Kingdom/Virtual

www.habitableworlds.co.uk/