National Aeronautics and Space Administration

# THE SPARK

TECH TRANSFER, PARTNERSHIPS, AND SBIR/STTR AT GODDARD

# NASA Returns to the Moon and Beyond

## How Goddard Supports NASA's Moon to Mars Mission

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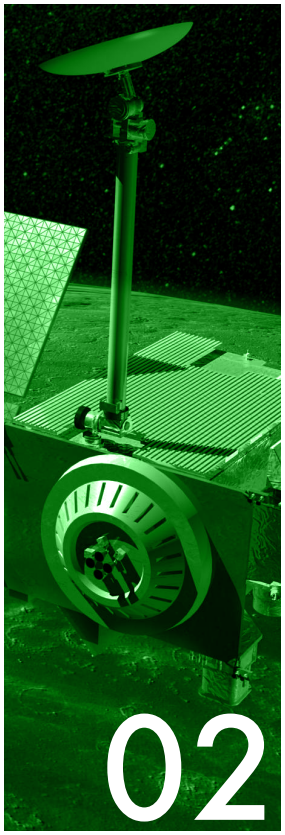



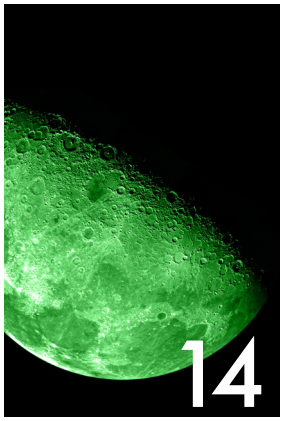


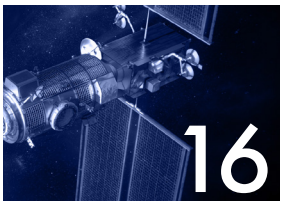



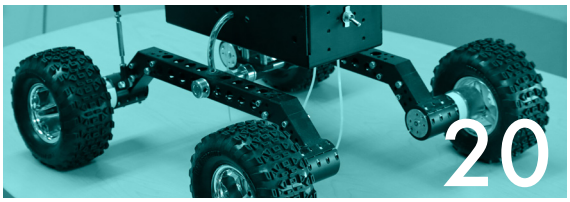




**ABOUT THE COVER**

An Artemis astronaut floats near the moon in an artist's impression.
Photo Credit: NASA


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*Photo Credit: Samantha Kilgore/GSFC*

As we conclude mid-fiscal year 2023, we reflect on the work that we do in the Strategic Partnerships Office (SPO) to promote and bring awareness to inventions and discoveries that Goddard engineers and scientists make in performing their work to support Goddard and NASA missions and programs. To date this fiscal year, SPO received 113 New Technology Reports (NTRs), issued 13 patents, and established 10 Space Act Agreements. We achieve these statistics and metrics by conducting a variety of in-reach and outreach campaigns aimed at bringing increased awareness to SPO programs (i.e., Technology Transfer, Small Business Innovation Research/Small Business Technology Transfer, and Partnerships). These initiatives not only assist the agency in meeting the requirements of the Bayh-Dole Act but also present chances to spark economic growth and encourage job creation across the country.

This issue of The Spark magazine highlights the work of Goddard scientists and engineers to support NASA's Artemis program and missions with the ultimate goal of completing a manned mission to Mars. In this issue, you will read how the Lunar Reconnaissance Orbiter (LRO) helped NASA identify the 13 candidate regions for an Artemis III lunar landing. You will also hear from Dr. Noah Petro, project scientist for Artemis III; Dr. Kelsey Young, Artemis science flight operations lead; Dr. Daniel Moriarty, assistant research scientist, and Dr. Natalie Curran, lunar geologist through an interactive Q&A session regarding their role and work to support the Artemis program.

Additionally, you will learn how Artemis astronauts will use the Goddard-developed Quantitative Elemental Reconnaissance Instrument (QuERI), a handheld X-ray fluorescence (XRF) spectrometer, to evaluate and select a diverse set of lunar samples to return to Earth for further analyses. QuERI incorporates the Goddard-developed and 2019 Government Invention of the Year winner known as the Miniaturized High Speed Modulated X-Ray Source. This x-ray source was developed by Goddard scientists and engineers Keith Gendreau, Zaven Arzoumanian, and Steven Kenyon.

Finally, you will read articles on the Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES) and Optical Navigation. Both initiatives play an important role in the Artemis program and NASA's return to the Moon initiative.

All these articles highlight the crucial importance that Goddard's technology development and technology transfer efforts play for the agency. You will read about a few technologies that have patents and are available for commercial licensing. After reading this issue of The Spark magazine, I am confident you will agree that these inventions are ideally positioned to help future NASA missions as well as the needs of the commercial space industry, in addition to Artemis missions.

**Darryl R. Mitchell, Chief**

Strategic Partnerships Office
NASA's Goddard Space Flight Center

# Destination Moon

## *LRO Leads the Way for Scientific Exploration of the Moon*


*The Atlas V/centaur rocket fires as it lifts NASA's Lunar Reconnaissance Orbiter, or LRO, and NASA's Lunar Crater Observation and Sensing Satellite, known as LCROSS, from Launch Complex 41 at Cape Canaveral Air Force Station in Florida. , Photo Credit: NASA*

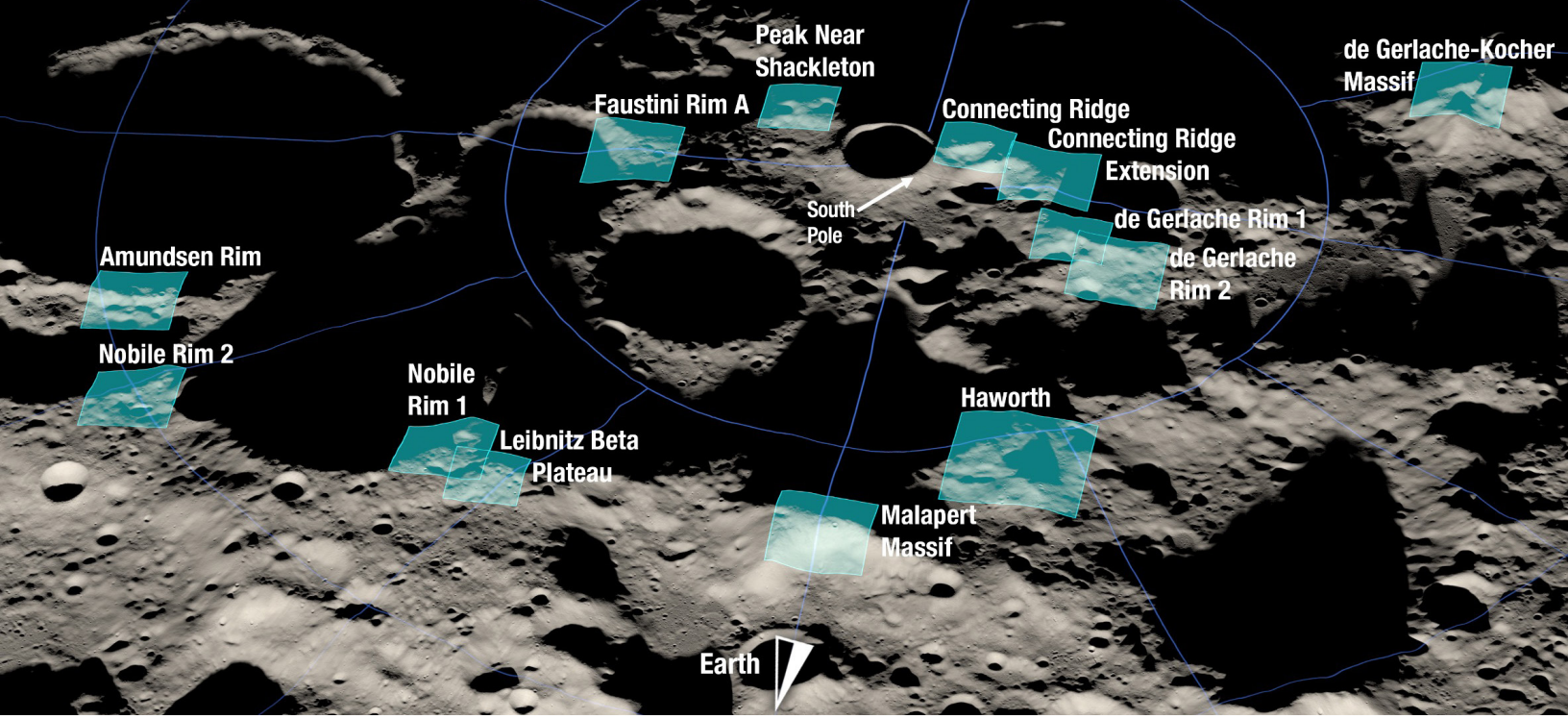
Sir Isaac Newton has been famously credited for saying, "What goes up, must come down." On June 18, 2009, an Atlas V rocket launched the Lunar Reconnaissance Orbiter (LRO) on its Lunar Crater Observation Sensing Satellite mission to the Moon. LRO, whose mission was to orbit the Moon and to help identify sites close to potential resources with high scientific value, favorable terrain, and the environment necessary for safe future robotic and human lunar missions, has not come down – yet.

LRO was only expected to last for a couple of years at most before running out of fuel and crashing on the lunar surface. Today, contrary to Sir Isaac Newton's adage, LRO is still orbiting the Moon and returning critical mapping data, such as day-night temperature maps, a global geodetic grid, high resolution color imaging, and the Moon's ultraviolet (UV) albedo to measure the reflectivity of the lunar surface. All this information is critical for Artemis lunar science and exploration missions.

"LRO was initially planned to be at the Moon for one or two years, with the idea that it could go a little bit longer, but it was not designed to last 14 years. No mission has now orbited the Moon for as long as LRO has," said Noah Petro, project scientist for LRO since its inception and project scientist for Artemis III at NASA Goddard. "For lack of a better word, we basically put LRO on cruise control. We [achieved that] by making the decision [to put the LRO] into an elliptical orbit that took us high over the North Pole and that allowed us to fly close over the South Pole. In doing so, that meant that we did not have to use as much fuel."

Although LRO's original objectives were exploratory in nature, its payload contained equipment [see sidebar] that have made a number of unexpected findings that have altered NASA's understanding of the Moon. Similar missions in the past had a one- to two-year lifespan. This 14 plus-year mission has allowed NASA to see and understand how the Moon has changed over time.

Lunar surface pits were first seen on the Moon in 2009. Since their discovery, NASA scientists had theorized that these pits serve as openings to underground caves and other subsurface geologic features. Understanding the temperatures within these pits is important for future exploration of the Moon, as they could be used for future sites or bases that require thermally stable environments. The largest revelation may not be that water only exists on the poles and in shadowed regions of the Moon, as had been previously as-




*Shown here is a rendering of 13 candidate landing regions for Artemis III. Each region is approximately 9.3 by 9.3 miles (15 by 15 kilometers). A landing site is a location within those regions with an approximate 328-foot (100-meter) radius. Image Credit: NASA*

sumed, but rather that water is present all across the surface.

"To me, there are multiple surprises and lunar pits are a fascinating feature on the lunar surface," noted Petro. "In addition, there is water on the Moon, and it was not where we thought it was. LRO has helped paint this picture of the complexity of volatiles on the Moon as well as the complexity of the lunar environment. Instruments [aboard LRO] helped and continue to paint a picture of what the Moon is and now over time. We are using the datasets [from LRO] to plan human and robotic missions to the lunar surface to satisfy the initial goal of why LRO was sent to the Moon in the first place, which was to facilitate exploration. When Artemis astronauts take their first steps on the Moon, they will be doing so having been guided by the data that LRO has collected."

In August 2022, using data from the LRO, NASA identified 13 candidate landing regions for Artemis III, the next human landing on the Moon since Apollo 17 in 1972. Each of the 13 regions are located near the lunar South Pole. Collectively, they contain diverse geologic features, which together will provide landing options for all potential Artemis III launch opportunities. Petro said specific landing sites are tightly coupled to the timing of the launch window, so multiple regions ensure flexibility to launch throughout the targeted launch, planned for 2025.

LRO detected zones will make it possible to achieve NASA's "moonwalk objective" of allowing the astronauts to walk on the Moon, collect samples, and conduct scientific analysis while limiting the disturbance to the landing site area on the lunar surface. All 13 regions provide continuous access to sunlight throughout a 6.5-day period, which is the planned duration of the Artemis III surface mission. Access to sunlight is critical for a long-term stay at the Moon because it provides a power source and minimizes temperature variations.

**NASA identified the following 13 candidate regions for an Artemis III lunar landing:**

- Faustini Rim A
- Peak Near Shackleton
- Connecting Ridge
- Connecting Ridge Extension
- de Gerlache Rim 1
- de Gerlache Rim 2
- de Gerlache-Kocher Massif
- Haworth
- Malapert Massif
- Leibnitz Beta Plateau
- Nobile Rim 1
- Nobile Rim 2
- Amundsen Rim

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"Selecting these regions means we are one giant leap closer to returning humans to the Moon for the first time since Apollo," said Mark Kirasich, deputy associate administrator for the Artemis Campaign Development Division at NASA Headquarters. "When we do, it will be unlike any mission that has come before as astronauts venture into dark areas previously unexplored by humans and lay the groundwork for future long-term stays."

A final decision on the Artemis III landing site will be made by a NASA headquarters driven cross-agency committee. "It will come down to the safest place that we can go to when we are ready to launch," Petro said. As for LRO, Petro estimates that the spacecraft still has enough fuel to continue its mission until October 1, 2025, after which it would potentially be replaced. Once it runs out of fuel, the mission is over, although it may be possible to extend the spacecraft's operational time even more.

"There is not any gas station [on the Moon] and, ultimately, we will be in a position where we can no longer operate the spacecraft the way we are accustomed [to doing]," said Petro. "What we can do is operate the spacecraft in a way that either totally reduces the amount of fuel or removes the necessity of fuel. By using these creative ways to operate the spacecraft, we may be able to extend it further and further without having to replenish fuel."

"With LRO, we have reduced a lot of the unknowns," he concluded. "Before LRO, we did not have a great broad understanding about the Moon and what the lunar surface looked like. Now, we have been able to basically look at the Moon in high-resolution images and we are armed with information to say: this is a safe landing site because there are no boulders, no craters, and no hazards in this area."

## LRO carries a complement of six instruments and one technology experiment:

**Cosmic Ray Telescope for the Effects of Radiation (CRaTER)**
The primary goal of CRaTER is to characterize the global lunar radiation environment and its biological impacts.

**Diviner Lunar Radiometer Experiment (DLRE)**
The DLRE measures surface temperatures on the Moon to provide information for future surface operations and exploration.

**Lyman-Alpha Mapping Project (LAMP)**
Using ultraviolet light generated by stars as well as the hydrogen atoms that are thinly spread throughout the Solar System, LAMP peers into permanently shadowed craters in search of water and ice.

**Lunar Exploration Neutron Detector (LEND)**
LEND provides measurements, creates maps, and detects possible near-surface water ice deposits.

**Lunar Orbiter Laser Altimeter (LOLA)**
LOLA provides a precise global lunar topographic model and geodetic grid.

**Lunar Reconnaissance Orbiter Camera (LROC)**
LROC, which is made up of two narrow-angle push-broom imaging cameras and one wide-angle camera, addresses the measurement requirements of landing site certification and polar illumination. It is expected that this photography will boost the ability to validate proposed landing sites..

**Mini-Radio Frequency (Mini-RF)**
The Mini-RF radar uses new lightweight Synthetic-Aperture Radar and communications technologies to locate water and ice.

*Artist rendering of the Lunar Reconnaissance Orbiter (LRO), above the moon, Photo Credit: NASA/GSFC*


Goddard has a significant role in defining and contributing to the science of Artemis.
-Dr. Noah Petro

## *Preparing for Science on the Moon Through Artemis Missions*

*NASA's Moon to Mars Artemis exploration approach sets a vision for a new era of scientific discovery and economic opportunity on the Moon while testing and demonstrating the operations and systems needed for human missions to Mars. NASA's Goddard Space Flight Center has made major strides over the past couple of years to establish the organizational structure and leadership required to bring that vision to life.*

*"As we work to send the first woman and first person of color to the Moon under Artemis, this generation – the Artemis Generation – is part of a sustainable exploration program that will last decades," said NASA Administrator Bill Nelson, "Artemis is a testament to our can-do spirit. We are going!"*

*As directed by the 2022 NASA Authorization Act, Artemis focuses on hardware development, science, mission integration, and risk management functions for programs critical to the agency's exploration approach. As with the Apollo missions over 50 years ago, NASA Goddard has the opportunity through Artemis to develop transformative technologies and knowledge as a new generation of engineers and scientists gear up to explore a region of the Moon. The question remains: As NASA prepares to return to the Moon, what exactly do we hope to learn?*

*In this Q&A, you will read about how Goddard scientists are studying Moon rocks, training astronauts, helping select Artemis landing sites, and more, in preparation for conducting science at the Moon's South Polar region. Additionally, you will learn about how the Artemis missions will lead to greater exploration of the Moon. This section features a free-wheeling conversation with some of the key Goddard scientists (at Code 698) who are working on returning humans to the Moon with Artemis. They include Dr. Noah Petro, project scientist for Artemis III; Dr. Kelsey Young, Artemis science flight operations lead; Dr. Daniel Moriarty, assistant research scientist, and Dr. Natalie Curran, lunar geologist. Note: The following answers have been edited for brevity and clarity.*

*Thumbnail Photo Credit: GSFC/Molly Wasser/NASA*

**Q: When we talk about scientific and exploration objectives of the Artemis mission, is a return to the Moon the first?**

**Dr. Noah Petro:** Last December, Artemis splashed down in the Pacific Ocean and that mission was successful, and we immediately turned our eyes to Artemis II. On Monday, April 3, 2023, the crew of Artemis II was announced and unlike crew announcements for the past 50 years, the crew of Artemis II is going to fly by the Moon, which has not been done since Apollo 17 in December 1972. As we have said time and time again over the past several months, Artemis is happening. NASA is going to send humans to the Moon. That question should no longer be asked. There is a question of timing, but it is going to happen.

**Q: In a broader sense, what is Artemis?**

**Dr. Noah Petro:** Quite simply, Artemis is the next major initiative to send humans to the lunar surface. The Artemis astronauts are set to explore an area around the lunar South Pole. It is an area that we know is compelling for a myriad of scientific reasons. There are ancient rocks that are among the oldest that we are aware of in the Solar System, some of which receive extensive illumination and some that do not. So, what Artemis astronauts are going to do is learn about the history of the Moon, and by association, the history of the Earth and the history of our Solar System. Artemis is also a long-term program. This is not a program that is intended to end after six missions. Artemis is intended to be a sustainable set of exploration missions to the Moon, leading towards the development of infrastructure designed for extended stays on the lunar surface. Apollo famously stayed on the Moon for just under three days, but Artemis will eventually provide us with a long-term presence near the Moon's South Pole. With Artemis, we will also learn how to live away from Earth and, as a result, how to live on a another planet, which will eventually assist us and our astronauts get ready to go explore Mars. More immediately and right now, we are preparing for the first stages of Artemis. With Artemis II, our astro-

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nauts will fly by the Moon and with Artemis III, our astronauts will land on the Moon. Dr. Kelsey Young, Dr. Daniel Moriarty, and Dr. Natalie Curran are helping us to make that a reality.

**Q: What is Goddard's role in Artemis?**

Dr. Noah Petro: Goddard has a significant role in defining and contributing to the science of Artemis. What will we learn when we go? We are of course playing a vital role in communications, in developing technologies supporting the fundamentals of making that mission work. Everyone here at Goddard remembers the significant contributions that we made to Apollo in terms of running the communications network, in addition to analyzing samples and data that came back from Apollo. And so, we are carrying on the legacy that started over 50 years ago to make Apollo as scientifically rich as it was.

**Q: What will we learn about science from the Artemis mission?**

Dr. Noah Petro: First, we do these things not because we want it for ourselves, but to share with the entire world. For 14 years, Goddard has led the way in communicating the value of the Moon for science. Part of the reason I do lunar science at Goddard is to improve our understanding of our nearest neighbor in space. But the Moon is also beautiful and captivating. In the next couple of nights, go out and look at the Moon and realize that it is just three days away from us. With Artemis, we are going to be sending humans to go and explore the Moon and learn about our place in the solar system. That is really cool. Artemis is not about what the four of us want to do; it is about bringing the entire world along in this journey to the Moon.

**Q: Dr. Moriarty, what are some of the big scientific questions you would like to explore through the myriad samples and observations that will come out of Artemis?**

Dr. Daniel Moriarty: The side of the Moon that faces the Earth is much, much different than the far side and the reason for this deals with several different factors and, most notably, the thickness of the crust. Like Earth, the Moon is divided into a core, a mantle, and a crust. So, the thickness of the crust on the near side of the Moon is much thinner than the far side. Another factor is the near side has experienced a much higher degree of volcanic activity than the far side. Therefore, the geochemistry of the surface is also much different between the near side and the far side. This is one of the great outstanding mysteries of the Moon. We don't understand why we have these fundamental differences between the two halves of the Moon. Artemis is going to the South Pole region, which is perfectly situated between the two sides of the Moon. So, we are hoping some of the samples from the Artemis mission will help us address this fundamental question of lunar evolution: Why are the near side and far side of the Moon so different?

**Q: Dr. Curran, I gather we are going to get a lot of information from those Moon rocks, which I assume will go into your laboratory back here on Earth. So, when you get samples from future Artemis missions, what are some of the questions that you want answered?**

Dr. Natalie Curran: In the Moon lab at Goddard, one of the main things that we look at is determining the age of the samples. We also determine whether they are volcanic or not, whether they are some of the first rocks to form on the surface of the Moon, or one of my favorites, whether they formed from impact crater events. If you look at the dark spots on the Moon, there are large basins that formed very early on in the Moon's history, about three and half billion years ago. What we are trying to do with the samples collected from Artemis is understand what type of impact event occurred and when these happened. Most of the rock samples collected so far from the earlier Apollo mission are in the equatorial region, but with Artemis we are going on the other side of the Moon to sample the South Pole-Aitken basin. We think this is one of the largest and oldest basins on the Moon. So, identifying an age for these rocks is critical to the understanding of our Solar System and Earth. I am looking forward to that.

**Q: From what I have just heard, there is a lot to learn from the samples astronauts will be gathering on the Moon. Dr. Young, as the science flight operations lead, what else are we hoping to get out of the Artemis endeavor?**

**Dr. Kelsey Young:** This is a global journey that we at NASA Goddard are all fortunate enough to be a part of, but it's also about inspiring the next generation of scientists. I am somebody who came into this field excited by the science and looking at Moon rocks. And Artemis is now doing that for the next generation, by getting them involved and excited about an endeavor like this. That is a big driving factor for a lot of us working on Artemis.

**Q: Dr. Curran, what have we learn so far from the rocks collected in the Apollo mission? How will that compare with the samples we collect from Artemis?**

**Dr. Natalie Curran:** As I mentioned, identifying an age for these rocks is critical to understanding our Solar System and Earth. Because the Moon is so close to Earth, we believe whatever happens on the Moon is also happening here on Earth. From these rock samples, we can learn about volcanism, the early history of the Moon, and if it has any water.

**Dr. Noah Petro:** Natalie mentioned water, and one of the reasons Artemis is going to the South Pole is to visit these unusual environments that are very cold and never receive any direct sunlight. Datasets collected from the Lunar Reconnaissance Orbiter (LRO) suggest that there may be water and various amounts of hydroxyls at or around the South Pole.

**Q: Dr. Moriarty, you have extensive experience working with one of the key datasets that has helped us understand that there is this peculiar distribution of water on the Moon. Can you tell us about the volatile nature of the South Pole?**

**Dr. Daniel Moriarty:** In terms of the geometry of the solar system, the Moon is not tilted very much with respect to the incoming sunlight. So, what the means is, if you are on a high-standing area of the South Pole, the Sun is coming in almost perpendicularly. As a result, high-standing areas of the Moon receive near permanent sunlight, whereas if you are down in a crater or a low-lying area, there is almost no way that sunlight can get into those areas. Those areas are in permanent shadow and are some of the coldest places in the solar system. If water or vapor molecules end up in one of those areas, they get trapped. It is so cold and has so little energy, they cannot escape and stay there throughout geologic time. And so, we have billions and billions of years of these water molecules accumulating. There is evidence from LRO sensing data that there is quite a bit of water and other volatile molecules trapped both in the Moon's North and South Poles. We are excited about what we will find when we get there.

**Q: What I am gathering from our conversation is there are many surprises that await us on the Moon.**

**Dr. Noah Petro:** There is a misconception that Apollo told us all we need to know about the Moon. It is true that it told us a lot about the Moon, but not everything. We have come a long way and learned a lot in the intervening 50 years. So, as you said, one of the things that we are looking forward to is the surprises. There are unexpected surprises awaiting us on the Moon. Exploring the lunar surface and analyzing lunar samples will yield a wealth of unexpected information.

**Q: Let me go around to each of you and ask, what are some of things that you find surprising about the Moon?**

**Dr. Kelsey Young:** I think one of my favorite observations about the Moon is that it is what I call a "witness plate" for our entire Solar System. I think Natalie said it earlier, but everything the Moon has experienced, our planet has experienced although we do have some annoying things like plate tectonics, oceans, vegetation, cities, and other things that obscure our geological record. It is great for us, but not for the geological record. But, on the Moon, we have four plus billion years of history that is there for us and just a couple of days away. Imagine being a geologist unraveling that with field and lab work. We can unravel not just those secrets of

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the Moon but also how life came to evolve and form on our planet. The fact that we can use this other planetary body to understand how we got here just never ceases to fascinate me. It is definitely a challenge to unpack all of that.

**Q: Dr. Curran, what surprises do you think await us?**

Natalie Curran: The South Pole is going to offer a bundle of really cool surprises. Continuing with what Kelsey said, I think one of my favorite things that I aways tell people is: some of the youngest rocks from the Moon are the volcanic ones, which are frequently three billion years old. They are some of the oldest rocks that we could find on Earth. However, due to plate tectonics and other things, most of the earliest geological history of Earth has just been erased and there is much about our planet we actually don't know. The Moon is a phenomenal "witness plate" place to go.

**Q: Dr. Moriarty, what surprises you?**

Dr. Daniel Moriarty: I think the thing that surprises me about the Moon is the diversity of volcanic processes that we observe. On Earth, a lot of the volcanic processes and variations that we observe are related to plate tectonics. Plate tectonics are in areas of interactions between continental and oceanic crust. On the Moon, it is a one-plate planet; there is no plate tectonics, and so we just have one solid lithosphere. But there is still a huge range of diverse volcanic landforms that we observe. So, we see areas of the crust that have been inflated by volcanic material that never quite broke to the surface but have kind of buckled and fractured to the crust that has almost inflated like a balloon. That is really something you would expect to see if you had plate tectonics. I don't think there is a huge amount of volcanic activity at the South Pole. But I am very interested to find out about the volcanic history of the South Pole.

**Q: You have all outlined several science questions that beg going to the surface of the Moon and returning samples. What I am hearing is that this effort intersects with all the things Goddard does – Earth Science, Planetary Science, Heliophysics, and Astrophysics. Is that correct?**

Dr. Noah Petro: As Kelsey said, the Moon is a "witness plate." The best place to understand and recreate all the events of the solar system when it formed four and a half billion years ago all lie on the surface of the Moon. So, in the next couple of years we are going to have astronauts going to the surface conducting experiments to help us disentangle all those scientific questions outlined earlier simultaneously.

**Q: Dr. Young, how specifically are we training astronauts for the South Pole?**

Dr. Kelsey Young: We are training the astronauts in a lot of ways. We are training them how to launch off Earth, how to land on the Moon, how to launch off the Moon and land back on Earth, how to fly multiple spacecraft between the Earth and the Moon and back, and how to operate all of that in a spacesuit. But, near and dear to our hearts is the science training. The astronauts are members of the science team, and we are empowering them to address our science objectives. Earlier in the interview, you asked about some of the science objectives. The South Pole is a rich geological target for all the reasons we've touched upon. There is a lot to the training, and we are doing that with a blend of classroom and field training. During some of the field training, we will visit locations on Earth that resemble the locations we anticipate they will visit, including field environments and relevant rocks. And we also train them in pressurized space suits at NASA facilities. To simulate the gravity conditions found on the surface of the Moon, we have a big swimming pool that we put astronauts in, and we have a big harness system that offloads the crew members. While those NASA facilities don't have representative rocks, it is critical for them to get all the training they can with the geology tools to do all the sampling on the Moon, so they can get those rock samples back to Natalie.

**Q: When you are out in the field with astronauts, what are the kinds of things that you are trying to instill in them?**

Dr. Kelsey Young: It is all about putting the entire picture together by allowing those testing and training events to

take place in a variety of different environments. So, for example, astronauts who are going to the South Pole are going to be looking at impact craters, which Natalie talked about. Later this year, we have a field event coming up, where we get out in field environments that replicate the impact craters. Just as critically, we must get all the mission support personnel in those environments trained as well. It's not just about astronauts, these human space flight missions are massive endeavors that include engineers, public affairs, budget, and admin staff, in addition to flight controllers and directors. All these people are part of the mission, and it is vitally important that they all understand these environments as well. When considering training, it is about testing hardware, it is about testing protocols and concepts of operations for exploration in these high-fidelity environments to give our entire exploration team the highest fidelity look at what to expect. I can tell you one of the most gratifying parts of my job the past few years is training not just astronauts but flight controllers, engineers, etc. So, it is important to bring not just the astronauts but the entire team along to train with us.

**Q: How concerned are you about spacecraft from Earth contaminating the Moon?**

Dr. Noah Petro: That is a complicated question. There is an aspirational answer and a realistic answer. The realistic answer is, with Apollo, we have already sent a bunch of stuff to the Moon. Apollo was trailblazing in many ways, but we had to get astronauts to the surface and back, and the way to do that was to leave things behind, whether it was a rover or a geological camera, or food wrappers. All of that happened and we can't go back and undo the events of 50 years ago. Looking forward to the exploration of the Moon, we need to land and do certain measurements. To do that, we must go to the lunar surface, so we want to ensure that we are sending clean material and we are not contaminating these environments. Every spacecraft that goes up in space has some water in it, which contains microbes that can contaminate an environment. Water is inherent in everything that we send from Earth. That is why lunar samples are so important because we know they have very, very small amounts of water. We need to reduce the contamination as much as we can because it is unavoidable to change the environment when collecting measurements. So, we do the best we can to decontaminate instruments and remove water by putting them in a vacuum chamber to kill off most of the microbes.

**Q: Dr. Moriarty, what are some of the things that you are thinking about in terms of the environment?**

Dr. Daniel Moriarty: A lot of the environment at the South Pole relates directly to illumination. On Earth we have an atmosphere, and that atmosphere helps us redistribute heat. If you have heat coming from the equator, it cycles in the atmosphere and that redistributes the heat all over Earth. On the Moon there is no atmosphere. At the equator of the Moon, you essentially have two weeks of illumination and then have two weeks of darkness. At the South Pole, you are much less dependent on rotation and much more dependent on local topography. There are some areas that are almost permanently illuminated, and other areas that are permanently shadowed. The environmental conditions, and especially the thermal conditions are just directly tied to illumination. I think that is going to be quite an adjustment for the astronauts to deal with.

**Q: Dr. Young, what is being done to prepare astronauts for those weird sun conditions at the South Pole?**

Dr. Kelsey Young: Yes, that is definitely a challenge. Best case scenario you have light right in your eyes, but at least you have some illumination. Worst case, you are in complete darkness, so preparing the hardware to be able to support the astronauts in those different environments is really critical. We have developed some creative solutions for testing and training in these field environments to simulate these critical conditions that Daniel is talking about, because this is vitally important for us to achieve our science objectives on the Moon while operating in these low-sun and no sun conditions. We have had simulated sun capabilities and hardware capabilities in the field. The spacesuits have lights on them of course, and so we could simulate that in the field. And we have been able to put crew members in darkness in field environments with portable Suns and suit lights to be able to simulate those low light conditions. We have also tested in virtual environments based on what time of

*continued on pg 12*

*continued from pg 11*

year we will be on the lunar surface and which landing sites are selected.

**Q: What role are robotics and artificial intelligence (AI) playing in these missions. Dr. Young, do you want to talk about robotics as it relates to exploration?**

Dr. Kelsey Young: Artemis is more than just crewed missions. It is more than just astronauts on the surface. It involves commercial landed service payloads delivering instruments and payloads to the lunar surface and that includes rovers. NASA has the Volatiles Investigating Polar Exploration Rover (VIPER), which is a lunar rover developed by the NASA Ames Research Center that is going to explore the South Pole of the Moon to look for volatiles. We expect robotic assets to support crewed mission phases as well. The crew will not be on the lunar surface for the entire year, so there will be phases of future Artemis missions that have robotic assets exploring the surface without crew members in the loop. So, there will be opportunities for AI machine learning and autonomous navigation technology demonstration with some of these robotic assets. Artemis really represents a spectrum that is far more than a crew program and so, robotics is absolutely a critical part of the lunar exploration program.

Dr. Noah Petro: I think our use of AI is still in the early stages, but we are looking at every resource and every tool to make sure when we pick a safe landing site that we as humans are not missing something that our automated friends can pick up on. We are trying to throw every possible resource toward looking at the surface of the Moon before we send our brave explorers to its surface.

**Q: We've talked a lot about bringing samples back to study, is there any science objective that would be better assessed in situ or on-site locally on the surface of the Moon?**

Dr. Natalie Curran: Here at Goddard, we have some super accurate instruments to study rocks that weigh about as much as a baby elephant that I am not sure can ever reach the Moon. I also want a sample from every spot on the Moon, but that is not always feasible. So having some situ instruments that can collect information from the samples as the astronauts go to different spots on the Moon would be super beneficial. We have some instruments in development here at Goddard that could be put in a rover to do instant age analysis of various samples. [see QuERI article on page 14]

Dr. Daniel Moriarty: Anything that you are trying to measure that is ongoing, you need to also do in situ. One example would be micrometeorite bombardment. The Moon is constantly being hit by fragments of material over a wide range of sizes from little specks of dust to small pebbles. We want to get an understanding of those, not only for basic scientific reasons but to understand the safety at the surface. If the Moon is constantly being pelted by little pieces of dust or rock, we want to know that with a high degree of accuracy.

**Q: Last year NASA announced there are 13 regions around the South Pole, within which there are multiple opportunities to land with Artemis III specifically. Has NASA chosen a specific site around the pole and why?**

Dr. Noah Petro: Artemis III is going to have a complicated set of criteria as to which site is selected on the Moon. Because the astronauts are going to have to get out and walk, we are going to have to land at a place that is illuminated or nearly illuminated for the six and a half days they are going to be on the Moon. They can't go out and land in the middle of the night. The landing site also should be in line of sight with the Earth, so all these different components will factor into which of these locations will be selected. Each of the 13 regions have their own story and special interest. All four of us had a small role in saying these are interesting places to go and not just interesting because they are on the Moon, but because there are science questions we want to address there.

**Q: Earth gets meteorites from the Moon. Does it ever happen the other way around? How can you tell if it happens in reverse?**

Dr. Natalie Curran: As you can imagine, each planetary body, the Moon, Mars, or the Earth, has its own fingerprints,

or its own chemistry. We have gotten very good at identifying if it is Moon rock or if it is not. We can look at the rock and say it may have a little bit more water and has a slightly different composition to say it could have formed on the Earth.

**Q: Have you found anything unusual or exciting in the recent lunar samples you are studying from Apollo 17?**

**Dr. Natalie Curran:** There has been nothing unusual. I have not found any new minerals or anything like that. We have a new project, and it is called Moon United that looks at Apollo 17 samples as part of the Apollo Next Generation Sample Analysis and the exciting thing about that project is we are using that to prepare us for Artemis. So, we will see when we bring new samples back from the Moon, how all the wonderful geology teams throughout the world will analyze those samples. Right now, we are working on the Apollo 17 samples and hopefully we will have some exciting results in the next couple of months. So far, we have not found anything new or unusual in the data that we have collected from these samples.

**Q: Anything you would like to say in conclusion?**

**Dr. Noah Petro:** I was just named project scientist for Artemis III and Barbara Cohen, planetary scientist at Goddard, has just been named project scientist for Artemis IV. There also will be an Artemis V and Artemis VI. What we learn from Artemis III we hope informs us about the places we go for Artemis IV. So, wherever we go in those 13 landing regions for Artemis III, we hope it gives us the opportunity to lay a foundation and build a legacy to either confirm or refute some of the things that we know about the Moon. It is up to all of us at NASA Goddard, not just us four, everybody, and all the scientists from around the world and the public at large to become engaged in the mission, contribute to the mission, and then use the lessons from Artemis III to prepare what is next.

> “As you can imagine, each planetary body, the Moon, Mars, or the Earth, has its own fingerprints, or its own chemistry.”
>
> *-Dr. Natalie Curran*

# Rock of Ages

*Goddard Researchers are Developing a Handheld X-Ray Fluorescence Spectrometer for Analyzing Rocks during Crewed Surface Operations on the Moon*

Back in 2019, scientists may have discovered the oldest Earth rock ever found from the Moon! They discovered that one of the lunar samples brought back by the Apollo 14 crew may have included a little piece of the Earth from roughly four billion years ago.

Scientists associated with the Center for Lunar Science and Exploration (CLSE), part of NASA's Solar System Exploration Research Virtual Institute, established evidence that the rock was launched from Earth by a large impacting asteroid or comet. This impact jettisoned material through Earth's primitive atmosphere and into space, where it collided with the surface of the Moon. CLSE Principal Investigator Dr. David A. Kring believes the rock was subsequently mixed with other lunar surface materials to allow its collection in one sample.

"It is an extraordinary find that helps paint a better picture of early Earth and the bombardment that modified our planet during the dawn of life," Kring said.

The Artemis program will return humans to the lunar surface, providing opportunities to advance NASA's current state of knowledge regarding the formation, differentiation, and evolution of the Moon. Previous samples returned from the Apollo missions show the Moon is composed of a variety of igneous rocks, which form when hot, molten rock crystallizes and hardens, with varied chemical and mineral compositions.

"Everything the Moon has experienced, our planet has experienced but we have some annoying things like plate tectonics, oceans, vegetation, cities, and things that obscure our geological records," added Dr. Kelsey Young, Artemis science flight operations lead. "It is great for us but not for the geological records. But on the Moon, we have four plus billion years of history that is there for us and just a couple of days away. So, the idea of going to the Moon to learn about the evolution of our planet is unendingly fascinating. It is definitely a challenge to unpack all of that."

"The Moon is our Rosetta Stone to understanding how planets work," added Dr. Noah Petro, Artemis III project scientist and lab chief for Planetary Geology at NASA Goddard. "Similar to how the Rosetta Stone helped unravel [Egyptian] history, we use the Apollo lunar samples to unravel and tell the history of Earth and of the solar system going back four and half billion years ago. Without those samples and without that data, we would not be in a position of making educated guesses about the composition of the Moon and the geological history of Earth.

Sample returns are a high priority science goal of the Artemis mission. In past Apollo missions, astronauts used a rock camera, a scoop, a rake, their eyes, and a lot of training to decide which rocks were most important to bring back to Earth. The problem is the number of samples that can be returned to Earth for study will be limited by spacecraft weight constraints. Because they lack formal geology training, astronauts must find a way to distinguish between rocks that should be transported back to Earth for investigation and those that are better left behind.

To fulfill this need, a mineralogist and research engineer at Goddard have teamed up to develop the Quantitative Elemental Reconnaissance Instrument (QuERI), a handheld X-ray fluorescence (XRF) spectrometer for crewed surface exploration of the Moon. QuERI will aid Artemis astronauts in selecting a diverse sample set for return to Earth and provide compositional data from rocks and regolith analyzed within the exploration area of the South Pole of the Moon. The device is designed to have the data collected sent to both the astronaut on the lunar surface and to geologists back on Earth.

"This is meant to be one [geological] tool in the astronaut's

toolbox," explained Cherie Achilles, research assistant and mineralogist in the Planetary Studies Directorate at Goddard. "The astronauts are going to be very well trained. They will go through hours and hours of geology training and be able to identify all these different types of rocks on the Moon. But you can't always tell the subtle compositional differences, which are things that scientists are really into. So, this is an instrument that will be a tool to help astronauts be able to notice some of those subtle compositional difference, to help make sure that we don't bring back duplicate rocks."

Looking something like a forehead scan thermometer, QuERI is a handheld X-ray fluorescence (XRF) spectrometer, which integrates an X-ray source, a detecting system, and associated electronics to measure the major element components of lunar surface materials. The device is battery operated and uses less than 10 watts of power. The astronaut will simply point the QuERI at any object they want to gather information about and pull the trigger.

"What we are getting is not a picture or an image but a spectrum, a detailed color X-ray of the rock sample," said Keith Gendreau, astrophysicist at the Science and Exploration Directorate at NASA Goddard. "You pull the trigger, and it will turn on the X-rays that will then strike the target and make a rough analysis of what elements are in the sample. The data will be recorded and shown on the display screen on the device to the astronaut and will be sent back to geologists on Earth."

The X-ray on QuERI, which is known as the Miniaturized High Speed Modulated X-Ray, was developed by Goddard scientists and engineers Keith Gendreau, Zaven Arzoumanian, and Steven Kenyon. The trio was named by NASA's Inventions and Contributions Board as the winner of the 2019 Government Invention of the Year. The X-ray source was originally designed to support the instrumentation of the Neutron Star Interior Composition Explorer (NICER) project as a calibration and verification tool.

Unlike the earlier Apollo missions, Artemis will explore the Moon's South Pole region. The main science objective aided by QuERI is to understand how and when the Moon formed.

"The area that the astronauts on Artemis will be going to is different from where they have been in the past with the Apollo mission," said Achilles. "The area we are targeting on the lunar South Pole is a major crater impact area that we think is so large, it blew out some of those rocks billions of years ago. It is those rocks that we are trying to look for and help us understand the whole formation history of the Moon. Those rocks will have a lot of certain elements in them, so it might be hard to figure out if we should bring back that rock type or not. QuERI will help us distinguish if those rocks have a higher presence of a certain element over another, so we can use this to really target those early rock formations."

Presently, QuERI is classified in Technology Readiness Level (TRL) 4, meaning it has been validated in a laboratory environment. Gendreau and Achilles said they expect to have it up to TRL 6 with a protype demonstration in a relevant environment by the time Artemis III is ready for launch in 2025 or 2026.

"We are in a great spot to make a lot of progress rather quickly and hoping it is going to be ready for the launch of Artemis III," said Gendreau.

"I like to think of the Moon as a continent of the Earth," said Petro. "It is a shared object amongst every culture and every person on the planet. I think that is really cool. When we study the Moon, we get a sense of not just the Moon's history but Earth's history as well. Artemis is a great opportunity to again develop that relationship with the Moon because in a few years we are going to have people walking on the surface of the Moon."

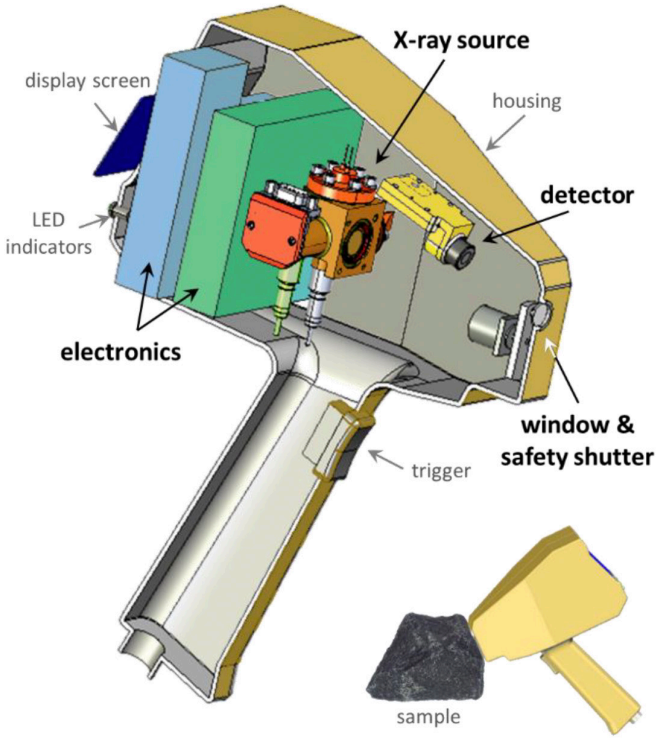
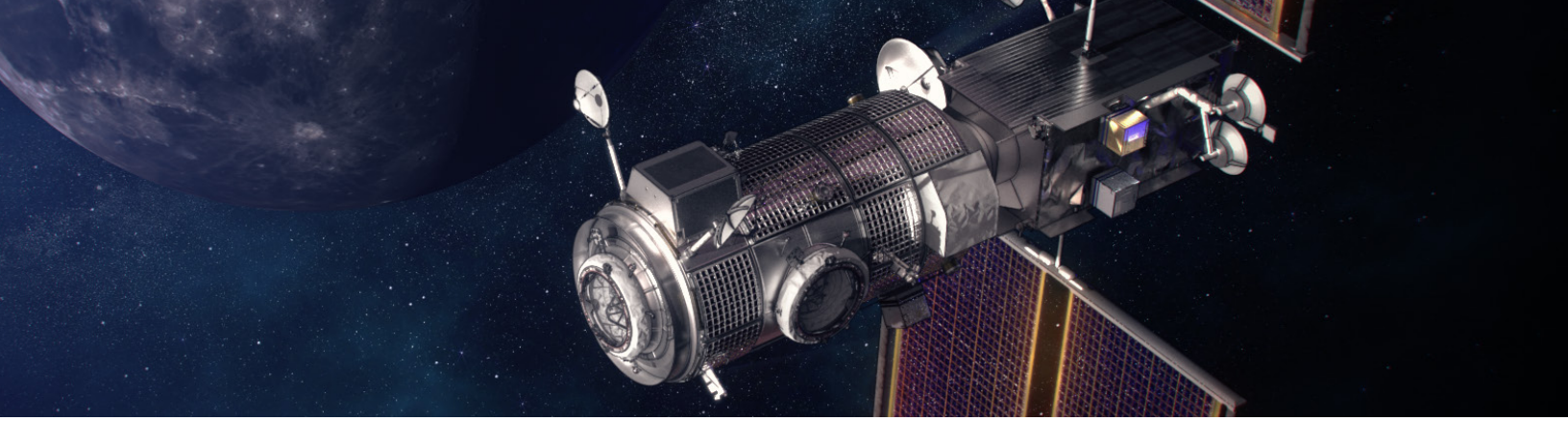



*Image Credit: NASA*



*Artist's concept of the Gateway Power and Propulsion Element, or PPE, and Habitation and Logistics Outpost, or HALO, in orbit around the Moon. The gold box on the right side of the image depicts the HERMES payload. The ERSA payload is the silver box just below it. Image Credits: NASA*

# Tracking Space Weather

If you ask three people what they think of when you say the word "radiation," you will likely get three completely different answers. One person may tell you how doctors use radiation to destroy cancer. Another might describe radiation in the context of the fall-out from a nuclear blast. And your comic-loving friend could explain how gamma rays turned Bruce Banner into the Incredible Hulk. Radiation comes in many forms and is all around us.

According to NASA, "radiation is a form of energy that is emitted in the form of rays, electromagnetic waves, and/or particles. In some cases, radiation can be seen (visible light) or felt (infrared radiation), while other forms — like x-rays and gamma rays — are not visible and can only be observed with special equipment." However, space radiation is a different kind of radiation than we experience here on Earth. NASA states that space radiation is made up of three kinds of radiation: "particles trapped in the Earth's magnetic field, particles shot into space during solar flares (or solar particle events), and galactic cosmic rays, which are high-energy protons and heavy ions from outside our solar system."

The space radiation beyond low-Earth orbit may place astronauts at significant risk for radiation sickness, cancer, diseases that affect the central nervous system, and degenerative issues. Earth's biggest source of radiation is the Sun. The Sun emits all wavelengths in the electromagnetic spectrum (EM). As NASA moves deeper into space in the years ahead, human and robotic explorers will face greater challenges from the sometimes violent and unpredictable outbursts of the Sun.

Expected to launch in October 2025, Gateway is NASA's lunar space station that will orbit the Moon and serve as a key linchpin for the Artemis mission. Gateway will serve as both the staging point for both human and robotic exploration of the Moon's lunar South Pole and potentially will be used as a staging area for NASA's future mission to Mars. Gateway will be where Artemis astronauts live and work as they orbit the Moon, supporting scientific experiments and technology development applicable to both lunar and future deep space human exploration.

The Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES) will be mounted on Gateway's Habitation and Logistics Outpost (HALO) module. Named after the herald and personal messenger of Zeus, king of the Greek gods, HERMES will concentrate on understanding the causes of space weather variability as driven by the Sun and modulated by the magnetosphere from the vantage point of Gateway's lunar polar orbit.

"In terms of human exploration, space weather is really about the radiation," explained Bill Paterson, project scientist for HERMES. "What is important about HERMES is that astronauts need to understand that the space weather environment can be hazardous. At the very least, maybe inside

their spacecraft, astronauts will have to have someplace where they can be shielded from the radiation environment. But to do that, we are going to need to know when the radiation arrives at the Gateway. For that purpose, you need some basic space weather information, which is where HERMES comes in."

Paterson stated that space weather includes a continuous stream of particles and magnetic fields known as the solar wind, blasts of billion-ton gas clouds known as coronal mass ejections, flashes of ultra-bright light from solar flares, and the disturbances each of these create in the near-Earth environment. While some of these events pose dangers to astronauts and robotic missions, they also provide exciting scientific opportunities to understand our Sun and the space around us.

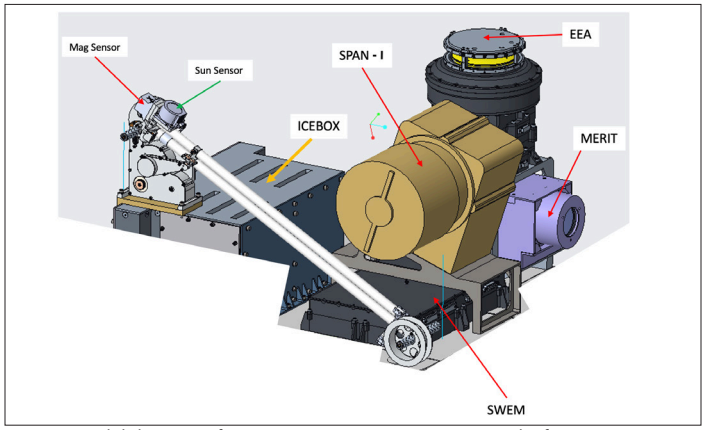
"HERMES is the first space weather monitoring platform on a crewed spacecraft to venture outside Earth's protective magnetic field," said Jim Spann, HERMES program scientist at NASA headquarters. "What we learn from HERMES will be critical to protecting astronauts as we venture forth with the Artemis mission."

HERMES will allow for the study of space weather in an especially variable environment. As the Moon orbits Earth each month, Gateway will spend about one week inside Earth's magnetotail, the portion of our magnetic field blown back from the Sun. When inside the magnetotail, HERMES will be flooded by particles and magnetic fields that have interacted with Earth. In the remaining three weeks while circling the Moon, Gateway will face the Sun allowing HERMES to measure the solar wind and space weather in pristine interplanetary space conditions.

NASA Goddard leads the HERMES project and includes four specialized instruments to take measurements. The Noise Eliminating Magnetometer Instrument in a Small Integrated System (NEMISIS) measures the magnetic fields around Gateway, and the Miniaturized Electron pRoton Telescope (MERiT) measures ions and electrons. The Electron Electrostatic Analyzer (EEA) measures the lower energy electrons that make up most of the solar wind, and the Solar Probe Analyzer for Ions (SPAN-I) measures protons and ions including oxygen. Goddard is providing the NEMISIS, MERiT, and EEA instruments, and the University of California, Berkeley, is providing SPAN-I.

The daily data and measurements sent back from these instruments are designed to help create a clearer picture of how space weather operates. "All of the data collected from HERMES will be sent to scientists and space weather modelers back on Earth for analysis," said Paterson. "Then the modelers will take those measurements to feed it into their models to make predictions about space weather."

HERMES will contribute to several other joint space weather observation campaigns. These include the first external payloads onboard the European Space Agency's European Radiation Sensors Array (ERSA) spacecraft and on NASA's Power and Propulsion Element (PPE) module, which will measure higher-energy particles in the solar wind. Together, they will provide Artemis astronauts with a more complete picture of the space weather conditions they are experiencing. HERMES will also collaborate with NASA's THEMIS mission, which has two spacecraft already in orbit around the Moon. THEMIS is designed to study how mass and energy move through the near-Earth space environment to determine the physical processes initiating auroras. Finally, HERMES will serve as a new asset in NASA's Heliophysics System Observatory of orbiting spacecraft missions monitoring space weather conditions throughout the solar system.




*A model diagram of NASA's HERMES instrument suite. The four instruments are shown along with the ICE BOX, or Instrument Control Electronics Box, and SWEM, or Solar Wind electrons alphas and protons Electronics Module. Image Credits: NASA*

"HERMES is a great opportunity to be part of historic human spaceflight missions while expanding the possibilities for new science with international partners," said Paterson. "We see this as a kind of pathfinder to help establish this capability that we think is going to be needed in the future to support exploration."

# UNLOST IN SPACE

When astronauts on the Artemis III mission land on the Moon and begin to explore the lunar surface, they won't find roadways, signage, GPS systems, or a gas station to stop into for directions if they get lost. As with the Apollo mission over 50 years ago, the only navigational tool to move about the Moon is a process called dead reckoning. This navigation system incorporates estimates of speed, course of travel, and elapsed time from a previously determined position. Unfortunately, dead reckoning is subject to errors that tend to add up over time.

The Moon will need its own information and technology infrastructure because it will not be possible to navigate using an Earth-based communication system due to the distance. This infrastructure will need to have a wireless communication network with data centers for the development of an Internet. To this end, a cross-functional team of networking, navigation, science, and systems engineering experts with NASA's Space Communications and Navigation (SCaN) program at Goddard are working on a project called LunaNet. This program will provide networking, navigation, detection, information, radio, and optical science services to the Artemis mission.

For lunar navigation, LunaNet offers operational independence from data processing on Earth while maintaining high precision. The architecture will provide Artemis missions with access to key measurements necessary for onboard orbit determination and guidance system operations, or surface positioning. Missions using LunaNet navigation services will have everything they need for autonomous navigation on the Moon, whether that be on the surface or in orbit.

"LunaNet will provide a new paradigm for Earth-independent navigation, assuring crewed and robotic missions can quickly and accurately determine their locations and feed that forward to their planning systems," said Cheryl Gramling, assistant chief technologist at Goddard's Mission Engineering and Systems Analysis Division (Code 590).

LunaNet is a promising concept under consideration by NASA. However, the space agency's vision for a sustainable lunar presence on the Moon requires a real-time information exchange with a surface presence. Although special GPS receivers to satellite relays on LunaNet will enable geolocalization on the lunar surface, these may not be available in places like craters or behind ridges, or at all times of the day.

Another separate team of engineers at Goddard are working on developing a complementary approach to solve that problem. Alvin Yew, a research engineer, and Andrew Liounis, a navigation engineer, are developing a handheld device to be used with LunaNet called Optical Navigation that uses the horizon of the Moon as a landmark to determine an exact location on the surface. Working in tandem with LunaNet, Optical Navigation fills in system downtime, possible signal outages, and cover regions on the Moon that may benefit from multiple data sources.

"Let us say you are walking around in Washington D.C.," explained Yew. "You get lost, you get a bad GPS signal, and don't know where you are. What if you could take out your smartphone and take an image of your surroundings? Algorithms in the device then identify features in the image and based on the spatial relationships between features, a geographic coordinate can be provided. Essentially, we're applying similar principles for lunar navigation, but leveraging the lunar horizon as the salient feature."

"The benefit of this technology is that we use far features, specifically the horizon to know where you are," added Liounis. "Typically, when you are using near-field features, you need the Sun to be in a good position. You need the Sun to be close to overhead, not too far down on the horizon, because if it is too far down, shadows get very long and that kind of takes away all your image features. It makes it difficult to use them as a point of reference."

Yew and Liounis said they envision Optical Navigation to not only be used to help astronauts know where they are, but also to precisely geolocate in areas on the Moon that were used for science observation and rocks that were picked up and shipped back to Earth. "Just knowing where you retrieved a sample or made a science observation is very important," noted Yew.

Although the idea behind optical navigation is novel, the actual device only makes use of common optical technology that may already be present on a mission. Specifically, the technology utilizes optical extra-vehicular (EVA) cameras that interact with computer imagery, digital elevation models (DEMs) that show the topographic surface, and albedo maps, which illustrate images without shadows or highlights.

Presently, Optical Navigation is in the protype phase, and it is being tested with simulated data at Goddard. Work has also begun to add a radio receiver to the device, so it will be able to communicate and receive data from LunaNet. Future plans call for testing the device in a remote location on Earth, where there is little vegetation similar to the Moon. Yew and Liounis expect to have the technology available when Artemis III lands on the Moon in 2025. When completed, the technology will be available for licensure with Goddard's Strategic Partnership Office.

"We have proven conceptually that it works," said Liounis. "There has been an avalanche of interest from NASA. We think this is an important piece of technology to get out there for people to use, especially with Artemis."

> "The benefit of this technology is that we use far features, specifically the horizon to know where you are."
>
> *-Andrew Liounis*

# Exploring Mars & Beyond

Mars is a fascinating planet. It is icy cold and covered with reddish dust and dirt. Like Earth, it has volcanoes, gullies, and flat plains. Scientists can see channels that look like they were carved a long time ago by rivers and streams. Over the years, NASA has sent five robotic vehicles to learn more about the Red Planet: Sojourner, Spirit, Opportunity, Curiosity, and Perseverance, which landed in February 2021.

Now that Artemis I has completed its picture-perfect splashdown in the Pacific Ocean in December 2022, NASA is moving full speed ahead with future Artemis missions, including humans reaching Mars by 2040. "This isn't a one flight and done," said Jim Free, NASA's associate administrator for Exploration Systems Development. "Hardware is already being prepared for Artemis II through V. There is also work to create a habitable Artemis Base Station on the Moon to prepare for flights to Mars."

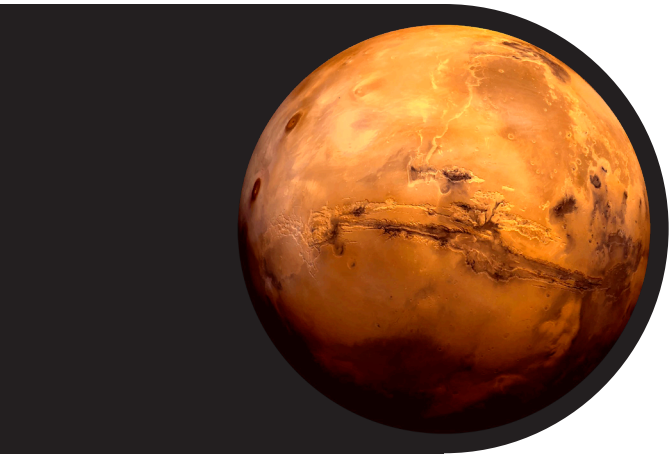
Before any humans set foot on Mars, an array of new robotic spacecraft will continue to take the first steps across the rocky Martian soil to see what lies ahead. NASA engineers across several centers have been developing different approaches for robotic planetary exploration of Mars and beyond. These efforts include Earth-based observations, airborne and orbital telescopes, drones, probes and fly-by spacecraft, orbiters, landers, rovers, and sample return missions.

These applied approaches have some advantages and disadvantages for planetary exploration but Free said, "the ability for surface mobility needs to be maximized to enhance the cost-effectiveness and efficiency of the mission." For example, an aerial platform like a drone provides the ability to access places that are not accessible by a surface platform, but their flight time is heavily dependent on wind and weather patterns. Their use is also limited to the small area around the scientific observation. As a result, there is interest at NASA in developing a multidimensional robotic rover concept that is both an aerial and wheeled, ground-based vehicle with enough mobility to cross obstacles like craters or mountains.

Two Goddard engineers have found the answer. James Loughlin, chief of the Mechanics Systems Division (Code 540) and Umeshkumar Patel, head of the Mechatronics and Robotics Branch (Code 544) have developed the Modular Multi-mission Planetary Exploration and Sampling Systems Concept. Looking something like a radio-controlled toy car, this two-foot-long rover uses small propellers like those on a helicopter to hover above the surface. It also has a set of lightweight metal mesh wheels to drive to the desired location area of scientific research on the surface. The rover is small and lightweight at less than 100 pounds but built robustly enough to handle the tough terrain on Mars.

*Umeshkumar Patel, holding prototype model of the Modular Multi-mission Planetary Exploration and Sampling System Concept, Photo Credit: N4 Solutions*

"Let us say you want to drive from Goddard to Dulles Airport," explained Loughlin. "The Cabin John Bridge is a



mess. Wouldn't it be nice if you could just hop in your car, lift above all of that, land someplace in Reston, Virginia, and then drive the rest of the way. So, imagine you are on Mars for example, and there is a mountain or a crater in the way of the area that you want to explore. Now, you can go up and down in the rover, and then drive to the area where you want to explore. That is how this works."

"The problem in the past is when you land a vehicle like a helicopter, there is also a big prop wash, everything in the area gets stirred up," added Patel. "For scientific observation, you don't want to disturb as much of the area as possible, you want it to be pristine when you get there. The propellors we are developing are strong enough to lift the vehicle from the surface but light enough that there will be little prop wash."

One drawback to this design is that because there is no atmosphere on the Moon, the rover could not be used there. An atmosphere is required for propellor blades to work. Loughlin and Patel are now exploring the idea of replacing the propellor blades with a set of thrusters instead for use on the Moon or other planets that do not have an atmosphere. "That is how we launched off the surface of Moon on the Apollo missions," said Loughlin. "We believe that it is possible to use thrusters with the rover."

Because of the extreme distance from Earth, Loughlin and Patel are also designing the rover to have a certain amount of autonomous guidance through artificial intelligence (AI). To that end, they are developing hazard detection lidar or remote sensing to the vehicle, which together with AI can keep a rover from crashing and on course to its desired destination. The rover is also being developed so it could carry other Goddard-developed technologies, such as the Terahertz Heterodyne Spectrometer for In Situ Resource Utilization (THSiRU) to locate water or the Quantitative Elemental Reconnaissance Instrument (QuERI) to determine the properties of rocks.

Development of the rover is now in the design phase. Under the direction of Patel, a protype of the rover was built last summer by students in NASA's Student Intern Program. The motor and propellor blades still need to be added. To simulate cold temperatures found on Mars or another planet, plans call for testing the rover in a thermal vacuum chamber. When completed, the technology will be available for licensure with Goddard's Strategic Partnership Office.

Aside from the rover, Loughlin and Patel are now working on the science instrumentation for NASA's Dragonfly project. Dragonfly is a joint NASA and Johns Hopkins University Applied Physics Laboratory mission to study Titan, one of the moons around Saturn. Scheduled to launch in 2026 and land in 2034, this will mark the first time NASA will fly a multi-rotor vehicle for science on another planet. Using its eight rotors, the rotorcraft will travel like a drone to investigate Titan's atmospheric and surface properties, along with subsurface ocean and liquid reservoirs. In addition, Dragonfly will search for chemical evidence of past or extant life.

> "The ability for surface mobility needs to be maximized to enhance the cost-effectiveness and efficiency of the mission."
>
> -Jim Free


## THE SPARK

Goddard's *The Spark* shares stories about technology transfer at NASA and the innovative people who make it all possible. The magazine is published quarterly by the Strategic Partnerships Office at NASA's Goddard Space Flight Center.

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