Statement of
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before the
Subcommittee on Space and Aeronautics
Committee on Science, Space and Technology
U. S. House of Representatives
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Hearing entitled:
What do Scientists Hope to Learn with NASA's Mars Perseverance Rover?

Chairman Beyer, Ranking Member Babin and members of the Subcommittee, thank you for your work to support science and exploration and thank you for the opportunity to appear today to discuss our exploration of Mars and what we hope to learn with NASA's Mars-2020 mission and the Perseverance rover.

I have worked for 15 years in planetary science, most extensively on Mars orbiter and rover missions, and am focused on the study of water, habitable environments, and the search for life in our solar system. I now have the privilege of being a member of the Mars-2020 Perseverance Science team as a Co-Investigator on the Mast Camera Zoom (Mastcam-Z) and Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC) instruments.

Our science team was thrilled February 18, 2021 when the Jet Propulsion Laboratory team successfully delivered our 1-ton rover to the surface of Mars. My teammates and colleagues Dr. Luther Beegle and Dr. Tanja Bosak will speak on instrument development and science enabled by sample return. I focus my testimony on important science questions answerable at Mars, the goals of our Perseverance science team for exploration at Jezero crater, and why this is a special site for sample return. I offer also a few thoughts on the United States' Mars Exploration Program, how it enables us to ask and answer big questions, and why this is important for the future.

Answering the Biggest Questions at Mars with the Mars Exploration Program
As we peer into the vast universe with telescopes and have begun to discover Earth-like worlds around other stars, we're drawn to ask profound questions: And are planets like our Earth rare or common? And is there life elsewhere in the universe?

A linchpin to answering these questions is understanding the different fates of our solar system's 3 Earth-like worlds -- Earth, Venus, Mars -- and whether life existed or exists on them.

Of these, Mars is the only planet that still preserves an accessible, largely pristine record of its first billion years. Mars' vast rock record at the surface spans 4 billion years. It offers the longest term record of coupled, system-level changes in climate and habitability in our solar system that require coordinated exploration, as recently reviewed by the Mars Architecture Strategy Working Group report[1]. Mars has outstanding access to environments fundamental to the search for life; it is also the closest potentially habitable world to Earth and a key destination for future human exploration.

Two decades of a systematic Mars Exploration Program orbital mapping have shown how extraordinarily Earth-like Mars once was. Thousands of rock outcrops preserve a record of diverse environments, variable in space and time, much like Earth today. At same time the first life is preserved in Earth's fossil record (~3.5 billion years ago), Mars hosted lakes, rivers, shallow seas, Yellowstone-like hydrothermal systems, clay-rich soils, and underground aquifers of water[2].

Today Mars is a cold desert, like the Antarctic Dry Valleys. Understanding why its path was starkly different from Earth teaches us about the fundamental processes that create habitable environments, and why they endure (or not). Understanding whether Mars does or did host life teaches about the conditions of life's emergence and resilience.

Armed with our instruments and our questions, we have so far visited just a tiny handful of spots with landed missions. What we have found has answered some questions and deepened others. For example, the Spirit rover found a volcanic hydrothermal system, not seen from orbit. The Opportunity rover explored orbital signatures of crystalline iron oxides and discovered they originally formed beneath shallow acid lakes. The Curiosity rover's ongoing explorations at Gale crater have found evidence of a deeper lake with neutral-alkaline water chemistry as well as evidence of organic matter essential to life, tantalizing clues that confirmed Mars' past habitability. But was (is) Mars in fact inhabited?

Next missions: The Mars-2020 Perseverance Rover and Mars Sample Return

Perseverance seeks to answer this question. Perseverance is both a surface science mission, like past rovers, and the first step in an ambitious 3-mission sequence to return samples from Mars to Earth.

The Perseverance's Mission Objectives[3] are (1) to study the rocks and landscape at the landing site to reveal the region's history, (2) to determine whether an area of interest was suitable for life and look for signs of ancient life itself, and (3) to collect samples for possible future return to Earth. An additional objective looks to our future exploration: (4) to test technologies that would help sustain human presence on Mars someday.

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[1] Mars Architecture Strategy Working Group (MASWG), Jakosky, B. M., et al. (2020). Mars, the Nearest Habitable World—A Comprehensive Program for Future Mars Exploration.
https://mepag.jpl.nasa.gov/reports/MASWG%20NASA%20Final%20Report%202020.pdf

[2] Ehlmann BL and CS Edwards (2014). Mineralogy of the Martian Surface, *Ann Review of Earth & Planetary Sciences*, 42, 219-315.

[3] Farley K et al. (2020) Mars 2020 Mission Overview. *Space Science Reviews*, 216(142)
https://link.springer.com/article/10.1007/s11214-020-00762-y

The Perseverance rover has already accomplished several of its technology goals: measurement of detailed conditions during entry-descent-and-landing, successful use of onboard image-based terrain-relative-navigation to guide Perseverance to its safe spot in a rough field, the first production of oxygen from CO_2 in the Martian atmosphere by the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) instrument, and on-the-ground weather measurement to compare with climate models. The team has flown a Mars helicopter, demonstrating the astounding feat of powered flight on another planet. The Ingenuity Mars helicopter lays the groundwork for future exploration technology, much as the 1997 technology demonstration Pathfinder rover laid the foundation for rovers to come.

Enabling Science: Sophisticated Instruments and Sample Caching for Return to Earth
Perseverance seeks the evidence of past life and past climate in rocks. Via textures, minerals, and chemicals the 4.5-billion year record can be teased apart to determine the relative importance of factors like a planet's size, its distance from the sun, whether it had an interior dynamo to generate a magnetic field, the history of volcanoes and tectonics, the composition of the atmosphere, the history of water, and the implications of these changes to life. The required measurements can only be made at the sub-meter and even sub-millimeter scales enabled by a landed mission.

One part of Perseverance's science is making select measurements "in the field" at Mars that one would typically perform in lab on Earth, like laser-induced breakdown spectroscopy (LIBS) and x-ray fluorescence for chemistry (XRF) and Raman spectroscopy for minerals and organics.

Our science team guides Perseverance to act as a robot geologist and geochemist, employing a strategy of nested scales of science observations from orbiter, to landscape, to outcrop, to millimeter. Right now, we're route-planning and debating two different paths our rover could take over the next several months. The science team makes decisions based on data from the Mastcam-Z instrument, which collects color and infrared images, and the SuperCam instrument, which collects remote data on mineralogy and chemistry. The Radar Imager for Mars' Subsurface Exploration (RIMFAX) uses radar to measure rock layers in the near subsurface. Together, data from these instruments guide our drive choices and help us decide which rocks and outcrops are most promising for a close look and a deeper investment of time.

Once adjacent to rocks, we direct Perseverance to use the instruments on its arm, the Planetary Instrument for X-Ray Lithochemistry (PIXL) and SHERLOC instruments, to make micrometer scale maps of texture, chemistry, minerals, and organics. Data from these instruments provide information on past volcanic activity, water chemistry, potential nutrients, and the processes which formed and shaped the rocks. With these data our team can also identify potential biosignatures down to sub-centimeter scale, pinpointing which samples are worthy of collection and addition to the cache for potential return to Earth.

Return of carefully selected samples from Mars to Earth has been a priority of the international planetary science community for decades[4]. Perseverance's samples would span diverse rock types not covered in the meteorite collection and be the first martian samples obtained with knowledge of their geological context and time order, which would allow us to measure isotopes and age date processes to trace the evolution of habitability. These samples would also allow us to search for microscopic-scale biosignatures, characteristic of Earth's earliest fossils, in ways not possible at the surface. In preparation for human exploration, it is also, frankly, prudent to demonstrate the technical ability to land, operate, and return to Earth.

Why Jezero? Landing and at the Right Spot

Succeeding in the quest to understand the changing habitability and search for life on Mars requires being at the right place with access to the right rocks recording the right time periods and environments. It took generations of geologists scouring all corners of the Earth to find Earth's oldest fossils. Armed with this experience, we chose a place on Mars that had multiple chances for preserving signs of past life, from different environments and different slices of Mars time, winnowing candidates from a field of dozens with data supplied by Mars Exploration Program orbiters. While returned samples from Perseverance would enormously advance our quest to understand habitability and the potential for past life on Mars, the reality is that the dozen finalists each captured a different epoch and environment, all potential habitats. There will remain more exploration after Perseverance.

The Jezero crater site offers the chance for an ambitious surface mission, rich with regions to explore, and a sample diversity worthy of our investment to bring them back. The 45-km diameter Jezero crater once held an open basin lake with two inlet valleys and outflow channel. The lake existed for thousands of years about 3 billion years ago. It preserves a prominent delta, a landform similar to that formed where the Mississippi River meets the Gulf of Mexico. Orbital infrared data show that the delta is enriched in clays, carbonates, and silica, some of the key minerals that preserve life and organic carbon on Earth.

Importantly, setting it apart from other Martian lakes, Jezero is located in one of best-preserved sequences of rocks from a still older epoch of Mars. Just outside of Jezero lie pieces of 4 billion year old layered igneous and sedimentary crust. Large mineral veins slice through this crust that were once part of an underground hydrothermal aquifer, now exhumed. These in turn are overlain by another igneous unit with discrete chemistry and still more waterlain rocks.

To a geologist, Jezero has two keystone stratigraphies for understanding Mars' evolution through time. In these rocks will be tiny inclusions that capture the composition of the Martian atmosphere and isotopes in mineral crystals that record the absolute ages of events. Its rocks preserve multiple types of habitats to search for biosignatures.

From the Octavia E. Butler Memorial Landing site, Perseverance will traverse the crater floor, collecting samples en route to the delta. There, it will search for deep lake sediments possibly

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[4] Beaty D et al. (2019), The potential science and engineering value of samples delivered to Earth by Mars sample return. Report of the International MSR Objectives and Samples Team (iMOST), *Meteoritics & Planetary Science* 54, Nr S1, S3–S152

enriched in organics. Then, in the next year, Perseverance expects to climb the crater's rim and into the older mesas of the watershed, stepping backward in time. As it traverses, it will collect at least 20 samples for potential return to Earth. As early as 2026, NASA anticipates sending the next legs, a Mars Ascent Vehicle with Fetch Rover and Sample Return Obiter to return the rock samples to Earth.

Sustainability, Perseverance, Teamwork, and the Next Generation

For our Perseverance rover, while the excitement of landing has passed, the true work of the mission is just at the beginning for the science team. In our two-year primary mission, we will explore from our landing site on the floor to the Jezero delta and out to the ancient highlands, caching as we go. We expect to cross sand ripples, rough terrain, steep slopes. Our team will also have to make hard decisions: which routes do we take and which do we forego? which samples are most important and which are left? As we come to agreement -- and sometimes, inevitably, disagree but must nonetheless move forward -- we demonstrate a different sort of resilience and perseverance, a commitment to a mission larger than ourselves.

I came of age as a scientist and, in fact am a scientist, because of the Mars Exploration Program, which is a crown jewel of our nation's space enterprise. As an undergraduate student who was given the chance to be part of early Spirit and Opportunity science operations, I fell in love with the process of getting and interpreting new data from places never before seen. But it is in the interrelated data from multiple instruments and multiple sites where the true power lies. Over the past two decades, the sustained, forward-looking commitment of the Mars Exploration Program to a sequence of coordinated missions has led to seminal advances in understanding, not only Mars, but also how Earth-like planets work as systems[5]. Developing the science goals, developing science instruments and vehicle hardware, and selecting a landing site for Perseverance built on decades of knowledge of Mars exploration that required consistency of purpose -- endurance and perseverance. The Perseverance mission is only possible because of this sustained, strategic program and interconnected set of missions. Our strategy of doing the hard work to deepen our science questions with each successive mission of discovery, and of coordinating scientific and human exploration priorities, is a strategy that has paid off and one that will continue.

The choices for the Mars Exploration Program in the next decade will be pivotal. The European Space Agency (ESA) has stepped up in a major way to partner with NASA, leading multiple core elements that enable Mars Sample Return to happen now and to happen at reasonable cost. As articulated by independent review, science is mature and the technology is ready[6].

Right now there are 11 operating spacecraft in Mars from 5 different space agencies: NASA, ESA, India, China, and the United Arab Emirates. China's CSA will attempt a rover landing in

[5] Mars Architecture Strategy Working Group (MASWG), Jakosky, B. M., et al. (2020). Mars, the Nearest Habitable World—A Comprehensive Program for Future Mars Exploration.
https://mepag.jpl.nasa.gov/reports/MASWG%20NASA%20Final%20Report%202020.pdf
[6]NASA-ESA Mars Sample Return Independent Review Board and NASA response.
https://www.nasa.gov/sites/default/files/atoms/files/nasa_esa_mars_sample_return_final_report_small.pdf

May of this year. Increasing commercial launch capabilities and commercial technologies being leveraged in small satellites around Earth and in landers at the Moon are lowering the technical barriers and costs to entry that will enable more participants in Mars exploration.

The push to send humans to Mars stands at the cusp of reality with investments by NASA and the ambitions of commercial entities. For example, the vehicle recently awarded the contract for human lunar landers[7] had been developed for future Mars exploration. NASA's Mars Exploration Program is thus at a point where proponents of human and robotic exploration share many common aims and measurements and can benefit one another. Coordination between the scientific community (via structures such as the Mars Exploration Program Analysis Group and the National Academies), NASA leadership, international partners, and private sector stakeholders is key to create the teamwork to formulate the missions that effectively utilize limited resources and realize our shared ambitions.

Sample return, started with Perseverance, is the next scientific big step at Mars. But questions will remain after sample return. Other sites and past environmental types remain to be explored in the search for life and the quest to understand how, when and why Mars changed. Major questions remain about modern climate change on Mars and whether liquid water can and does ephermally exist on the surface or underground. And is there life on Mars today?

Growing up in Tallahassee, FL, I was a little kid who was always reading and whose parents fostered curiosity. From the plants, lizards, and frogs in my backyard to the almanacs, atlases, and National Geographic magazines stacked in a corner of our living room, weekly trips to the library, and a TV perpetually tuned to PBS, curiosity was encouraged. I embarked on a career in science and technology because I was inspired by exploration. Realizing in my teens that our nation was generating new knowledge each day from another planet and that I could be a part of this inspired me and has powered me through every tough moment of the long path to a Ph.D. and established career. I would love to see the U.S. commit to a continual landed presence on Mars; I would love to see operations centers for planetary missions at universities across the country. We inspire the next generation of explorers by introducing them early to the joy and teamwork of discovery.

I look forward to the coming decades as we continue our program of Mars Exploration to seek answers that help us answer the big questions, search for life, understand our own Earth's place in the cosmos, and inspire the next generation of explorers.

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[7] Apr 16, 2021 RELEASE 21-042 As Artemis Moves Forward, NASA Picks SpaceX to Land Next Americans on Moon
https://www.nasa.gov/press-release/as-artemis-moves-forward-nasa-picks-spacex-to-land-next-americans-on-moon

26 April 2021

Biography: Dr. Bethany L. Ehlmann
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Prof. Ehlmann's research focuses on the mineralogy and chemistry of planetary surfaces, remote sensing techniques and instruments, astrobiology, and science policy and outreach. Her primary focus is unraveling Mars' environmental history and understanding water in the solar system.

Prof. Ehlmann is Principal Investigator of Lunar Trailblazer, a NASA smallsat mission with a goal to map the form, distribution, and abundance of water on the Moon and understand the lunar water cycle. She is a Deputy PI of the CRISM imaging spectrometer on the Mars Reconnaissance Orbiter, Participating Scientist on the Mars Science Laboratory Curiosity rover, Co-I on the Mastcam-Z and SHERLOC teams for the Mars 2020 Perseverance rover, and Co-I on the EMIT space station-based imaging spectrometer to explore Earth's dust source regions. She was also a member of the science team for the Mars Exploration Rovers (Spirit and Opportunity) and an Affiliate of the Dawn orbiter team during its exploration of the largest asteroid and dwarf planet Ceres. Prof. Ehlmann is working to propose instrument and mission concepts for Europa, Enceladus, Venus, the Moon, and asteroids.

In addition to her scientific research Prof. Ehlmann is active in policy and outreach. She presently serves as a member of the National Academies Committee on Astrobiology and Planetary Science and the Planetary Science and Astrobiology Decadal Survey 2023-2032 (Steering Committee member and Mars Panel vice-chair). She is President of the Planetary Society, the world's largest non-profit focused on fostering space exploration. In 2018, she authored a children's book on solar system exploration with Jennifer Swanson and National Geographic Kids, *Dr. E's Super Stellar Solar System*.

Prof. Ehlmann is an American Geophysical Union fellow, 2013 National Geographic Emerging Explorer, a former Mineralogical Society of America Distinguished Lecturer, and a recipient of the AGU's Macelwane medal, the American Astronomical Society Planetary Science Division Urey prize, and COSPAR's Zeldovich medal, as well as NASA Group Achievement Awards.

Prior to her appointment at Caltech, Prof. Ehlmann was a European Union Marie Curie Fellow at the Institut d'Astrophysique Spatiale, Orsay, France. Originally from Tallahassee, FL, she earned her undergraduate degree at Washington University in St. Louis, earned M.Sc. degrees from the University of Oxford in Environmental Change and Management and in Geography as a Rhodes Scholar, and earned her M.S. and Ph.D. in Geological Sciences as a National Science Foundation graduate fellow at Brown University.