CubeSats: Preparing the Way Forward For Human Missions to the Moon

by Kesha Rogers

Aug. 21—America is not going back to the Moon; we are going forward to the Moon, and we are going in a big way! Are you ready? For the first time in a very long time, our nation is being led by a vision of profound scientific progress, that is advancing at a remarkable pace. Even in the midst of all the obstacles, challenges, and imposed setbacks, we are persevering.

Did you ever imagine that after President Trump signed the Space Policy Directive 1 in December 2017, outlining a renewed mission for our nation to send American astronauts to the Moon, that we would have advanced so far in that direction so quickly? Space Policy Directive 1, which calls for human expansion across the Solar system, provides for a U.S.-led, integrated program, with private sector partners, for a human return to the Moon, followed by missions to Mars and beyond.

At the time of the signing, President Trump made the following statement, "It marks a first step in returning American astronauts to the Moon for the first time since 1972, for long-term exploration and use. This time, we will not only plant our flag and leave our footprints—we will establish a foundation for an eventual mission to Mars, and perhaps someday, to many worlds beyond."

We later learned that our mission is not simply to return American astronauts to the Moon, but to send the first woman and the next man under the newly named Artemis program—the lunar program named for the twin sister of Apollo—representing a new generation of space explorers, scientists and engineers, and many others, who will break through many barriers and make many creative leaps and scientific breakthroughs to fulfill such a bold mission.

In the course of a short period of time, we have made incredible gains toward achieving the goal of launching American astronauts forward to the Moon, with a commitment to establishing a permanent presence there, by developing the resources on the Moon that will prepare us for Mars and beyond.

In this report I am going to focus on a remarkable new revolution in space technology that has become known as the SmallSat or CubeSat revolution. These very small and innovative spacecraft are poised to play a role in NASA's Artemis program, which will return humans to the Moon by 2024. According to Christopher Baker, the Small Spacecraft Technology program executive within NASA's Space Technology Mission Directorate, "CubeSats also offer frequent, flexible, low-cost access to space, while the schedule from conception to launch of these diminutive spacecraft can be fast-paced.… They allow you to do things that previously would not have been possible with a large, monolithic spacecraft."

NASA/Aubrey Gemignani

President Donald Trump, in the Roosevelt Room of the White House, signs Presidential Space Directive-1 on December 11, 2017, directing NASA to return humans to the Moon, and then pursue missions to Mars and beyond.

To learn more about these fascinating missions, I took the opportunity to speak with Pamela Clark, Science Principal Investigator of the NASA Artemis 1 Lunar IceCube Mission, and Technical Advisor of the Cubesat

Development Lab at JPL, NASA's Jet Propulsion Laboratory in Pasadena, California.

I asked Dr. Clark to tell us more about the CubeSat missions and how they will prepare us to meet the goal of returning humans to the Moon and developing the resources for long-term presence and industrialization of the Moon.

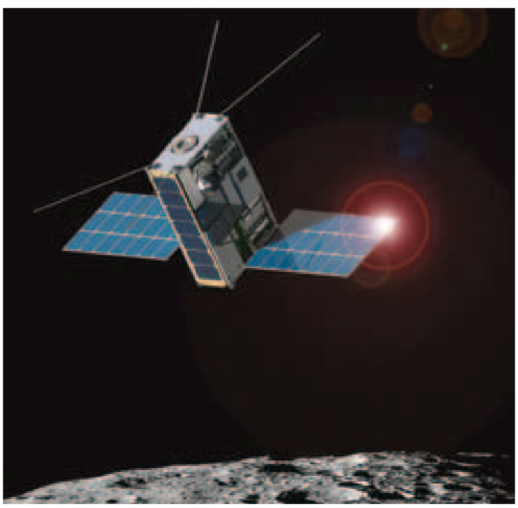
LPAC-TV

Pamela Clark, Science Principal Investigator of NASA's Artemis-1 Lunar IceCube Mission.

Dr. Clark: Artemis 1 will deploy 13 6U CubeSats; the official launch date is 2021. NASA's goal to have "boots on the Moon" in 2024 is actually driving that date. The reason that Lunar IceCube and the two other CubeSat lunar science missions—Lunar Flashlight and LunaH-Map—are important is that all of us are looking at distribution of water on the Moon, from a number of different standpoints.

We have many questions: Why is there water on the Moon, and what role did it play in the lunar formation or the Earth's formation, or even the formation of the Solar system? What's the source of water? Where does it get stored and how much is there really? Because we really don't know. You have some tantalizing data from orbit. When it comes to water on the Moon, really as a function of depth, where is it? How well distributed, how heterogeneously distributed is it? What are the concentrations? How deep?

These three missions will provide three different types of information that will help us get measurements that will provide a better model for water distribution. This is very important from a resource extraction standpoint, an economically viable mining standpoint. Where it is, how economically viable is water as a resource to provide fuel, support human habitat, and a lot of different things.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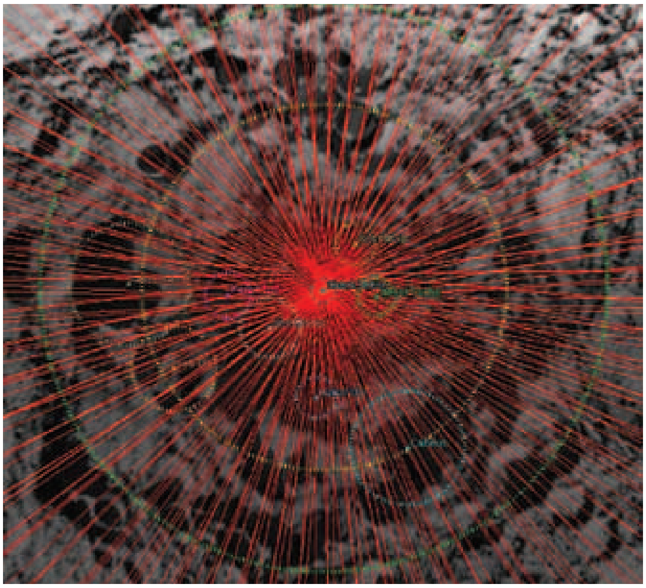
Artist's rendering of NASA's Lunar IceCube orbiter. It will prospect for water and other volatiles using infrared spectrometry.

Lunar IceCube will use its BIRCHES (Broadband InfraRed Compact High-resolution Exploration Spectrometer)—a compact infrared spectrometer that fully captures the broad three-micron band associated with several water-related features (molecular, adsorbed, and bound water; ice; and the hydroxyl ion)—to map the distribution of these features as a function of time of day. It is evident that we have water in a variety of forms on the Moon, seen from orbit, and that we're even seeing water down to about 30 degrees latitude, which is virtually the edge of the equatorial region. We do know there is a time-of-day impact: at local noon, morning or evening, we have different temperatures, illumination conditions, and shadowing on the Moon.

Of course the colder it is, the more likely we are to find ice on the surface. Adsorbed water that's weakly held to the regolith and released as molecular water, depending on the temperature, is part of the exosphere on the Moon. Hydroxyl, the "OH" component of water (H_2O) behaves similarly and can be difficult to distinguish from molecular water. We also have water bound during formation, as in pyroclastics (explosively ejected volcanic rock).

Lunar IceCube will be covering the same swaths at different times of day during successive lunar cycles (28-day lunations). The longer we can stay up there (nominally three months), the more times of day we can observe for each swath. Because we know the Moon pretty well, we may be able to get indications of how different terrains on the Moon behave at the same times of day. Our viewing footprint will be [swaths] as small as 10 kilometers.

LunaH-Map, the Lunar Polar Hydrogen Mapper, will provide repeated coverage of the South Pole from its polar orbit around the Moon. The closest point of its orbit to the Moon (its periapsis) is near the lunar South Pole. Its neutron spectrometer will measure any reduction of neutron flux induced by the pres-



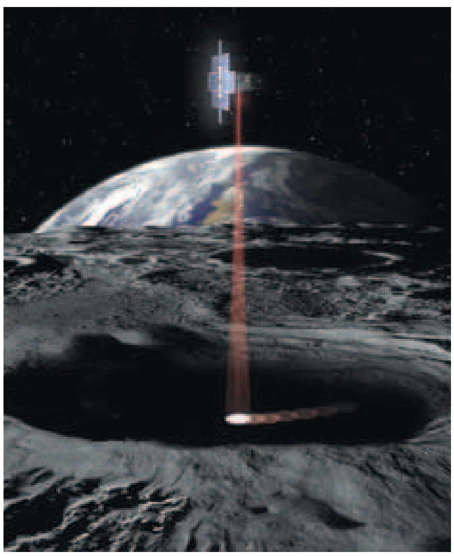
NASA

The Lunar Polar Hydrogen (LunaH) Mapper satellite is already providing continuous coverage of the Moon's South Pole from its polar orbit, using neutron spectroscopy. Shown is a LunaH map constructed from different altitudes.

ence of extra protons, implying ice, down to one meter below the surface, within several degrees latitude of the pole.

In a similar orbit, Lunar Flashlight has onboard laser sources, and receivers tuned to the same wavelengths as the lasers. The wavelengths used are known ice absorption bands and the immediately adjacent wavelengths. At the adjacent wavelength not associated with ice absorption, the laser light will be reflected and received onboard. If ice is present on the surface, light will be absorbed rather than reflected from the band associated with ice absorption when laser light strikes the surface. Thus the ratio of the two bands will change if surface ice is present. Permanently shadowed areas within a few degrees of the South Pole—the most likely candidates for surface ice—will be the target of Lunar Flashlight.

Combined measurements from the three missions will give you a sense of what's at the poles, buried water, surface ice, and what's going on with various water features as a function of time of day, all leading into a model to help us understand where the water is on the Moon.



NASA

The Lunar Flashlight, a CubeSat lunar orbiter, will look for surface ice using lasers.

Once we get reconnaissance from orbit, then the next step will be to send landers and rovers that can actually go and get information on surface and subsurface water.

Another mission on the radar that has not been fully selected yet is Lunar Trailblazer, which will also have mid-infrared and thermal infrared detectors onboard. Trailblazer will collect that data from orbit as well, with resolutions of between 100 and 200 meters. Such data will provide similar measurements on the meters to tens-of-meters scale on the surface, to locate likely extraction sites.

The next fully selected mission on the books is a rover called VIPER (Volatiles Investigating Polar Exploration Rover), which will be sent to an as-yet unselected landing spot, probably near the South Pole. It will expend effort trying to drill into the ground to extract ice. To identify a likely spot, it will utilize a neutron spectrometer and an infrared spectrometer to provide surface and subsurface "signatures" of ice. VIPER will test drilling technology for icy lunar regolith.

More systematic surface reconnaissance will be necessary to demonstrate highly probable or proven reserves, perhaps utilizing a little fleet of small rovers, armed with compact surface and subsurface ice detection instruments, that we can deploy from a larger lander across a likely target. It would be nice to have an infrared spectrometer providing surface volatile signatures, combined with two instruments providing complementary measurements on subsurface water down to one meter, namely a ground penetrating radar for measuring changes in dielectric constant associated with water/ice, and a neutron spectrometer measuring changes in neutron flux, implying subsurface water/ice.

You may measure water feature distribution on a larger scale from orbit, but we need to know how that water is distributed on a local scale, in order to support actual extraction. Is it all in one "hot spot"? Is it a meter below the surface? Is it evenly distributed? These are all the things you need to know to find out if it's viable or not.

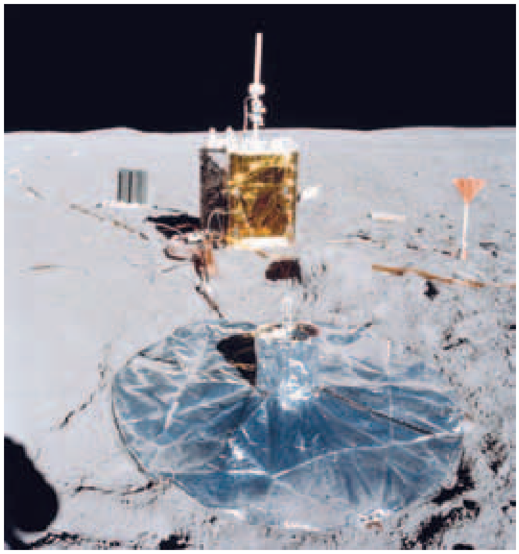
Rogers: So these missions will prepare us for living and working on the Moon in future lunar colonies.

Dr. Clark: Yes. Proving that we have ice that is extractable is going to be critical for deciding what kind of investment we're going to need for Moon colonies, and where we're going to put those Moon colonies. What kind of equipment will they need, to be able to extract the resources? What do they need to bring with them? All these questions tie into the timeframe we need to put something on the Moon that will be viable.

One of the greatest challenges we will see is that the Moon undergoes extremes in temperatures and for long periods of time. You have a 28-day cycle—14 days extremely hot and illuminated, and 14 days extremely cold and not illuminated. The Apollo missions solved the daytime operation problem: They successfully utilized solar panels to provide power, and very effective parabolic radiator reflectors to provide the cooling necessary to operate during the day [shadow shielding].

Nighttime survival—and in some cases nighttime operation—for the instrument packages deployed by the astronauts (ALSEPs, Apollo Lunar Surface Experiment Packages) was provided by using radioisotope power systems, but those are expensive, have remained limited in availability, and add significant mass and volume. Thus, the biggest problem we're going to have is finding a lower-resource way to keep small, low-cost payloads warm enough to operate on at least a limited duty cycle during lunar night.

Because the Moon is such a thermally challenging target, and heat removal is a bigger problem for more compact systems such as CubeSats, NASA has already funded a number of thermal technology development efforts. One of my goals when I came to JPL was to get people interested in the thermal engineering problem. After two years at JPL, I got to know a thermal engineer who was very interested as well. We discussed ideas about a thermal component that would be far more efficient than anything flown before. We got people interested in investing internal funds at JPL.



NASA

The Apollo Lunar Passive Seismic Experiment, deployed at the Apollo 16 site, to detect lunar "moonquakes" and other information about the internal structure of the Moon.

As a result of that we are now looking at longer term, broader NASA investment in a generic reconfiguration of thermal package design that takes advantage of advances in several components, including far more efficient (25 times more efficient than previously flown) thermal switches to control (prevent or enable) heat flow; far more conforming multilayer insulation; and lower contact packaging systems.

The goal is to complete development for such generic, yet reconfigurable packaging within two to three years, by 2022 or 2023, to provide the reconnaissance necessary to support "boots on the Moon" in 2024. I'd like to see a network of instruments all over the lunar surface and in lunar orbit, to give us a three-dimensional understanding of the Moon.

Rogers: What is the challenge on the far side of the Moon—the side that never faces Earth?

Dr. Clark: The challenge with the far side is to have a communications network that reaches Earth. One of the reasons that the Chinese put a satellite at one of the LaGrange points was so they'd be able to communicate with their lander, which they have now landed on the far side, something that American aerospace folks have talked about for 50 years. There are some unique features on the far side you don't have on the near side. That's where you have evidence for the largest and oldest confirmed basin on the Moon. There are also proposals for missions or facilities that require radio quiet (no terrestrial communication system interference for frequencies of interest) on the far side of the Moon.

Rogers: How far along are we toward achieving the goal of human settlements on the Moon and toward building future habitats on Mars?

Dr. Clark: We've made much more progress with this administration than we have in a long time. If we continue on this trajectory, we will achieve the goal of a sustainable presence in cislunar space within years rather than decades—an infrastructure I believe is crucial to support sustainable exploration of Mars.

There is water on Mars, and potentially life has existed and may still exist in niches on Mars. Because of the resulting planetary protection issues [concerns about "contaminating" Mars with microorganisms from Earth], access to the surface and to resources such as water on Mars is more challenging.

One thing we can learn from sustainable cislunar presence that will be crucial for Mars exploration, is the optimal interface between humans and robotics and the ability for far more autonomy at the infrastructure level (communication, transportation). Because with Mars, we'll have to have real autonomy for human safety reasons, if for no other reason. The fact that you need 10 or 20 minutes to communicate, means you have to solve programs in real time. The Moon is a few seconds away in comparison, and thus doable with an externally monitored or controlled system (ground control).


NASA/Joel Kowsky
Former Apollo 8 astronaut Jim Lovell, with the flight plan which first took humans around the Moon.

Being able to have completely autonomous operations will be critical. You practice that on the Moon. That is one of the most important things we can do. I would recommend doing it on the Moon, where we have a fallback position, rather than trying it on Mars for the first time. The Moon provides the space we need to fully explore that fail-safe environment—getting people back and forth, solving an emergency involving saving a life or keeping a system operational.

I would like to see us have some permanent bases on the Moon within a few years. You know how long it took us to get to the Moon under Apollo? Eight years. The one critical piece we're missing now is the manufacturing sector we had during the Apollo program, because it has been systematically shredded by a number of administrations. This administration has recognized this for the first time in decades, and has at least been trying to bring it back.

We have to bring back critical infrastructure. Expanding transportation and communication infrastructure will be important for anywhere we go, including low Earth orbit and cislunar space. You probably know that there are many components needed for the national power, communication and transportation grid that we can't make in this country any more. This is the most challenging problem we face as a nation.

One great attribute of NASA is its legacy of a team culture, where everyone gets to come to the table, everyone is seen as having an important skill set to share. Instrument builders, electrical engineers, theoretical modelers, program managers, lab technicians, even, as Jim Lovell indicated, cleaners. As he said when they asked him how does it feel to be a great hero? He said, "It's really not about me, it's about the thousands of people who made this possible, the guy that does the last check on the capsule, to the guy who cleans the floor of the control room." I believe that the understanding of how critical that is, is what has made this country great.

I know we can do this. If we wanted to, we could have permanently established bases on the Moon and be flying out to Mars in less than ten years, no question. I have no doubt about that. Of course we want cooperation with our international partners as part of it. We'll collaborate with anybody. Like we did, even during the Cold War, with the Russians.

Rogers: What will it take to inspire a new generation of youth?

Dr. Clark: I have spent part of my career as an educator. One of my students, a summer intern, said to me one day, "You're so lucky because you have always had a vision of what you wanted to do and what contributions you could make, and what this country could be because you had the space program, because you had the Apollo program." I thought to myself, "Wow, what a terrible loss! I have a student who never saw himself or herself as part of an inspiring vision!" I've thought about it a lot.

The reason I have a vision is because of the way I was raised: You give back more than you take. You are a unique child of God, no one else will ever be like you and you have to make a contribution, because you have a special gift that nobody else has. You have to find out what those gifts are, and then use them. Always think about giving more than you take.

So I thought, what could I do that caught my imagination? There are a lot of problems to be solved. I thought, space is the new frontier, demanding courage and a pioneering spirit. I said, whatever it takes, I'll make it work somehow, get the right tools, whether the system rewards you or not, even when faced with major obstacles, such as women even becoming engineers when I started out. Whenever I talked about being part of the space program, my whole family ridiculed me. (When I succeeded, they came around!) A young lady wanting to become a space scientist or an astronaut or engineer was laughable to them, and to my peers.

Really good teachers can help you to overcome these obstacles; they can even change your life. My sixth-grade teacher, Mr. Edmund Vandall, a Native American who grew up in grinding poverty, changed my life and the lives of several other students I knew who didn't "fit in." He took us seriously. He treated us as real persons, as intelligent individuals. He challenged us all the time. We need more teachers like that, especially now, teachers who refuse to teach from a script. My sixth-grade teacher broke all the rules all the time, treating each of us according to what our needs were, and not according to the "presumptions" about sixth graders. He had a knack for that, as someone who had been knocked down and humiliated plenty when he was growing up, and what a difference it made for his students!