NASA VIPER ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

ANTHONY COLAPRETE
INTERVIEWED BY SANDRA JOHNSON
MORGAN HILL, CALIFORNIA – SEPTEMBER 8, 2022

JOHNSON: Today is September 8th, 2022. This interview with Tony Colaprete is being conducted for the VIPER [Volatiles Investigating Polar Exploration Rover] Oral History Project. The interviewer is Sandra Johnson. Dr. Colaprete is in Morgan Hill, California, and talking to me today over Microsoft Teams. I appreciate you talking to me again today for this project in particular. In the last interview we talked about your background, and we also talked about your work with the LCROSS [Lunar Crater Observation and Sensing Satellite] mission, where water ice was detected in the vapor plume and the ejecta curtain created when the Centaur impacted the Moon near the lunar south pole. Now more than 10 years later you're involved in this first resource mapping mission to the Moon, which will not only help with the Moon but on to Mars and any other celestial body. Just talk briefly about some of the things you were doing between LCROSS and VIPER. Any of the work or projects or payloads you worked on leading up to VIPER that maybe had some application or helped to build toward this project.

COLAPRETE: Sure. In large part the LCROSS mission was the first step towards VIPER. It was shortly after some of the results were being published for LCROSS that actually Jackie [W.] Quinn at Kennedy Space Center [Florida] reached out to me. At the time she was managing an in-situ resource utilization technology effort called RESOLVE [Regolith and Environment Science and Oxygen and Lunar Volatiles Extraction]. She wanted to know if I was interested in being the lead scientist for it. They had a number of technologies that they were developing for identifying where water might be and how to extract it and process it and utilize it. But they didn't have any planetary scientist as part of their team. They were mostly technologists and engineers.

Following LCROSS she said, "Well, are you interested?" I said, "Absolutely. This sounds really interesting and fun." So, I got involved with that, and as I got involved, one of the things I suggested we could do was actually take the payload they were developing and build around it a mission. How would this be used? Just as a way to really better demonstrate how these technologies would be used. A better way to tell the story of what the mission might be, and how it could move forward.

We started to pursue that. We started looking at mission concepts. How would we put this on a rover? Where would it go? Etc. About the same time, I was working with Dr. Dave [David] Paige at UCLA on a mission concept to the south pole of the Moon as part of a New Frontiers [Program] proposal. The New Frontiers call was for a sample return from the South Pole-Aitken Basin, a large impact basin on the far side of the Moon. But you could actually get some of the samples if you went to the south pole of the Moon.

Based on analysis that Dave Paige did, actually that appeared in the issue with LCROSS results, the *Science* issue, there were places of really persistently lit terrain near areas of permanent shadow. This was just coming to our attention at the time. Realizing that hey, you can actually conduct a solar power rover mission at one of the poles of the Moon, and be able to drive around, staying in sunlight when necessary. But able to duck into permanent shadowed craters to get samples.

This is all about 2011 or so. That was the concept we started to build the mission around, the idea for RESOLVE. After working on that for a bit, we decided to test the idea, test the concept of a rover-based mission that searched for water and extracted it, in a field demonstration.

In 2012 Jackie and her team led a field test out in Hawaii. That included a number of payloads, some developed at Kennedy, Johnson, and at Ames. Two of the instruments at Ames were a neutron spectrometer, led by Rick [Richard C.] Elphic, and a near-infrared spectrometer, led by myself.

The rover came from CSA, the Canadian Space Agency, as well as a drill from Canada. The near-infrared spectrometer that we used in this field demonstration was actually a spare unit from LCROSS. It was kind of a fun little connection right there to LCROSS. We had this spare instrument [Resolve]. I thought it would be a good idea to put it on, because it could help us identify composition in ways that they weren't.

To illuminate the samples, we literally went down to Home Depot and got some flashlight parts and built up a lamp, a ruggedized flashlight, that eventually evolved into what's on the NIRVSS [Near Infrared Volatile Spectrometer Subsystem] instrument on VIPER.

This field demonstration went quite well. We actually buried sheets of plastic out in the sand there up on the volcano and drove a rover, and found the plastic sheets, which mimicked buried water ice in terms of neutrons, with the neutron spectrometer. Then we drilled and we looked at it with the near-infrared spectrometer. We really were demonstrating many of the pieces that are VIPER now. That was in 2012.

A couple folks from the Advanced Exploration Systems office, AES, came out and actually witnessed it as well. They were really impressed and said, "Let's move forward with this as actually a flight mission." We were like, "Wow, yay, this is it, we're going to get this mission to go." Again, that was in 2012.

That was the start of the Resource Prospector concept. It initially started with again a Canadian-provided rover, with a number of instruments provided by Kennedy, Johnson [Space Center, Houston, Texas], and Ames [Research Center, Moffett Field, California], and eventually a drill from Honeybee Robotics [The Regolith and Ice Drill for Exploration of New Terrains, TRIDENT]. We pursued this concept from 2013 to 2014 or so, and actually had a mission concept review. This was all again in the human exploration side of NASA. It was still owned and managed by AES.

In 2015 we actually built a ground prototype of the rover that had prototypes of the instruments in it, including the drill and sample handling system, etc. This rover and instruments and everything else was then operated remotely from Ames in the Rock Yard at JSC. This entire effort, we called it RP15 [Resource Prospector 2015]. We literally went from a design goals requirements to operating the actual hardware in the Rock Yard in one year. It was a phenomenal undertaking. I should say at this point CSA had to pull out from providing the rover. CSA just didn't have the kind of budget to be able to support that. So, we looked to Johnson to see if they were interested in providing the rover. Absolutely they were. That was in the late 2013 timeframe I believe.

They built the rover and integrated the instruments in 2015 and that was phenomenal. The systems engineering group that helped lead all that got the [NASA] Systems Engineering [Technical Excellence] Award for the year, which is a very high honor. That was great. That was RP15.

Now we were still within AES. We were working with a number of lander concepts too. Okay, we've got the rover. Johnson is going to build the rover. We've got the instruments. How are we getting there? For a while we were working with Marshall [Space Flight Center, Huntsville, Alabama] on a lander concept. But eventually to get this thing to go, and to get to the final hurdle of okay, you're actually flying, we looked outside for lander providers, and worked for about a year with Taiwan to provide the lander for the Resource Prospector mission. This was all worked through the State Department and NASA. It was a fairly significant political undertaking. We had a number of members travel out to Taiwan several times. Our counterparts from Taiwan visited us here in the U.S. We were making good progress there.

But still senior management in what was HEOMD [Human Exploration and Operations Mission Directorate] at the time still did not give the green light for RP for actual flight, despite all this work going on.

In 2018 or so, they decided for a number of reasons, mostly financial, on the reorganization of HEOMD, AES was getting kind of reorganized, and what they were doing was getting moved into other directorates within HEO. They decided to move Resource Prospector into the Science Mission Directorate, SMD.

That was not very well coordinated within the Agency. The AA [Associate Administrator] of SMD at the time, Thomas [H.] Zurbuchen, was even out of the country when the transition was being made. There was no budget alignment made at the time. Really the RP Project was orphaned at that point, and without anybody actually picking it up. In [May] of that year, the RP mission concept was canceled officially.

That said they looked at the instruments that were being built for RP, and an independent review panel looked at it, and recommended that SMD pick up those instruments and continue to work on them, because they were good instruments to have for these applications. They were already so mature that just a little bit more work would really get them ready for flight.

The drill, the mass spectrometer system, the neutron spectrometer, and the near-infrared spectrometer system all continued their work forward. They got funding for another year to continue maturation of those instruments. But they were instruments without a home. RP had been officially canceled.

Then it was however a few months later that a new concept started to come up. Steve [Steven W. Clarke] started talking with the management of RP, Dan [Daniel R.] Andrews and myself. Steve Clarke wanted to see if we could actually revisit sending a rover mission. At the time it was in the Lunar Exploration Program, what would eventually become ESSIO [Exploration Science Strategy and Integration Office] right now that runs the CLPS [Commercial Lunar Payload Services] Program as well. They basically kind of quietly started exploring what we could do. Maybe not a full-up RP, but is there something a little bit smaller, a little bit lighter, a little bit faster in terms of development that we might be able to do, because this is really really a good idea.

We pursued that for a number of months, just a handful of us, key individuals from [NASA] Headquarters [Washington, DC], key individuals from the RP Project, and came up with a plan, and presented those ideas to Thomas Zurbuchen. Eventually that's what became VIPER.

About a year after RP's cancellation, VIPER was officially born, if you will, and moving forward. VIPER looks a lot like RP did. It had some simplification of how samples are handled. It got rid of some of the more complex oven crucible baking devices that RP had. It's a little bit simpler mission in terms of its payload. But otherwise, it's very much the same beast.

JOHNSON: Were you talking about at that time using commercial partners for launch? Did that come later?

COLAPRETE: Not on RP. But once VIPER was born yes. That came up from the get-go. That was a big push from the get-go, what kind of things can we do to really innovative here. One of them is well, why don't we use the commercial landed systems for launching VIPER.

JOHNSON: During that time were you still working with the NIRVSS instrument also while you were trying to track through this?

COLAPRETE: Yes. Absolutely. Because the instruments for RP were continued even though the mission concept itself got canceled. The instruments got funding to move forward. The NIRVSS instrument along with MSolo [Mass Spectrometer observing lunar operations] and NSS [Neutron Spectrometer System] continued to mature. Yes. NIRVSS continued to get matured as it went along.

The person who came to Dan Andrews first, and then Dan roped me in to talk about well, what if we resurrected RP in something else, was Steve Clarke. He was instrumental in standing up VIPER. Him and then also Ben [J.] Bussey, who was his Program Scientist at the time, they were really instrumental in making VIPER happen.

NIRVSS was always being worked on and developed. At about the same time as there was discussions about VIPER becoming a thing, there was a solicitation that was put out by the CLPS Office, the Commercial Lunar Payload Services Office, for any and all ready to go on the shelf or nearly on the shelf instruments to fly on commercial landers. We applied, NIRVSS, and said, "Oh yes, we've been working on this instrument for a long time. It's an instrument without a home." Sure enough, we were selected for one of the first CLPS landers on the Astrobotic Peregrine-1 landed mission. Along with the other then RP instruments. So MSolo, the mass spectrometer, and NSS, the neutron spectrometer. All those instruments that were on RP and got continuation funding to continue to be matured all got selected to fly on one of the first CLPS missions.

That was great. Then actually we all got selected to fly on a second mission as well. However, that mission, the provider of the lander has since pulled out, and they're trying to remanifest those payloads. But regardless, those RP instruments moved forward. Before there was VIPER, they were getting slated to be built and flown on these commercial landers. It was a very astute move by NASA Headquarters to say, "Hey, we've invested in these instruments. Now is a great time to be able to fly them. They're ready to go. We need ready to go payloads for quick turnaround on these landers." So that's what happened.

As we started to put VIPER together, I saw this as a really good thing, and argued with the program office, or Headquarters—not argued against but argued to them and the VIPER project management—that the development of these instruments for the CLPS landers is a fantastic risk buydown for the instruments for VIPER. So much so that I think you can actually not even have a payload element lead manager, payload management element within VIPER. You can actually really flatten the management structure within VIPER to do that.

They agreed, and one of the reasons why I argued that is Dan Andrews was looking at me to be the payload manager, and I didn't want to do that. We don't need to do that. It was again really a different turn from how things are traditionally done. But then we argued. I'm saying argued. But we presented that to the independent review team, the VRT, VIPER Review Team, led by Geoff [Geoffrey L.] Yoder. He liked that idea too. Then ultimately Thomas Zurbuchen has become a real big fan of it. He's looked at how each of these leads have put together instruments for CLPS and in doing so just retired so much of the technical risk on these instruments prior to use on the primary mission VIPER. I think it might be a good model going forward for other lunar missions.

That's how that all came to be. A couple other really interesting points about the payload that I think are worth capturing is that a lot of what we saw on LCROSS in terms of the payload and the use of commercial off-the-shelf instrumentation, modifying that COTS instrumentation for spaceflight, that process which allows for a very rapid prototyping and delivery of an instrument for flight, we saw that applied for then Resource Prospector but also the CLPS and VIPER instruments. MSolo teamed with a commercial mass spectrometer company, INFICON, to ruggedize one of their mass spectrometers for flight. The NIRVSS instrument through an SBIR [Small Business Innovation Research] ruggedized a commercial near-infrared spectrometer built by Brimrose Corporation for flight. There's a lot of that LCROSS process that found its way into VIPER in terms of how the payloads were developed.

I think that's actually a good thing that that process continued to go forward. It allows MSolo to be built for a relatively incredibly inexpensive price. Likewise, NIRVSS. We can turn around these instruments very quickly now because they actually have adopted a number of commercial practices in terms of how things are processed and built and so on. It's an interesting connection back to LCROSS that's within VIPER.

JOHNSON: Like you mentioned, it's a model going forward to get things done and to try to make sure that things can move quickly, but also be tested and retested before they go into some of the more maybe costly flights like VIPER.

COLAPRETE: Yes. Like VIPER. Exactly. Now it's interesting. On VIPER it's actually caused some difficulty in that the instruments were so mature relative to the rover that there's optimization that's sometimes difficult. The engineers love that you have a very well known, very mature, very stable interface on your instrument. That's great. However, once they start to accommodate that within the rover, if they run into difficulties, if it wasn't so mature, they could come back to the instrument and say, "Oh, could you just change that a little bit? That would make our life a little easier." Of course we're saying no. We're built. We're done. In that respect it actually creates some difficulties that are put onto accommodation at the rover side.

But otherwise it's fantastic. Being able to fly the instrument prior to VIPER, we won't learn in time to affect the design for VIPER. The VIPER instruments are literally already built and getting delivered very soon. However, what we will learn is how the instruments really behave in the lunar environment. That's really important. Every instrument, you can characterize it as best you can in the laboratory. But once you get it into the space environment there's subtleties, and sometimes not so subtle differences that you saw in the lab. You need to account for those.

Being able to actually see how these instruments operate on the Moon is going to be a big help in terms of preparing ourselves for VIPER. VIPER, we want to hit the ground literally running, or rolling. We want to get the instruments operating right away. Start taking samples. There's no commissioning period. Usually in a mission there's a monthlong commissioning period for the instruments or something like that. We don't have that luxury. So really these early flights of the instruments actually provide a commissioning of those instruments, if you will, and allows us to really be prepared operationally for VIPER. It's great in that it forces you to build the design, test it, and qualify it early. Buying down risk all across the board. But also, once you get to fly it early, you get all that operational experience that immediately flows into the next mission. There's a lot of benefit to this approach for flying these instruments early.

JOHNSON: The Peregrine lander, that hasn't flown yet.

COLAPRETE: Not yet. We are integrated on to the lander deck. We have electrical interface testing like in a week or two. Then final functional testing. I haven't seen an official launch date yet, but all indicators suggest early next year, so soon.

JOHNSON: Let's talk about the instruments and NIRVSS. Jackie talked about MSolo. But let's run down how they work and how they will work on these landers and then again on the rover, and how they'll work together, and what they'll be looking for.

COLAPRETE: Sure. There are three instruments that are what we call the prospecting instruments. They're on continuously while roving, while drilling. Any time we're on the surface we're trying to keep these instruments on. One of the reasons for that is a lot of what we want to do on the Moon is mapping where volatiles are, where water is. That requires a certain density of coverage to actually build up the statistics sufficiently to be able to predict where potential water is. That's why we want them on all the time. You can't just turn them on once in a while. You really need them on while you're roving to build up the areal density coverage.

The three prospecting instruments are NSS, the Neutron Spectrometer System. It is sensing neutrons that are leaking out of the regolith. The neutrons are generated by galactic cosmic rays coming in, interacting with the lunar regolith, the lunar soil, and kicking off neutrons. As those neutrons then leak up out of the soil they can get modulated by other materials in their way, and one of the great modulators for neutrons is hydrogen atoms. If there's hydrogen in the dirt as well, you'll see a decrease in the number and a decrease in the energy of the neutrons that are leaking out of the soil. That's how the neutron spectrometer works. It's sensing those neutrons coming out, measuring them in two channels, basically an energetic and not so energetic energy spectrum. By looking at those it can deduce the total amount of hydrogen in the soil and also the approximate depth of where that hydrogen is concentrated. It's what we often refer to as the bloodhound of the rover. It actually sticks out ahead of the rover and as we drive it's sensing down to about almost a meter, 80 centimeters to 100 centimeters deep, neutrons that are coming up out of the ground. Then in real time, calculating; we calculate the potential hydrogen in the subsurface.

Then there are two other spectrometers that are looking down under the rover. There's the MSolo instrument, which is a mass spectrometer system. Then there's the NIRVSS instrument. Really, it's a combination of three sensors. It's a near-infrared spectrometer, a camera system with seven colors of LEDs [light-emitting diodes] that range from the ultraviolet through the near-infrared, and a thermal radiometer which provides surface temperature observations.

MSolo and NIRVSS are constantly looking, again operating all the time, and looking at the surface, just the surface, as we're roving along. What's great about these two instruments is the NIRVSS instrument is providing images that provide context for those two instruments. What are we looking at when we're looking? Because the mass spectrometer is obviously not an imager. It doesn't really know what it's looking at in terms of the surface. Are we going over some certain kind of soil or some kind of rocks or whatever? NIRVSS provides that. Then the near-infrared spectrometer, what it is really sensitive to is solid forms of volatiles, for example water ice. It can measure water ice, the solid form of water, very well. It can also measure water that's trapped in the rocks, like if it's adsorbed or locked into the matrix of the soil it can measure that very well.

What it cannot measure well is water in its vapor form or gaseous form. Just because it doesn't have enough pathlength to be able to do that to the surface. However, that's where MSolo comes in. MSolo is very very good at measuring any water vapor gas. As it's roving it's looking for any gases that get kicked up underneath the rover. It can measure those gases in such sensitivity that it can actually determine isotopic ratios of some of these gases, which is really key to understanding the origin of the gas. Water for example, if it measured the deuterium-to-hydrogen ratio in water vapor, it could give you clues as to where that water actually came from: comets or asteroids or the solar wind, etc.

The NIRVSS instrument and the MSolo instrument really are super complementary. It's looking at, for example, water. Not just water, but water both in its solid form and various solid states and also its gaseous state. Those are operating continuously.

Likewise, we're measuring temperature continuously with NIRVSS, so we know what the surface temperature is. Are we not seeing water because it's too warm? Or is it cold enough to retain water and we're just not seeing it? That's an important contextual piece of information we want to have. We know temperature is critical for the stability of water. What is the temperature so we can actually understand better if it's just not there for some reason, but cold enough to retain it, or maybe it's just too hot, that's why we're not seeing it? We want to understand that.

All those instruments are on continuously working together, measuring things in a very complementary way, building a map of subsurface hydrogen and surface water as well as other volatiles. Likewise, the NIRVSS instrument is imaging continuously at each waypoint when the rover stops to take new images. We call that a waypoint. It takes multiple-color images with its LEDs, which gives us information about the mineralogy of the soil. That's the rover in what we call prospecting mode.

Now there's really two other instruments on the rover that are being used for science. But they came to us via the rover itself, via rover engineering. The first is the camera system. All the navigation cameras and hazard cameras are excellent scientific tools. We've worked with the rover navigation team to incorporate those instruments and those observations into our science planning and scientific analysis. We now have a scientist, Ross [A.] Beyer, who leads the visual imaging system or VIS. It is the scientific adaption of the navigation cameras. We're using those to understand morphology, textural differences. We're looking at wheel tracks with them to understand load bearing strength and other geotechnical parameters. We've turned the camera system into a scientific instrument itself.

Then the other rover system that we've turned into an instrument is the inertial measurement unit. The IMU is in the heart of the rover, and it measures basically the attitude or pose of the rover, its roll, pitch, and yaw, and that's what it's meant for, and that's what they're really interested in using it for. However, it also has accelerometers. The IMU has accelerometers. As it's roving, those accelerometers are reacting to the actual gravity field of the Moon. If you're careful and smart enough, you can use that data to sample the deep soil many many meters below the rover, and get at variations in gravity that are associated with, for example, varied ejecta blankets or blockiness, etc. The depth of the regolith. We're actually, while we're roving, making these deep sounding measurements below the surface.

This idea came to us when we added eight new science co-investigators. We had a callout. This was really unique to VIPER too, to build up the science team and to more broadly include science community involvement. We put out a call for proposals for new science team members. Now, often missions will have what are called guest investigator programs or something like that. They're usually added scientists that come in late in the mission development, sometimes even after the mission is launched, to add science value, do extra science, and that's great. But what we really wanted was these scientists to come in very early so they could influence the design of the mission and contribute in a much more integrated way and be part of the science operations team.

This was never really done before. We worked with Headquarters to make this happen. Sarah [K.] Noble, who's our Program Scientist at Headquarters, really spearheaded this at Headquarters. We got eight new scientists on board on the team. They were selected last December, so they've been on the team now for about seven, eight months, and they're very much integrated into the team now. One of those coinvestigators has been working with the IMU data on Mars 2020 [Perseverance rover], and he had this idea. Now the IMU on Mars 2020 was never intended to do this, but he went ahead—his name is Kevin Lewis—he went ahead and tried it and got really useful results out of it and got those results published in *Science*. He was selected as a new team member and brought these ideas forward. He and I worked with the navigation team, who actually controls the IMU engineering, and proposed a number of extra calibration steps that will help us do these measurements on the Moon. The rover calibration team was thrilled. They were like, "This is so cool, yes." This is a great example of how the new science team member was actually able to come in early enough and influence the design of the mission itself and the testing. It's kind of ironic in that the IMU we're using on VIPER is the Mars 2020 flight spare IMU. He's very familiar with it and that's all great.

The cool thing with this IMU unit in my opinion is when we are parked and drilling, the drilling percussion actually is sending sound waves down into the soil. They are planning on using the IMU with its accelerometers to listen to the sound waves coming back up. It will be a seismic experiment, the first of its kind since Apollo, and the first ever at a lunar pole, measuring the sounds coming up from below the surface.

Why that's important is the sound waves are very sensitive to water ice concentrations. We'll be able to measure water ice at the 1 or 2 percent concentration level down to several meters deep below the rover. It added a whole new dimension of scale of visibility into the subsurface that we didn't have before. I'm really excited about that, and we're doing everything we can ahead of the mission to calibrate the IMU in ways that will really make that science more effective.

There's the three prospecting instruments and then the camera system, the VIS, and the IMU. Then of course there's the drill. The drill is an instrument unto itself. It's not just a sampling apparatus. It is a scientific instrument. I know you talked to Kris [A. Zacny], so you probably heard all about it. From all the experience we had with RP with testing we did at Glenn [Research Center, Cleveland, Ohio], we actually conducted four or five tests in thermal vac chambers at Glenn with NIRVSS, MSolo, and versions of the TRIDENT drill that we really got to a nice, sweet spot with the drill in terms of its optimization. It has two temperature sensors in it, one at the tip and one about 20 centimeters up. It has a heater at about the same level at 20 centimeters' height. Not only does it drill and bring up samples for NIRVSS and MSolo to witness and observe and look for water ice, but using those temperature sensors we can measure the subsurface temperature, which is critical.

We can actually use the heater and those two temperature measurements to understand the thermal conductivity of the regolith, which helps us with all of our thermal modeling of the lunar soil. Also just understanding the force necessary to drill tells us about the geotechnical properties of the regolith, including potentially if we find a place with significant ice is it cemented or is it just loosely intermixed with the grains. There's just a ton of science that's coming out of the drill alone. But of course, the samples it brings up every 10 centimeters, MSolo and NIRVSS will look at, being able to identify any solid water ice or any water ice vapors that are coming off. Again, because NIRVSS and MSolo look at both sides of the same coin for water vapor, we get a very complementary set of observations that make the result that much more definitive. When we compile all of our information together, we'll get a really tightly locked solution for the total amount of water that was in the cuttings pile. Hopefully that answers your question.

JOHNSON: Yes, it does. That's a lot of good information. One of the questions that brought up, when you mentioned the co-Is, and you said that it was to include this community science environment but it hadn't been done before. Who or why did your team decide to do this? Was it to make sure you could get as much science done as possible at this opportunity? Or to see things from different perspectives that your team may not have been examining?

COLAPRETE: Yes. It's a great question. In part it's rooted back in the move of Resource Prospector from AES into SMD. When RP, Resource Prospector, was in AES and I was the Project Scientist, they had a very different attitude towards how a team was built. It was just different from what SMD does. The Headquarters executive told me that they looked to me as the Project Scientist, lead scientist, to build the science team we thought we needed.

I was given authority to go out without competition, find the talent we needed, and that's basically what I did. I said, "Okay, we need somebody who's really good on thermal modeling. Who's the best lunar thermal modeler I know of?" I go and I talk to them and bring them on. Like for engineering. The science was treated much more like an engineering subject matter expert if you will. We need the best SME. Who's the best SME? Let's go get him or her.

When we moved to SMD, that is very counterculture to what SMD does, where almost all science missions—not all, but most—are competitively selected. That was an issue within some parts of Planetary Science Division. They did not like the fact that not only were they getting a directed mission, a noncompeted mission, but the entire science team was noncompeted. Again, Sarah Noble, who was really instrumental in making lemonade out of this potential basket of lemons, saw that there was this unease, discontent within Planetary Science about how VIPER came to be.

She and I talked about this, and I said, "Look, I would love to have more scientists and more science input." But at the same time one option that was put on the table was we're going to recompete the entire VIPER science team. I explained to Sarah that that would be infinitely disruptive. We are working right now. The science team is really important early on in a mission because they are helping to define the principal, the top-level requirements that the engineers are going to try to achieve. I said, “If you stop this right now and go and do a four-month or six-month proposal process to find a whole new science team, that’s really disruptive. That’s not very good.”

She agreed and she talked to Thomas about it and he totally agreed too. But we all agreed that one, bringing new science talent in would be a great thing, and two, we should be responsive to that criticism that there was no competition. Usually science teams have some level of competition.

We came up with this idea that first of all each of the existing science co-Is on the VIPER team I brought forward to Thomas with their resume and their role on the project and asked him to agree that they should stay on. Basically, bless them if you will, approve them at his level. That formally got Thomas’ approval for the existing science co-Is, and they were all approved without any issue.

Then Sarah and I came up with this plan, really mostly Sarah. Let’s compete and add six to eight or something like that. She and I threw around numbers of how many science team members. I said, “Great. Also, however, the science team members really need to be aligned with the goals of the mission.” She completely agreed. At the same time, because VIPER has a very unique science operation and a level of science integration into the mission, they had to be willing to be a part of that too. We didn’t want scientists who were just looking to get data and process data. That’s what often a guest investigator scientist does. They just want the data. I’m not knocking this. This is some people’s operational viewpoint, “I want the data, I want to do the science with the data, I'm really not interested just professionally in being integrated into a mission."

I talked to Sarah about this. "I think these people really need to be integrated." She agreed, so we put together a proposal call that had these points in it, that said, "We're looking for new scientists to join the team. This is not a guest investigator program. We need scientists that align to these areas of expertise, that align to our mission goals, and who are excited to be integrated into the mission, including helping with operations, being on console, working on mission planning, development, etc."

We put that into the call that this is not you just getting some data and going off and working on the data. That took a while to put that together. Sarah championed it at Headquarters. Again, it had to get through that whole Headquarters review process, being different, just one more thing that was different about VIPER. Took a little while, but it finally went out, and we had over 50 applicants propose to it, which was fantastic. I was not a reviewer. I was deemed conflicted. However, I was able to assign, my two deputy project scientists were allowed to participate in the review process, to make sure that the people were really aligned to what we needed for the mission. That all went really well. When I saw the final list of who proposed and what they proposed, I do not envy the selection committee. These were so many good proposals and so many excellent people that I would love to have had as part of the mission. But they only had so much money, so they selected these eight. They're all absolutely fantastic.

JOHNSON: Let's talk about the rest of the team. You and Jackie of course were part of Resource Prospector working on those instruments. Did the rest of the team, the other people that were working on those instruments, did they follow also into this mission? You're working the science side, but then like you said, the engineers are building the rover, and of course since you're ahead of them, they're having to incorporate your instruments into that. But then I read that you also have Earth geologists from the U.S. Geological Survey [USGS] on your team. Talk about mixing all these different people from these different areas together on a team for this project.

COLAPRETE: Yes. A lot of the same managers and engineers that were part of Resource Prospector and worked on Resource Prospector for two or three years or more even carried forward to VIPER. A big part of the team has been working on this for five, six years plus. Then a good number date back to 2012 field campaign. Jackie for example, but Rick Elphic who's the lead for the NSS instrument, myself, and a number of the NIRVSS team date back to that field test. There are a good number of folks that are on the instrument side who go back to the 2012 field demo.

But when we moved the rover from CSA to Johnson in 2013ish or so, a lot of those engineers have carried all the way forward, and management of the rover team. There's been a fantastic continuity in personnel. I think that's really important. When we lost RP and literally took a year off from the rover development to VIPER, it was basically a full year before VIPER was able to get stood back up out of the ashes of RP. All those engineers at Johnson could have gone away and got onto other projects and got onto other things. Likewise at NASA Ames.

Often in an engineering organization individuals are matrixed. There's a project and you're assigned to that project. When VIPER stood back up, the management at Ames and at Johnson were so good to say, "No, we're going to get the band back together." Key individuals like Bill (William J.] Bluethmann there at Johnson who leads the rover, Dan Andrews at Ames, they were able to retain essentially, I don't know, I guess 80 percent of the team from the RP days to at least get going and start on VIPER.

Of course, there's been changeover and things come and go over the last few years. But for the most part we retained all the critical talent and knowledge and history. All that was retained. That was key to VIPER being able to get a really good running start. The instruments as we discussed were already off and running and being built for CLPS landers. They were really well on the way.

The science team from RP was still pretty small. We built it up with these eight new co-Is. But when VIPER came about, I was the only project scientist. Really on VIPER I'm not a project scientist per the usual definition of project scientist. Usually SMD has PI-led missions. This is a PM-led [project manager-led] mission. I have the title Project Scientist, but really, I perform all the duties that a PI would. Meaning develop all the mission level requirements, manage the overall science team, science operations, delivery of data. Project scientists usually don't do all that. They assist the PM usually in interpreting science requirements, etc.

I needed help. As we started to build up VIPER, I looked to bring on two deputies, and I looked in two specific areas I knew I wanted added expertise. One was in data archiving, analysis, and overall help with project management. I asked Kimberly Ennico-Smith who was Deputy Project Scientist for New Horizons, and she was Project Scientist for a while for SOFIA [Stratospheric Observatory for Infrared Astronomy] as well, if she would join the team, and she said yes. Now Kimberly leads the data archiving effort for VIPER, which is a huge effort. Data archiving is often underappreciated in terms of the level of effort to do a good data archive. She also helps with outreach activities, E/PO [Education and Public Outreach], and leads a lot of the just general project management activities.

Then the other person I asked to join was Darlene [S.] Lim. She has a background in science operations. She's conducted and led a number of very complex field expeditions. Everything from submersibles to rover field, and so on and so forth. I looked to her to lead the science operations side of things. Because VIPER has got such a unique opportunity to be operated differently, I thought she would bring these really novel innovative approaches to the idea.

That was a big difference from RP to VIPER. One, the science management team tripled. That's been huge. The three of us really work as equals. When any one of us is out for whatever reason we know the others have our back, and that's critical. That level of trust and knowing you can step away and the sky is not going to fall because others are holding it up.

With them in their roles, and really it was important to me that I give them the latitude and the authority and confidence to build what they needed to build to make it work, they brought in other people as well. On Darlene's side she brought in somebody she's worked with for a number of years and has a background in sociology. Zara [L.] Mirmalek is her name. She has worked with the MER [Mars Exploration Rovers], with United Airlines, a number of other large institutions to understand operational dynamics within a team. She's actually Darlene's deputy on the science operations and integration team that looks to really understand the organizational structure and dynamic to build a very unique science operations team.

Then Kimberly brought on Noe Eldar Dobrea, who is an excellent spectroscopist, he's also on the NIRVSS team, to help with data archiving, because he just knows the PDS [Planetary Data System] data archive. It was really kind of cool just to watch how that team at the top blossomed and expanded in a really good way to support VIPER much more than what we were ever doing for RP. That was really cool.

Then we brought in a number as you know, the new science coinvestigators. Then also we're growing in a different way and that's through collaborators. As I mentioned, there was a great number of people that would love to have been brought on as science coinvestigators but couldn't. However, per the stipulations that we've agreed to with Headquarters, we have a document called the rules of the road that stipulates how the science team behaves in terms of disclosing information, working with others, presenting data, etc. It also describes the various roles within the science team, everything from the project scientist to the instrument scientists to coinvestigators and collaborators. A collaborator can be brought on, a science collaborator, if they have a science coinvestigator sponsor.

Now a collaborator isn't funded directly by the project. However, they can work with the project and be integrated into the project as long as, like I said, they have a coinvestigator who is funded by the project to sponsor them and to be responsible for them, meaning being responsible for their adherence to these rules of the road. This isn't really novel. It's been done on a number of missions in the past. But I've been able to work closely with Headquarters to use that to bring on a number of people who weren't selected, who had really good ideas, just weren't selected, and some who didn't even propose who had really good ideas, to expand even more broadly the science reach. So, the VIPER science reach is ever expanding, and now we have a number of collaborators who are coming on and working closely with coinvestigators supporting the project. Just again expanding the value of VIPER.

One of the things I say frequently is VIPER science has already begun. We're already doing science now. Science doesn't begin when we land on the Moon. We're already actually publishing papers based on work we're doing for VIPER, science papers. Collaborators are already doing work and publishing work based on work they're doing with the coinvestigators. We didn't have this for RP.

That was one of the big things. Once we got to VIPER working with Sarah Noble was a big part of it. We've greatly expanded the science reach beyond what we ever had with RP. Again, that's because where we live now is in the Planetary Science Division. Our primary purpose is science. When we were in AES, it wasn't. Our primary purpose was resource exploration.

The last thing I'll mention is you mentioned terrestrial geologists. That was a big part of it actually. When we were in AES, I mentioned resource exploration, I for a long time appreciated that we've been doing resource exploration on Earth for a long time, and a lot of money has been put into how to do it. How to take measurements and analyze those measurements in a way that you can go to a bank and ask for a $2 billion loan to build a mine. That's high stakes data acquisition and analysis.

Actually, when we were still Resource Prospector, I reached out to a colleague at USGS. We have USGS actually colocated with us at NASA Ames. His name is Jon [Jonathan] Stock and I talked to him. I said, "I need a geo-economics expert on this team. Do you have somebody in mind?" He did. His name is Josh [Joshua A.] Coyan and he's with the USGS, works out of Seattle. His job is resource economics, geo-economics. He takes data and builds various models of predictivity so he can have a model and tell you the likelihood you're going to find oil in this area or that area. He does this for drilling companies, for oil companies, for mineral rights, whatever. They then take his results and go to the bank and ask for the $2 billion loan.

He came in on the team and was one of the original coinvestigators that I got approval from Thomas on. That's fantastic because he just brings this whole dimension that is new to planetary science. I like to think of it as applied planetary science, where he's taking what he's done for the Earth and all the techniques that have been developed over many many years and adapting it to the Moon.

One of the new coinvestigators that was selected was also from the USGS and is a terrestrial resource mapping expert. So yes, we've got two USGS persons on our team. This is one of the most exciting parts for me, how we really are adapting techniques for the Earth and applying them to the Moon in a way that other missions have not done.

VIPER is a mapping mission. It is conducting itself in a way that no other rover has conducted itself on another planetary surface. The Mars rovers don't go out to an area and then start zigzagging back and forth. That would be crazy. They're interested in finding specific rock samples for curation. At least Mars 2020 is, for return to home.

But VIPER is really trying to build what's called a prospectivity map, meaning what are the prospects for finding water in this location, and then using that data to extrapolate to the rest of the Moon. To do that you need to make measurements in a certain way. These folks from the USGS understand how that's done. They're bringing that knowledge and expertise to the project and adapting it for the Moon. It's not a one-to-one adaption usually. There's always little things you have to change because the two worlds are different. What we're starting to even see now though is some of the ideas and concepts and even some of the technologies that we're adapting for the Moon are starting to find their way back to the terrestrial companies. They're seeing value in what they're doing on Earth to what we're doing on the Moon. It's becoming a two-way street. I think as we progress down this road for sustained presence on the Moon, that feedback back to terrestrial operations and technologies and whatnot is going to increase more and more. It's really kind of fun to watch this ecology develop through VIPER.

JOHNSON: You mentioned the rules of the road, the document. Is that unique to VIPER or is that something that most science missions have?

COLAPRETE: Most science missions have that because you don't want somebody to run off with some data and take credit or publish too early. It's meant to protect individuals' intellectual proprietary information as well as data. But it also is meant to build a structure and understanding so that you can manage more broadly the science team. It's signed by Headquarters, the Program Scientist, and by the Project Scientist or the PI, and then the rest of the instrument PIs.

We actually thought at one point about having the PM sign it, because VIPER is PM-led. But after conversations with Dan Andrews and Sarah Noble we decided no, no, let's keep it focused, science centric. But no, it is not unique. We actually borrowed ours from the mission Lucy [spacecraft launched to explore the Trojan asteroids] and adapted it from there. It's got a number of very unique things to VIPER. For example, one is there's a clause in there that if we get information on a particular piece of hardware that is deemed proprietary to the manufacturer of that hardware, it stays within the science team and is not to be released. That was specifically put in there so that we could get IMU [Inertial Measurement Unit] engineering data that is normally not an instrument that the scientists get to play with to the science team, so the science team could begin doing calibrations. The IMU is built by Northrop Grumman. They said, "Oh, you can put that in your rules of the road?"

I'm like, "Yes."

"It's signed by Headquarters and you?"

"Yes."

They're like, "That's great. We'll give you the data." It's a tool, it's a living document too. It's not something you put in place and it never changes. It's meant to adapt to the needs of the mission to just really optimize, one, protect the scientists and their ideas, and two, to optimize the likelihood of success for the team.

JOHNSON: The other thing you mentioned made me think about our conversation about LCROSS and how in the middle of the night, when you were having the press conference, you were starting to get information back. There was a lot of discussion on whether you should announce it or not or wait like normal for everything to come back and then the publications come out, which is usually several months, a year later. But you said that on VIPER there's already papers being published. The science has already started. Is that something really unique for this type of mission? Or is this because of the type of mission?

COLAPRETE: I don't think it's entirely unique. Other projects have published similar type papers. Often these papers are either predictive papers, I predict we're going to see this, or they're summaries of analyses you've done about the environment. The landing site looks like this. That's pretty typical.

What I think is unique about some of the results that VIPER has is that in trying to understand the Moon at the level we want to understand the Moon prior to the mission, a number of new data sets and even technologies to produce those data sets have been developed and used.

For example, there's a process called photoclinometry, or shape-from-shading it's often referred to, that uses images at various illumination angles from the Sun of the same produced terrain to create a digital elevation map. It allows you to build up a 3D model of the terrain using images. Often this is done with stereo images. Most people are familiar with that. VIPER uses stereo cameras to get 3D terrain, but that's usually only precise down to several camera pixels. If your camera has got 1-meter resolution, your terrain model will have a resolution of maybe 3 meters or 4 meters. The shape-from-shading technique that was developed at NASA Ames by Ross Beyer and others allows you to make an elevation model at the native resolution of the image. So, if the image has got 1 meter per pixel, then you're going to get a terrain model at 1 meter per pixel. That's really really enabling, if you're trying to plan a rover traverse, having that kind of resolution, understanding slopes and craters and things like that at resolution, are really significant. That's hugely helpful.

But what's interesting too is we had never made DEMs [Digital Elevation Models] like this of the Moon. VIPER actually supported the development of this technology, the maturation of it. It existed, but it had never been applied to the Moon. Then once we had that and the scientists started working with the data, they were discovering things about the crater population that were unexpected and actually not predicted.

One of our science team members, Caleb Fassett, who's an expert in crater morphology, was floored quite honestly by what he saw in the new data set. He's like, "There's some process we've never appreciated here before." We discovered something that we never knew was going on at small scales with craters because of the data set that we needed to help plan our traverses. That's an example where I think there's new science coming out completely unanticipated. It's one thing to say, "I described the landing area. It's got so many rocks and so many craters." But this is something different. This goes beyond that. This says, "In our description of that we discovered a whole new process that's occurring on the Moon, a physical process that no one's ever talked about before." So that's pretty exciting actually. That's an example of how VIPER science is already being conducted.

JOHNSON: One of the things you said last time when you were talking about in LCROSS and the decisions made to try to get some photos inside the crater, and they were the deepest photos ever captured because of the way you were adjusting things in real time. You made the statement that that's been carried forward into VIPER as far as working in real time. Tell me what you meant by that.

COLAPRETE: Sure. This is actually one of my ultimate favorite parts of VIPER and I think will be one of the lasting legacies of VIPER, and that's the science operations and integration. That's what we call the science operations effort, science operations and integration. That's key, because the integration, what that's referring to is integrating science throughout the entire mission. By that I mean science isn't at the end of the decision tree. It's up front in the beginning of the decision tree, the middle, and at the end. It's integrated throughout the entire mission and mission operations.

This is unique in a number of ways to VIPER but it has its roots in that LCROSS moment where science could reach directly to command and ask for an operation to occur without going through a couple other intermediate steps. VIPER science is run through what we call the VIPER Mission Science Center. On other projects, often you'll hear about a science back room. We took that as a derogatory term, back room. A story that Jim [James W.] Head told me—Jim

Head is a professor at Brown University, you may know him, and he was actually one of the scientists who trained Apollo astronauts and worked in the Apollo science back room. He has this great story where on Apollo 15 he was in the back room talking to one of the Apollo astronauts [James A. Lovell] about something he'd seen in the data and was trying to relay what he thought the astronauts actively on the Moon in a sortie should do. Finally, out of exhaustion the astronaut said, "Just come with me. Come with me." He grabbed him and he brought Jim up into the command room, front room, which is totally against all protocol. Can't let scientists in here. But he said, "You go sit down next to CapCom [Capsule Communicator position, held by Joseph P. Allen during that shift], and you tell him what you're telling me. I don't need to be running back and forth here trying to understand what you're trying to get the astronauts on the Moon to do." That's an incredibly valuable lesson there, that in a real-time circumstance, when you are literally working with only time delays of less than 10 seconds, to really take advantage of that you need very tight integration across the team.

On VIPER we have a position in operations called real-time scientist. This person sits literally right next to the rover driver. They are at the very tip of the spear with the rover driver, helping the rover driver do a number of things. When we're on rails driving, meaning we're not in a science station, we're going from point A to point B, they're helping the rover driver keep the rover safe.

They're lunar scientists. They understand the Moon better than the rover driver understands the Moon. They know what a fresh crater looks like, where the distal ejecta blanket might be soft, where oh, those are pyroclastic beads, they could have slip. Or those agglutinates might get stuck. Watch out for this, watch out for that. They can also help with landmark recognition and navigation, and we've already seen this in some of the operation sims [simulations] we've done where the rover driver is like, "Where do I need to go?" The real-time scientist can say, "All right, you see that crater to the right? That's this fresh crater. I can tell in this image. We need to be just to the left of that."

That's one role of the real-time scientist. But when we're in a science station, the real-time scientist is taking a general plan given to them by the Mission Science Center via the science lead. A science lead is another role who's sitting next to the real-time scientist in the Mission Ops [Operations] Center. A general plan for the science we're conducting that day. There's a number of goals, a number of objectives. Certain hypotheses we want to test. Rather than the rover driver just driving from point A to point B, along waypoints kind of blindly, the real-time scientist is there to help optimize and maximize the science return based on the plans given to them for that particular shift. The idea here is that the scientists are integrated into that whole operational approach. They aren't the end of the line. The word doesn't get down to them and they think about it and then write it down. The MER exploration rover is very much this science back-room philosophy where there's a back room with scientists. They chewed on the data. They came up with a plan. That plan then went to planners, and the planners then operationalized it. That works for Mars to the extent that the time delay forces you into a one- or two-day cadence, operational update. For the Moon, we want to make decisions on order of minutes or less. The science team who's helping to make those decisions has got to be integrated across the entire operations team, and that's what we're doing.

In the mission ops center there's a real-time scientist and a science lead. Then the science lead talks to the Mission Science Center via a Mission Science Center lead there. In the Mission Science Center there are science theme leads, so people who are worried about mapping, people who are worried about geomorphology, there are instrument science leads that are paying attention to the science data, helping the rest of the team interpret it if that's needed, etc. They're working as a cohesive unit monitoring progress toward science goals, looking for discoveries, and then reacting to that progress and those discoveries in a way that we can really optimize our time on the surface of the Moon.

In every science station by default we drill three times. Always the third drill site is assumed to be undefined until the Mission Science Center defines it. Baked into the nominal operations are science decision points that occur in real time that are passed on to the rover driver and the mission planning team to execute. That little request for command change from LCROSS has evolved. We've looked across how many different missions have operated, everything from Apollo to the Mars rovers to LCROSS to other orbiters. We really developed a unique system we think that takes advantage of the real-time operations that VIPER has.

This is why the sociologist was brought in because she has this expertise in these kinds of operational scenarios, and we can build the structures to actually facilitate this kind of integration. It addresses Jim Head's story. We don't have to get access to the CapCom. We have a scientist literally sitting next to the rover driver, they're right there.

JOHNSON: Bringing the sociologist in, is that unusual to have someone like that?

COLAPRETE: That is. Yes, it is for NASA. But it isn't for corporate America or commercial sectors. Yes, that is pretty unique. Although like I said she worked on MER, so she has worked as part of other NASA missions. But I don't think other projects or missions have brought in a sociologist this early on to help develop the constructs for communicating and operating effectively in the team.

JOHNSON: Sounds like this mission is using everything available and creating some unique and new ways of doing missions. With the success I'm sure that we'll move on to other types of missions.

COLAPRETE: That's the hope. Yes. Hopefully we are successful. But you're right. We're trying to do things in different ways. I'm on the Mars 2020 team. I'm a co-I on the Mastcam-Z [mast-mounted camera system] instrument. I'm fairly familiar with the operations there and how that goes. Even on Mars 2020 Perseverance they developed some new roles to actually accelerate or catalyze science input into the planning process. I think this is in general a trend going forward. VIPER is just bringing it to the nth degree if you will. I can imagine it's got lots of application to Artemis when you have humans on the surface. Are we going to do it like Apollo where you have to run the scientist from the back room or are we going to have science really integrated like we have on VIPER? We'll see.

It's interesting because there's a lot of, again, ingrained cultural understandings and beliefs that even just for VIPER we had to overcome. Our mission operations lead, he was a flight controller for ISS [International Space Station], and he also worked MER rovers too. Jay [P.] Trimble. He and I had a lot of just heart-to-heart conversations about these kinds of things. He's been great in that he's been open to seeing what it is we're talking about, challenging us. But not being dogmatic. My experience so far is when we've had these science operation sims and we invite some of the mission operator designers to come in and observe, once they start doing that, they're like, "I get what you're trying to do here now. I understand this. This is good. This is good." Now they're really on board.

We still have to remind them every once in a while, "No, no, any time you do this operation, you need to include science lead."

"Oh yes, oh yes, right, right, right, of course." But the team in general as we get into operation sims is really starting to see the benefit of this new kind of involvement of science at every level.

JOHNSON: Yes. Like you said, in Apollo science was an afterthought. It was something they didn't do until the very end. They brought in those scientist astronauts finally. Whereas VIPER, the science is the purpose.

COLAPRETE: Right. First and foremost.

JOHNSON: We've been to the Moon. We know we can go to the Moon. But the science being the purpose this time.

COLAPRETE: Exactly, yes, that's right.

JOHNSON: Speaking of the science, where it lands and where the rover will traverse, how were those decisions made? Were you part of that?

COLAPRETE: Oh yes. I mentioned that we really started thinking about these areas of persistent illumination near areas of permanent shadow regions, dating back to like 2010. The concept that you didn't need a nuclear-powered rover to conduct a mission like this, that you could rely on solar, has been brewing for a long time, since a decade ago. For RP we began developing a process where we looked at various data sets to understand the areas that had persistent illumination, also had direct view to Earth for direct-to-Earth communication, and other constraints, like slopes. Where are the slopes under 15 degrees, meaning we could drive on them? Where are the permanently shadowed regions with respect to the areas of sunlight, com [communications], and slopes?

Over the last eight years, the team has been developing data products, like I mentioned these high-resolution maps, but also tools to be able to automatically search areas that met all the mission constraints, like we need so much Sun, so much com, slopes under a certain degree.

In doing so, it highlighted several mission areas that we thought VIPER could go to. Then we conducted a very detailed process for VIPER of looking at each one of those sites and ranking them in terms of their mission risk, is this a riskier site or less risky site, and their mission opportunity with respect to science, is there more opportunity to get more science here or less. This culminated in a presentation to Thomas Zurbuchen. I led that as the science lead working with mission systems planners and the science team. I first presented it to the project and mission systems engineering to get their approval. Then we presented it to Center management to get their approval. Then we presented it to Thomas to get his approval.

This process actually was very similar in many ways to the LCROSS impact site selection process. It was really similar navigation of constraints and science optimization, and so myself and a number of others who were involved in the LCROSS selection were also involved in this selection, and it was very familiar to us, this process. Yes, we were very much involved with it. The science team along with mission systems planning were the ones who pulled it all together and then presented it to Thomas for selection, and he approved it really without any question. He agreed we chose the right place.

Ultimately it was a balance of hey, we think we can get the most mission out of this area, and there's some nice large old PSRs [Permanently Shadowed Regions] we can go into in this area. Others have often said, "Well, gee, it looks like there's more hydrogen over there, over there." Yes, but you can only have a two-day mission there. There's a balance here. The important thing to keep in mind, and this is something that we frequently need to remind ourselves and others about, VIPER isn't going there to find water. It's going there to characterize an area where there may be water. There may not be water. Whatever that answer is is important to understanding the rest of the poles of the Moon.

Often, you'll find a person who'll say, "Oh, well, the best place to find water is right there." As far as we understand it, that may be true. But what we need is an area where given our capabilities we can map it sufficiently to be able to extrapolate to the rest of the poles, and that was very very important to selecting the mission area. We needed to be able to access the range of thermal environments, everything from permanently shadowed to semishadowed to full Sun. We need to access old craters like 3.5 billion years old, young craters less than 100 million years old. We had to have access to a range of variables so that we could build up as much correlation between these variables as possible. If we landed to a single place that looked like it might be the sweet spot in terms of water, and we drilled once and we found water, that honestly wouldn't have been much better than LCROSS. LCROSS basically did that. Really that was key to selecting our mission area, was find an area that provided that opportunity and kept the rover safe.

JOHNSON: During this process there's been delays because of various things, the biggest being the COVID pandemic. It's halted a lot of work in a lot of places with NASA, beginning in March 2020. Then after that there's been delays because of supply chain problems. Then of course the most recent delay for the launch of VIPER. Talk about some of those delays and how or even if it affected your team, or if you were far enough along with those instruments and getting things ready, and how you worked through some of those, especially the COVID situation.

COLAPRETE: There's an old saying, space is hard. You don't need extra stuff to make it harder. It's hard enough as it is. Yes. A lot of adaption had to occur when the pandemic occurred and the lockdowns occurred. We had to go into a hybrid—not even hybrid, a full remote working environment. From a science point of view that wasn't too impactful. The science team is largely distributed remotely anyways. We were able to manage that fairly well.

The instruments, you mentioned a really important point, were far enough along that the supply chain issues that started to begin maybe a year or so into the pandemic didn't impact them all that much. What did impact them was for us at Ames, we couldn't get onto site for at least a few months following that initial lockdown. So, all the hardware development did pause. We did then return to on-site work agreements and procedures and processes, and those eventually got approved. But that did for the instruments result in a few-month delay at least in terms of the hardware builds, mostly for the early CLPS missions, not for VIPER.

I think in large part the instruments avoided some of the supply chain issues because we had already ordered our parts, and they were coming along.

In the case of NIRVSS it did get hit by a supply chain issue very late in the game just months ago, as we were finishing up for the VIPER unit a calibration called a radiometric calibration. It uses an instrument called a blackbody to supply thermal radiation of a very known quantity, and we use that to calibrate the instrument. We have a blackbody. We were sending it out for recertification calibration, which is what you do. Every two years you need these things recertified. It was damaged on return from the vendor and inoperable.

We then tried to work with the vendor to get it repaired. Because of shutdowns due to COVID and to closures of offices they were consolidating their office into a different region and it was impossible to get in contact with them almost, let alone get this thing repaired and back to us in time.

We started looking at "Well, let's buy a new one."

Sure enough, "Oh yes, we can definitely get you one in about 72 weeks or so." Like uh no. This was really a big deal. This would have made us late for delivery to the rover, even with the one-year delay. It would have made us late. We were really kind of frantic, looking at ways we could change the calibration approach.

Then we came around to learning that a calibration lab at Marshall had some of these units. We called them up and they said, "Oh, sure, we'll ship them out to you next week." They saved the day.

While the buildup of the instruments was not affected by some of these delays, certain operational and functional aspects have been. The delays have certainly impacted the rover team because they were not as far along much more significantly. Probably almost every vendor they're working with has some kind of delay or another. There's not a lot you can do about that. The management team and the rover engineers, they've gone out to the vendors and sat down with them, really trying to build relationships and understand where things can be helped, doing everything they can, and that helps. But there's no panacea to fix the problems that are seen across the world right now in terms of material shortages and whatnot. That's really affected the rover quite a bit.

One interesting thing is there's been a little bit of a benefit in terms of being able to work remotely on the science operations side of things. Because we have scientists who are distributed across the nation and actually across the world in some cases—we have a Canadian science team member—during science mission operations, we need to have what we call a hybrid approach, where we have individuals on-site here at Ames in the Mission Science Center, but also, we'll have people that are remote. They need to be able to participate in the operations almost as if they were there.

Again, being part of Mars 2020, they launched right at the beginning of all this. All the mission science operations were made remote as much as possible, and we actually learned quite a bit from them on how to build that infrastructure and how to put that in place. That's what we're working on now, making sure the Mission Science Center has all the capabilities needed to bring in individuals remotely, see what everyone is seeing there easily in person, and being able to exchange information, ideas, etc., effectively.

We're going to use this a lot because of the way VIPER operations go. We have basically two weeks when the Earth communications is up, we're driving the rover, we're doing science, but every two weeks or so the Earth sets, and we hunker the rover down, we park it in a sunny spot, and we wait for the Earth to come back up. In those two weeks we're still doing science. We're looking at the data. We're replanning. We're rethinking and everything else. But often people aren't going to want to stay in Mountain View, California, for months at a time, so they're going to go home to their families, their institutions, whatever. This hybrid environment, just the general practices of working remotely that we've developed and gotten used to, will be taken advantage of during the mission. I think in that sense it's actually helped a little bit. I would much rather have learned these things on our own accord.

JOHNSON: Right, we all would.

COLAPRETE: Exactly. There's that. Then the one-year delay, like I said space is hard, and then you add all the supply chain impacts. All the CLPS providers, the early ones, have slipped to the right. None have gone when they said they were going to go. It's the first time these companies are building lunar landers. Even these smaller landers with small payloads, there's a certain amount of risk tolerance that's accepted, and that's good in my opinion.

When you're talking about bringing a $500 million or $430 million rover to the surface, the cost value is important. But the strategic value to the Agency, in terms of the data it's returning, is so valuable that I completely appreciate the pause that Headquarters had and then said to Astrobotic, after reviewing their plan, "We would like you to add a few extra tests of your propulsion system to really make sure it's ready."

I'm sure Astrobotic appreciated that. I don't know that. I'm guessing they did though. We're happy too. If you're willing to pay for them, we're happy to do them. Because we want to be successful too. I think it was a really wise decision to say, "Wait a minute. Let's look at what you got. Let's take a breath and do the right thing here."

It's still being nimble. It's still working with the commercial services. It's all the things that we want to do to push forward into this new paradigm, but it's also doing it smartly.

The thing about the Moon is that the seasons, if you want to stay at the south pole, you have to wait basically a full year. You can't go three months later or six months later, to get there at early southern hemisphere spring, you have to wait basically a whole year. That forces us into a one-year delay cadence. For Mars it's a two-year delay cadence. That's that.

Now, all that said, it gives us more time and opportunity to get even more prepared. It's somewhat ironic. We were going to announce our final landing site this last July for the 2023 mission. Then they announced the delay. We knew it was coming, but they announced it in June. It was official in June. We'd been working towards that final site selection for two plus years.

The new final site selection right now in the schedule is this October. It can be that soon, because over the last three, four years, we've developed the tools, the data sets, the understanding, the processes to quickly analyze and assess our mission plans. So that really did impact. The delay didn't impact that all that much, but it does actually provide us potentially some opportunity to go earlier than what we were planning. That's to be determined. Rather than a November launch, an October launch. It has given us from a science perspective more time to get our science operations training done and develop some of the software tools we need. All that time is going to be put to good use for sure from the science side of things.

Then on the instrument side, they're all being delivered relatively soon. NIRVSS is getting delivered in November. NSS is getting ready to be delivered in December. I think MSolo is the spring. All the instruments are getting ready to deliver anyway. They weren't really impacted by the delay, or not a lot they can take advantage of in the delay I should say.

But the rover of course did. To meet that 2023 date there were a lot of abbreviated tests. They were all understood in terms of their increase in risk, but now this gave us the opportunity to back up, reevaluate all those decisions we made for the 2023 date, and add back in extra testing. Add back in extra schedule for vendor delivery delays, which continue. They haven't gone away, but it's made us healthy on the rover side in a number of places as well. From a mission science perspective, it didn't at all impact the science. We're going to be able to do all the same science, and maybe more because we have more time to prepare.

JOHNSON: That's good that it hasn't affected the science. I know we've been going 2 hours. If you have just a couple of minutes, I just have an end question. It shouldn't take but a couple of minutes if you're willing to talk to me a little bit longer.

COLAPRETE: Sure. Absolutely.

JOHNSON: Whatever happens, or whatever we find during this mission, how is that going to help and affect space exploration going forward? It's not just the Moon. It's these techniques, how they're going to apply to Mars and how they're going to apply further on. Talk about why it's important to do this mission and how it's going to affect exploration going forward.

COLAPRETE: Okay. There's a number of reasons why this mission is important. But I think if we look at the two primary goals of the mission it highlights the two prongs, the two thrusts that VIPER is really focusing on that influence or impact the future. The first is understanding the origin of water on the Moon. VIPER is first and foremost a science mission. It will be making completely unique measurements in an area of the Moon that we've never been before on the surface, and really informing in unique ways what water exists there, the form of the water, and where did it come from. That is of huge importance to understanding the lunar history, the Earth-Moon system, and just interior solar system planetary science. It will be really informing science in a way that we haven't yet been able to inform planetary science of the Moon. That's first and foremost.

I like to say LCROSS helped to rewrite the science books. VIPER is definitely going to add a chapter with the results it returns. That's really important because follow-on scientific missions will build off of that. That's how science works. It builds off of previous studies. This is a unique study, so it will be a point of departure for more and more studies going forward.

The second goal of VIPER is to inform in situ resource utilization [ISRU]. This is really important and it has several aspects to it that we've touched on. The way VIPER is being conducted in terms of it's a mapping mission, it's involving terrestrial resource exploration experts who are typically not usually involved in space missions. It is really a launching point if you will for that off-world exploration of resources by the United States. I think that extends to Mars, to asteroids, and beyond. It is a launching point for that whole new paradigm of what I call applied planetary science or off-world exploration of resources.

When I talk to folks at USGS and now also the DOE, Department of Energy, that's how they're talking now. They're talking about off-world exploration beginning at the Moon and extending beyond the Moon. That's really important. The same processes, techniques, and that thinking like I said extends to Mars. Ultimately the same kind of approach will apply to Mars and asteroids and beyond. It is a proving ground. It's a development process too for these other applications, which is really important.

It is a really strategic mission in that how NASA goes forward with its ISRU development and technologies is in large part decided by the VIPER mission. Not entirely but in large part. From a resource utilization point of view, from an oxygen extraction at the Moon approach, there's a couple ways you can do it that are the first two techniques that are really in competition. One is by finding water and electrolyzing the water. The other is by doing oxygen extraction from lunar regolith by baking the regolith and doing hydrogen reduction or other reduction techniques. Right now, both of those pathways are being explored by the Space Technology [Mission] Directorate. Which one wins, or maybe they both win, but certainly a decision needs to be made as to which to pursue for the poles and for the sustained lunar base that we're going to have at the pole of the Moon.

They are looking to VIPER to provide some of the key information to make that decision. We may need—I think we will need—a follow-up to VIPER, at least one, to verify our models and our prospectivity map. Then based on that I think NASA will be able to decide we're going the water route or we're going the regolith route in terms of oxygen extraction. That's huge. That is really deciding on the architecture for the sustained presence on the Moon in terms of ISRU. Now I think water will still have a place as a resource, radiation shielding or something else. But from the large-scale production point of view that decision will have to be made here relatively soon.

Then there's the operations point of view that we talked about. I think that's going to be one of the lasting legacies of VIPER. I certainly hope it is, in that science will be integrated throughout the mission concept, throughout the program, so that isn't the last thought or an afterthought. It's up front and leading the way along with the operators and engineers and management in future missions to the Moon, Artemis for example, but also to Mars. Mars is a different beast where time delays make it that much more difficult. But maybe even more the reason to have scientists actually integrated into those mission crews when we have humans at

Mars. I think VIPER will have a profound impact in several areas going forward for both the Moon and Mars and even asteroids.

JOHNSON: I think that's a good place to stop. Is there anything we haven't talked about that you wanted to mention before we go?

COLAPRETE: I don't think so. I think we've pretty much touched on everything.

JOHNSON: Okay. Thank you for talking to us today.

COLAPRETE: My pleasure. Always fun.

[End of interview]