NASA Discovery 30th Anniversary Oral History Project
Edited Oral History Transcript

James B. Garvin
Interviewed by Sandra Johnson
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Johnson: Today is April 20th, 2022. This interview with Dr. James Garvin is being conducted for the Discovery 30th Anniversary Oral History Project. The interviewer is Sandra Johnson. Dr. Garvin is in Columbia, Maryland, and talking to me today over Microsoft Teams. I appreciate you talking to me for a second interview, this is great. When we ended up last time we had skipped ahead and we talked about DAVINCI [Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging]. But I'd like to go back to that time period before the Lunar Reconnaissance Orbiter [LRO]. In January 2004 President George [W.] Bush announced *The Vision for Space Exploration* [VSE] and it was for NASA to undertake lunar exploration activities to enable sustained human and robotic exploration of Mars and beyond. Let's talk about that time period, what you were doing, and how you became involved with LRO and that whole period of time and that evolution in relationship with Discovery.

Garvin: Thanks for having me, Sandra, and it's great to be here talking NASA. Let's look back in time to those days literally when the President of the United States and his team were crafting a new *Vision for Space Exploration* [late 2003 into 2004]. Integrating people, women and men, machines, back to the Moon, on to Mars. Very exciting time. It was the 100th anniversary when this planning was happening of the Wright brothers' historic early flights. It's fitting 100 years later we're learning to fly in space even better than Apollo.

At that point I was supporting the Agency Chief Scientist, who was John [M.] Grunsfeld at that time, famous astronaut, friend, scientist, who serviced the Hubble Space Telescope three times. I was also acting in a position that was known as the Assistant Associate Administrator for Moon to Mars. Strange name. But they were evolving. One of the things that happened just at the time the President was about to make his announcement [January 14, 2004] was there was a bunch of formative meetings by the community at NASA Headquarters [Washington, DC] across the NASA family, and asking, "Okay, what is the first step to take to bring people back to the Moon? We've talked about going back, we talked during the Sally [K.] Ride committee work of the late '80s [*NASA Leadership and America's Future in Space*] that the Moon is the natural space station we should use as a leadership item for NASA beyond the ISS [International Space Station] and all that (circa 1987-88). But now we're going back in the 2000s.

Working with some of those very important colleagues, the question was posed to me, only because I had worked restructuring the Mars Exploration Program five years before. To me the big gap on the Moon was something that was left from the time of Apollo, which was to complete the integrated global reconnaissance to open the lunar frontier for everyone once and for all. Ironically, we didn't actually finish that within the Apollo years. With Apollo happening, Apollo 8 going, excitement, missions, Apollo 11 landing, all this great stuff, coming back and looking at reconnaissance of the entire Moon at the scales that people work, live, play, whatever, explore, was never completes, even after all the great missions of the '60s. People said, "We need that." I think in 1971 there were proclamations by the leaders of NASA and by the lead engineers that did Apollo, Max [Maxime A.] Faget and those amazing folks.

But anyway, here we were now in late 2003 into 2004 and the team putting together the President's *Vision for Space Exploration*, it was labelled NSPD 31B, National Space Policy

Directive 31B, I think was the actual name. They said, "What can we do?" To me it was oh my goodness, what an opportunity, we need to conduct the global reconnaissance that our community has been wanting for 30 years, we need to do that. We need to do it in a box so it's going to benefit human exploration, engineers, and the scientists that want such a mission and its foundational measurement sets. The Lunar Prospector mission, one of the early Discovery missions, had painted a new view of the composition of the Moon, so that was a key ingredient, well done, in the late '90s. Alan Binder's mission. But there were still these gaps. What was the topography and sub-meter scale morphology?

Sitting down in the *Columbia Cafe* [on 9th floor at NASA Headquarters,] in late 2003 with a couple of leaders of NASA, we were talking and I drew on a napkin the reconnaissance step I thought we needed to open the lunar frontier for engineers, explorers, scientists, and this Presidential vision. These senior colleagues, far higher pay grade than I, said, "This works. What could we do?"

I said, "Well, we just did a Mars Reconnaissance Orbiter [MRO]. We've sent a reconnaissance orbiter to Saturn, much bigger, Cassini. Why don't we do it to the Moon in that mindset? Why don't we reconnoiter what we need to go back, and in doing so do science, and open those lunar poles up where there's all this interesting stuff?"

They loved it. It went into the framework documents of the President's vision as one of the planks that by 2008 because of presidential terms and all that of course, we will have initiated and flown this mission that became named the Lunar Reconnaissance Orbiter, LRO, to map the Moon for the good of the exploration.

Immediately upon President Bush's visit to NASA Headquarters, I was there sitting next to my friend Lisa Guerra when he was talking about this great vision with lots of elements that excited us, separating crew from cargo, back to the Moon, on to Mars, things like that. One of the elements was we will do a reconnaissance orbiter to the Moon, and it was very exciting to see that that held as a first thing.

Immediately after that some of the Agency leaders grabbed me and said, "Okay, you know how to do requirements with the community. Only it's multiple communities now, it's not just science, it's exploration, astronauts, everyone. We need to get this together fast." The scope back then, Sandra, was imagined as being big and bold. People thought of this LRO as possibly this *Battlestar Galactica* full of a dozen instruments, a grandiose scope that would have been of course fantastic. It took a month or two to get the appetite expectations down to something that we could build in four years, fly it, deliver data, that people would use, not just the science customers who are used to dealing with weird data, but to actually be usable by engineers designing human landing systems or driving lunar mobile vehicles with women and men in them and going to the poles, which had been largely unexplored until the time of Clementine [Mission] in the '90s and then this mission.

Getting that down was a real challenge. One of the things borrowed from the history actually of the mindset of Discovery Program was asking could we do this mission in the box that was the Discovery resources box. That class of mission in cost, scope, development time, operational time that fits into a risk-controlled box that people could achieve with confidence. That's what the Discovery Program did. It opened, what should I say, that trade space. What could you do for a few hundred million dollars with a rocket going to a place with enough money to have transformative measurements, but not do everything for everyone? Because that's a hard task to do. And to open the doors for this option.

Some of our leaders at NASA in what soon became the Science Mission Directorate—back then it was split between Earth [Science: Code Y] and Space [Science: Code S], but it came together that summer of 2004—we put together the framework for a Discovery-class mission to the Moon that would have a payload that was openly competed based on goals and objectives that were grabbed from the lunar community. I had to, as the leader of that process, and the evaluation chairperson eventually for this new mission, develop a set of objective requirements for the mission. I was not allowed to operate as usual for NASA science, because it was not a pure science mission, so we couldn't asset up a classical science definition team [SDT], which is a standard mechanism at NASA for big flagship missions. We have an SDT for big telescopes and big Mars rovers and big missions to Saturn. That's a process, people come together, they're selected, they ultimately write a big report, it goes, it's used, it's published, it's great. We didn't have time for that.

We had to do this fast and we had to engage multiple communities. We had a bunch of workshops, all virtual, telecons, and then one face to face in Houston over three days. We brought together community influencers who knew the Moon, who knew exploration, and who knew engineering. Sat them down for basically two days and said, "Let's go through what we can do. We have to launch in four years; that's what the President said." That's pretty good guidance, we're probably going to listen.

A lot of expectations. We can do more, we can do this. Then saying, "Well, you got four years to develop a mission." The Discovery timeframe was really important. These colleagues got together, a lot of great women and men, wrote down the key stuff. We fixed it, had it reviewed, vetted. We used it as the framework, and less than two months after that was done to have an open call for proposals, an announcement of opportunity [AO] for the payload of the Lunar Reconnaissance Orbiter.

What was important about that was the normal signature cycle of getting an acquisition request through an open competition through the federal paperwork is quite—it's a large mountain to climb. It took a lot of the best leaders at NASA Headquarters to grease the skids. We had signing parties where several of the key people signed all in one room. Sign this, sign this, sign this, sign this, sign this. It's good enough, we're going. We got the AO out for the payload for this key mission in the President's *Vision for Space Exploration* in record time. Then we only gave the colleagues 60 days to respond. We said, "We have to get this payload."

The mission assignment of building the spacecraft was given to Goddard Space Flight Center [Greenbelt, Maryland] as part of a new robotic precursor mission sequence to the Moon that was then part of the architecture for *The Vision for Space Exploration* to send women and men back to the Moon. The leaders of that met with me right after we had this requirements thing. I remember Craig [R.] Tooley and Jim [James] Watzin and they said, "Okay, we think we can get to the Moon cheaply with this class of orbiter. We can only carry this much mass. Your payloads if they're bigger than that we probably can't accommodate them. We're used to big orbiters around Earth and the big one at Mars, MRO. It's a more expensive mission. Today's dollars, it would be two Discoverys." LRO is still working by the way, rather beautifully after 13 years in low lunar orbit.

But there were a lot of good inputs from experts. Chris [Christopher J.] Scolese, who was then the Deputy Associate Administrator for Science and a great engineer, was so helpful in gauging the appetite and calibrating what could be engineered. Also, Orlando Figueroa, who was the Director of the Planetary Science Division at NASA Headquarters. Between those colleagues we ratcheted the appetite into a "Discovery-class" box. We put the call out. We got dozens of proposals, all fantastic stuff. I had a 22-person science exploration peer panel just to look at the measurements they wanted to make via instrument-based investigations. I remember that panel because it was so hard to grade these wonderful submissions. Cameras and spectrometers and things that could see the action of the Sun on the Moon and lasers and radars. They were a really amazing suite. Some of the instruments we still haven't done. One of the instruments was a kind of radar with a long wavelength called L-band that had the ability to see polarimetrically into the lunar regolith, into the soil, and could have mapped the whole Moon down to 5 meters deep just beautifully. But it was a big instrument. Some big things don't fit on smaller spacecraft. Your family sport utility vehicle can't carry 20 kids and all their gear, as much as you would love to get them to the beach or the mountains or wherever.

We did the competition; proposals came in. We only had two and a half months to fully evaluate them with a technical, management risk, and science panel, and get an answer to the leaders of the Agency. At that point Admiral [Craig E.] Steidle was leading the Exploration Systems Mission Directorate, and Al [Alphonso V.] Diaz and his team were leading what became the Science Mission [Directorate]. We had to literally speed up the process and literally every step was all-nighters and things like that to get this presentable to the decision makers. But that was my job, to run the competition and give them a trade space and say, "It's your money, it's your mass, let's do this for the President and the future of NASA at the Moon." Which was very exciting to all of us.

At the same time, I was actually transitioning into a new job, because the Administrator, while I was doing this LRO payload evaluation, asked me to become the new NASA Agency Chief Scientist. I was already doing Mars and running this competition for the LRO. I asked the

Administrator, Sean O'Keefe, and his team. I said, "Okay, Sean, I'll do anything for the Agency. I'm NASA for life. But I kind of have three things to do."

He said, "Look, finish LRO, I know you care about that. Find a replacement to run the Chief Scientist for Mars. You started it, there's plenty of good women and men. Do this for us now as we implement the President's vision."

I said, "Okay, sir, it's great." We got to the selection officials in late November; it was the Monday after Thanksgiving. Presented the case. They selected a payload. Seven instruments and a technology demo that are all still working around the Moon, largely still delivering world-class measurements. It was to have been a one-to-two-year mission. It's now on year 13 plus, still mapping. Pretty good for a little spacecraft the size of a refrigerator. I'll never forget, because the Administrator had a retreat in New Orleans, [Louisiana] where he's from, Administrator, O'Keefe, I should say. We had picked the payload; we were all excited. I guess because of the end of the year, whatever it is, I don't know the budget stuff, no money had flowed to the project at Goddard to start work.

I get a call. They said, "Jim, we know you have the payload for us. We have some people working but we don't have any money."

Walking along the streets of New Orleans I said, "Mr. Administrator, sir, sorry to bug you." He's a big guy. I'm not so big. I said, "Could I ask you a favor?"

He goes, "Jim, what's up?"

I said, "Well, we want to go back to the Moon. The President said we have new money. It's all great. We don't have any money actually at the project to start the mission. There's some good people working. But I don't know what they're being paid with. Maybe dinners."

He said, "Well, what do you need?"

I said, "Well, sir, $50 million." He made a couple of calls on his cell phone and within a day or two money was flowing into the LRO project and a few weeks later I remember we had a kickoff meeting. One of the most exciting things for me personally, Sandra, this is one personal note, so I ran the evaluation for all these important people in the Agency. We talked to the people on the President's staff who were designing this vision. It was great stuff. Astronauts too of course were involved. But they told me after we picked the payload and had money actually going to the project to build the spacecraft and pay for the people to design it all, they said, "Why don't you call the selected PIs [principal investigators] who've won the role of flying these experiments to the Moon?"

I was sitting in my little office at NASA Headquarters calling these folks that got a chance to send their payloads to the Moon. It was really thrilling to hear their excitement. They all delivered great stuff. All the instruments doing wonderfully. The camera team with Mark [S.] Robinson (from Arizona State University) of course was just off the charts. The team that built the laser altimeter at Goddard and MIT [Massachusetts Institute of Technology, Cambridge], fabulous people. Dave [David E.] Smith. I can go on and on. It was just fabulous. The CRaTER [Cosmic Ray Telescope for the Effects of Radiation] team that built the human tissue emulation experiment that's really important for future human spaceflight at Boston University, now University of New Hampshire [Durham]. It was also great. We were off and running literally less than a year after the President's speech at NASA Headquarters, which I think was, what was it, January 14th, 2004, I just remember because we were all in line going through metal detectors for a couple hours to get into the auditorium. The President is coming, I can see the importance. We all got to, well, sort of, walk by and wave at the President, which was neat to have him and his staff there. It was actually incredible.

LRO was designed at that point. I should say rapidly conceptualized to become a Discovery-class orbiter at the Moon to do two things which were really hard to mesh. Make measurements that science cares about, that the National Academy of Sciences would say, "That's what we want to do at the Moon as we go back to learn about cycles of volatiles, volcanism, impact processes, formation of regolith, resources. All those great questions. And to produce the engineering boundary conditions to design better, smarter, cheaper, and safer systems for people to go to the Moon." Which we're now doing through the project called Artemis [Program] of course, and very exciting, we're going back with human landing systems and things. It's just fabulous.

But those systems need to be designed to what's the ground like, what's the sunlight like, what's the thermal radiation, what's the radiation from the galactic cosmic background, all that stuff. The job of LRO was to fill in most of those gaps, or as many as we could afford. At the same time Japan was flying a mission known as Kaguya, and they were filling in some other gaps. We knew we had friends working it as well from other nations in this case, the Japanese Space Agency did a great job.

But LRO was really a pathfinder. Not like the Lunar Prospector. A pathfinder to serve the human exploration community and the science community with value-added data sets that engineers could design to and data sets that scientists could use and to get the people excited about the Moon.

One of the reasons why in the competition a camera with resolution that was probably three or four times better than we thought we needed at first glance was flown, the Lunar Reconnaissance Orbiter Camera [LROC], a Narrow Angle Camera, designed by Malin Space Science Systems with Mark Robinson as the leader, has 50-centimeter resolution from the nominal orbit. That's not very big. We know the Moon; we've been there six times with Apollo. But they did that mode to go beyond current perceptions (to sub-meter scales), and today they've mapped the whole Moon at a few-meter scale. We have this global image mosaic, this *Google Moon* that we can use to plan what we do with people. They continue to do it. The laser altimeter [Lunar Orbiter Laser Altimeter, LOLA] has measured the height of the ground to tens of centimeters. We know the lay of the ground. We can drive and build and eventually dig, and all the stuff we want to do as part of Artemis.

LRO was designed to do all that. It was a science measurement mission that served engineering needs but also could do science, and that balance is very difficult to achieve other than by directed strategic missions, because in a competition, the best science wins. If you're doing a bunch of mundane foundation measurements of things, it's like surveying your property to build the foundation for your house, it's critical but it's kind of boring. It's not like okay, let's site the house with the best light, let's have your backyard facing whatever you like. That's fine. Where are you going to put the foundation so the thing doesn't crumble? That's the civil engineering problem. We needed to do civil engineering for the Moon to live and work there.

The teams doing this had to measure the temperature in the coldtraps, the polar permanently shadowed regions [PSRs], which is really so cold we didn't know how cold it was, which they did, the Diviner team from UCLA [University of California Los Angeles] and JPL [Jet Propulsion Laboratory] did it. They had to measure hydrogen from neutrons scattered collimated to smaller scale so we could see where it's clustered. We did that. We had to measure the topography of the ground at human scales where you'd build rovers and things. Did that. See things as small as the boulders that would impede us from landing. Done that with the LROC. Measure the space radiation effect on tissue-equivalent plastic, which we're going to build things out of. We need to know if it sits up in the lunar environment away from the Van Allen [radiation] belt protecting our Earth, what do we need to do, how thick. All these critical things.

Then we had a tech demo designed to test new radio frequency communications in a much smaller package called the Mini-RF [Miniature Radio Frequency], which also had the capacity to make synthetic aperture radar "imaging" measurements. It was just great and we did a laser ranging experiment from the Earth to the orbiter to do better orbits. Lots of stuff that LRO did that were like pathfinders for things the Discovery Program would bring in as tech demos, student collaborations. Things that would be extras you could fly if you want to. I think that's where some of the ideas of seeding the Discovery Program with tech demos, TDOs [Tech Demo Opportunities] as we call them, student collaborations started to gain a foothold. Because LRO showed you can do those things. We didn't fly everything we wanted to fly in all fairness, but we were really lucky because the next Discovery call someone bid an instrument that would fly on the India orbiter known as Chandrayaan-1 that filled a gap that LRO was unable to fill. The M3 [Moon Mineralogy Mapper] experiment from Professor Carle [M.] Pieters mapped the mineralogy using the Indian Space Agency's Chandrayaan-1 orbiter mission. We wanted to fly something like that on LRO, just didn't quite fit. The engineers said, "We got one, it's a little big. What can we do?" They bid it.

We had other experiments that couldn't fly that were a fantastic bigger gamma ray spectrometer with a big boom. It would have been fabulous. We just didn't have room for the big boom. You can't fly everything. I wish we had had a second LRO. But I think the message in all this in the history is the Discovery Program helped us know that there was a level we could build, design, and fly to to have tremendous value, and that we could scope it and know it's not going to break. It's like if you go into a car dealer and you want a Rolls-Royce and you end up with one of those little Honda Fits, the smallest ones they have. There's a big gap in that. They're both good vehicles. They'll drive you around. One in massive luxury I presume. I've not been in a Rolls-Royce. But I've been in the little Honda Fit. It's a cute little car. Drive it around. There's a big gap. You might be able to afford a Honda Fit. You may not afford a $100,000 Rolls-Royce.

We didn't have the Rolls-Royce for this first step. We needed to save that money to build the program to get the people back to the Moon that I think was eventually called Constellation for a while. Very exciting to all of us to be doing that. But LRO was designed to be that catalyst. The President and his people realized even something as mundane as an orbiter with solar panels and a bunch of cameras and things hanging off it could visibly open the frontier.

In some sense we were very excited to get a chance to do it. The team that built it across all the partners, Goddard Space Flight Center, the project manager was Craig Tooley, and his team were just first-rate. They delivered for all of us. I think in some sense the fact that LRO is still working is giving us the confidence to do Artemis with the first woman to the Moon and all that.

JOHNSON: Like I said I think before we talked, when I'm looking up information about LRO, I have one list where it's considered part of Discovery. I have another list where it's not. Is that because those instruments were competed but the idea and everything came out of something separate? Is that why it crosses over?

GARVIN: It was very complicated. It started as the anchor first step in the President's vision. The premise was it would be developed in the Exploration Systems Mission Directorate that was headed by Admiral Steidle at that point. But then Admiral Steidle in talking to Ed [Edward J.] Weiler, who was head of space science at that point with Chris Scolese, said, "We do that kind of mission. Your guy working on pulling together requirements to run the competition for the payload, he works in the science domain. Why don't we implement this mission as hybrid? Why doesn't the Science Mission Directorate run the competition for this mission (as we did)? Let the hardware be built by the Center that it was assigned to." Someone assigned it to Goddard, the Administrator I presume. But whatever, I don't know. And run it that way to a point where it delivers its first data as a big slug of data about the Moon that's enough to get us started to get the people back as part of the vision. Then we'll hand it off to science.

It was sort of developed competitively as a payload, seven experiments, through the standard science practices that have worked within Discovery. I ran the payload competition for the Mars Reconnaissance Orbiter. We got a bunch of bids, we picked a payload, we gave it to the project, at JPL. They got a spacecraft from Lockheed-Martin. Flew it to Mars through the Mars Program. This was a new program because it fell in multiple families.

What we did was—not we, the leadership at NASA. They ran the competition in the science mode, like Discovery, like others. Flew the mission for a first year as an exploration mission operated by ESMD [Exploration Systems Mission Directorate] group, they managed it. It had the project manager at Goddard. But they managed it from Headquarters that way. Then they had a transition. I think Mike [Michael D.] Griffin, the Administrator, then made this possible. To transition it over to science. It delivered the maps they needed. They were delivered within a year as required. It met all of its expectations. The spacecraft was still working. Let's keep it going. It was handed off to science [the Science Mission Directorate, SMD] to be operated as a science mission.

It actually transitioned from an exploration supporting mission for engineering technologies to a science mission that would operate as if it were an orbiter like MAVEN [Mars Atmosphere and Volatile Evolution] in Discovery at Mars. That was an interesting way. It was a dual use mission. Most missions have multiple uses; let's face it, they do. You learn something, it's applied to whatever you're going to be doing. But this one in particular had a lot of those elements. Some of the resolutions and sensitivities were higher than science questions said they absolutely needed. But they were selected by the leading people and recommended by people like me because they could do both. The better you can do both, the better it is. Here we are after being there since summer of 2009, and 13 years later it's still mapping. I think it's the first multi-petabit mission to ever map another world other than Earth, which of course we've been mapping for a while given we live here.

It was a very interesting checkerboarding starting here, being managed here. We had this one guy running it. He (me) becomes the Agency Chief Scientist but he's still running the payload acquisition for LRO (first step in the President's VSE), because I had experience in that. It wasn't like I was any great shakes. I was someone who'd gone through running competitions for big payloads for planets like the Moon and Mars. I was the stuckee. But it was a joy to do. Just a lot of work. Didn't sleep a lot for about six months. But delivered a great mission that NASA should be proud of because it's still delivering.

JOHNSON: My interview list includes a couple of people to talk to about LCROSS [Lunar Crater Observation and Sensing Satellite], because that launched with LRO. Not technically Discovery, but it launched. If you would, talk about that relationship or how that happened.

GARVIN: With LRO, very early the project at Goddard and the Chief Engineer and the Project Manager, that was Craig Tooley and Joe [Joseph] Burt and another colleague, Arlin Bartels, realized they had to put this mission on a bigger launch vehicle than a little Delta II. It just needed more oomph. It was a bigger spacecraft; it had more payload. So, they had to scale up to the Atlas V. Now they had excess launch capacity. We're going to the Moon with this first step in the President's vision, and we have excess launch, like a lot. Why don't we use it?

NASA Headquarters was very creative, I think it was Scott [J.] Horowitz, Doc Horowitz, who was running the Exploration Systems Mission Directorate at that point. A great guy. Good dude. He said, "Why don't we compete internally within NASA for that excess mass to use it to do something at the Moon that's relevant to human exploration?" They ran an internal competition with multiple steps. I know that because actually the new NASA Administrator had decided come the summer of 2005 that they no longer needed an Office of the Chief Scientist. I was the NASA Chief Scientist at the time. He told me to pack it up and we're going to close down that office. We have a Science Mission Directorate and we have Exploration. We're happy. Go do something else.

I said, "Okay." My team and I, we packed up, archived everything. I was basically sent out to Goddard to become what became the Chief Scientist of Goddard Space Flight Center. Fine. Great, lovely place. But when I got out there this competition had just started. The NASA Centers, all of 10 healthy Centers, were able to compete with a certain cost cap in a very constricted proposing mechanism. It was a two-step, initially a little 15-page proposal. What could you do? Then another step more like 40 pages, how much is it going to cost, how will you fit in the available excess mass on this big launch that was going to happen in late 2008.

A bunch of proposals came in. A bunch of us at Goddard actually with several astronauts wrote a proposal to add a little tiny lander that could land on the Moon and then hop into a polar crater. We did that. We called it LEx after Lex Luthor, but **L**unar **Ex**ploration. Other people bid the LCROSS that cleverly used the excess upper tank of the Centaur [upper stage rocket] to get the mission as a vehicle to crash into the Moon and watch it. That was very creative. That was LCROSS implemented via NASA Ames Research Center. There was another one from Langley [Research Center, Hampton, Virginia] to fly something that would measure the particles and fields interacting with the Moon. There were approximately five finalists. They had orals and writtens and lots of reviews. In the end they picked LCROSS, which was wonderful, I have to say, incredibly innovative. It shows NASA can innovate. With a very small cost cap. I think in the end the cost cap was under $100 million. The LCROSS team, led by Tony [Anthony Colaprete] out at Ames and other colleagues with Northrop Grumman, put together this elegant mission to go and literally make a crater in a place where we suspected, in the crater Cabeus on the Moon, there might be excess hydrogen in the form of ice in the regolith in a permanently shadowed area, and see if we could see its expression from a little accompanying spacecraft, and also use LRO in orbit to look at it.

What happened was the competition produced the impacting spacecraft and the little shepherding flying spacecraft with it with a bunch of elegant little cameras. That was really a super job. Tony and the team at Ames did an amazing mission with that. But the beauty of the mission was we also watched the event from Hubble [Space Telescope]. Hubble can look at the lunar limb, which I actually did in 2005 for the Administrator as the first use of Hubble to search for resources on the Moon, because Hubble's ultraviolet imaging for astronomy is better than anything planetary has ever flown. It's the most sensitive known to woman or man. We looked at the Moon and mapped literally titanium content in lunar soils from Hubble from Earth orbit in 2005. Exciting that Hubble can do that? Just shows how people can learn good stuff. Wrote a paper, it's all good.

But anyway, LCROSS had the ability to also have LRO watch the plume that it made from the impact. LRO's instruments saw the signature of the released water and were able to independently confirm some of the measurements that the LCROSS experiment made with its little shepherding vehicle that followed the impactor in and didn't last long, whereas LRO went back several orbits and watched the unfolding plume using its infrared camera systems and its far ultraviolet instrument, which was actually developed by Alan Stern.

We had multi-viewing of this human-made impacting event. LCROSS was an example of a piggyback that was competed, but it competed internally, not through the whole science and engineering community. I think the reason they did that—and Sandra, to be honest, I don't know. It was a choice made by Admiral Steidle's team, certainly not me, and then Doc Horowitz's team. I think once we release an open AO the acquisition/procurement regulations take more time to go through openness and to procure missions. The process of evaluation would have taken longer. The Discovery process to pick missions takes a year and a half. Two big steps. The final proposals were like 35-page with budget, single-spaced proposals that had a simple guideline. Fit in the mass, don't cost too much, tell us what you're going to do, how does that affect human exploration. The first step took like 40 ideas down to 5, and the final step picked 1.

They did it for the cost, and hats off to the team who did LCROSS, because it was really a very clever brilliant idea. As much as I wanted to fly our little LEx lander, which was about the size of a little coffee table, I see the value of that given the power of having LRO and the LCROSS little minispacecraft watch the impact. It went to a great place. It was all good. Actually, LRO targeted the place. We used our LRO to find the place, a crater that would be hittable, impactable, by the big spent upper stage Centaur. It all worked. The fact that we did all that in like four years, for real cost cap missions, and LRO came in on cost, LCROSS came in on cost, all that was done, the prime missions were done, it was a real hallmark for NASA.

Mr. [Daniel S.] Goldin had been saying in the ’90s faster, better, cheaper. We did things cheaper, better, smarter. We demonstrated with LRO, LCROSS that we could do that with a short timeframe. Time is money. That’s all I know. I’m sure there’s other people that know other more detailed stuff.

JOHNSON: No, that’s good information. While you were talking, made me think of balancing science and technology in these missions. You want the science, but the technology takes a big leap too. Also, with LRO, that human exploration is benefited because you’re learning things like that. Are there other missions that you can think of that were similar to that in Discovery? Or was this just unique in that balance of that technology, science, and then human endeavor in the future?

GARVIN: I think all of the missions within the Discovery portfolio and those similar, LRO being one designed to be similar, came from different roots, have all demonstrated elements of that. It depends on the degree of how much you think the consequences of what they did was. Deep

Impact. It made a crater and watched the crater it made on a small object, so it did a hypervelocity impact cratering experiment but not on Earth. That's good. In a place where we could observe it. The team learned a lot about the physics of that process. The two sample return missions, Genesis and Stardust, collected unique new kinds of samples to bring back to Earth, different than Apollo of course, who brought hundreds of pounds of great lunar stuff back. Still a gift that keeps giving.

There were technologies that allowed them to do that. Those are two examples that come to mind. The InSight Lander on Mars took a super next-generation kind of seismometer to a planetary surface that has listened to the ringing of impacts made on Mars 3,000 kilometers away. It can detect the ringing inside the planet of that, in Discovery. That kind of mission would have been considered impossible, and yet thanks to Discovery, with technology and partnerships. InSight has partnerships with France and Germany. We could do new and great things. Those are different models.

The business models for doing things in space to serve the customer base, science, human exploration, the public who pay for it all, and even commercial now as that's becoming a part of it. The trade space is being opened. I think Discovery was the example in planetary domain where we said, "Yes, we can do that. We can add a payload that's a tech demo [technology demonstration], that doesn't have to do science the way science does. It has to prove you can do something. But it might not work." The tech demo on LRO was a small compact antenna radar that flew what's called a compact polarimetric radar to the Moon. That's pretty good. We wanted one at the Moon. So, we got one, but it wasn't the size of a school bus. It was the size of a little card table. That's pretty cool. The technology came partly out of DARPA [Defense Advanced Research Projects Agency. The laser altimeter. A multibeam laser altimeter on LRO.

Instead of one beam, bing bing bing bing, it's what we've been doing around Earth, that's how we map Mars, this used a special kind of beam-splitting optic to spread the beams into multiple ones so we could fly a swath. That technique is being used now in space for other missions. Again, applying a technology that had a risk but it was an acceptable risk where people were willing to believe in it.

The MAVEN mission at Mars in orbit now for a long time, since 2013. It has a very advanced mass spectrometer that deep-dips down to the very upper reaches of the Martian atmosphere, collects samples, and figures out what they're made of, where they came from. Come on. That's like sample return without bringing a sample back. These types of Discovery missions, and there's many more. Lucy [Mission] is going to a whole new class of object. The Trojans [Asteroids], oh my God. Psyche [Asteroid Mission] of course going to an M-class asteroid parent body, Psyche. Lucy is in flight, and Psyche will launch this summer [delayed until mid-2023]. These are the stuff of miracles. Again, the Discovery process filters out the things that are too far a stretch. In the case of our DAVINCI mission now selected, we have a new technology in which what has been a large, complex type of ultraviolet spectrometer that can measure what things are made of using UV wavelengths, normally something the size of, I don't know, a big oven, is shrunk down to a little box like this, with special kinds of optics. That's a tech demo. It'll see if that can do the job. But since we can't get all the data back, it's going to use an artificial intelligence machine learning technique to look through all the spectra it collects and send back what it thinks they tell us without sending them all back right away, because we don't have a big enough radio transmitting system to get all the data back. DAVINCI is cost capped, we couldn't afford the big Ka-band antennas. We have little ones.

All the missions in Discovery going back to the first two, the two that seeded the program, NEAR [Near Earth Asteroid Rendezvous] Shoemaker and Mars Pathfinder, all had elements of technologies. The first rover on Mars, Sojourner on Mars Pathfinder. NEAR ended up actually landing on the asteroid Eros. Come on. Docking might be a better word, but it came to rest on this size of a city asteroid that it mapped.

All these have little elements. I remember in the case of several of these instruments that people said could not work of different types were pioneered and flown. They did work. Whole class of laser instruments that people said, "They're too risky, never going to work." When we first proposed the MOLA [Mars Orbiter Laser Altimeter] instrument on the Mars Global Surveyor to map Mars, literally the leaders of the community said, "Come on, Jim, you're crazy, it'll never work." You're not going to map the topography of Mars with a laser beam pounding away. We're still using the MOLA data now as we land [Mars] rovers like Curiosity and Perseverance. It took technology and trust.

Within the Discovery Program, the competition for the science with technology, with focused science questions, with a cost cap forces you to make choices. Choices about how far you're going to stretch. A flagship mission, you can stretch all the way. The big flagship missions like James Webb Space Telescope, they invent new things. You don't even know they can be done. They're done, they're working. Big missions to planets, Cassini at Saturn. We can name them all. They're great, but in Discovery you can push so far, and often that's far enough to make it a game changer in learning or in just proving a technology is not ready to go. The Dawn Mission at Vesta and Ceres went to two objects, two important main belt asteroids, for a Discovery budget. That's pretty amazing. It had multiple targets. Lucy is going to multiple Trojans. These are hallmarks of a more creative model for how we explore. I think that goes back to the vision I think I told you about last time of the way Sally Ride got people thinking after *Challenger* [accident, STS-51L], about what are the innovations that demonstrate leadership. They don't always have to be big and grandiose and tons of money. They sometimes can be targeted and smart. I think the Discovery Program, now 30 years in life, has demonstrated that repeatedly, from the very first mission, [Mars] Pathfinder and NEAR Shoemaker, to the first competed mission, Lunar Prospector, the sample return missions, all the way to the missions that are about to launch like Psyche, which is going to a totally bizarre new kind of place, and of course Lucy to the Trojans. Yet other Discovery missions have gone to the surface of Mars, like InSight, to bring a new class of measurement there.

Sometimes the technologies don't fully work. Not because of the technology, because the target isn't cooperative. We learn. You learn well, Mars doesn't work that way. The Moon doesn't work that way. I'm bullish about these programs because the quality of competition has only gone up. The breadth and scope for the same price, the creativity by the women and men, from what I've seen it's rising. That's not grade inflation. That's quality of thought and community engagement. That's why Discovery is so important. The recently announced Planetary/Astrobiology Decadal Survey 2022 just released says per decade we should fly five Discovery missions. They're that important. Not one a decade, five. That's the goal that they're recommending to NASA from the community. But that's amazing. We've had that kind of flight rate. The last Discovery competition resulted in the selection of Lucy and Psyche, well, almost both are launched. Previously we had Mars InSight, which was phenomenal, still working on Mars far beyond design life. Still measuring marsquakes and other things too. I'm bullish on this because I can see looking back the risks and the benefits. They've all worked. That's pretty darn good.

JOHNSON: It's pretty amazing.

GARVIN: It really is if you think of it. Every one had perilous moments, potential failures. But by keeping them in a box with good management, great women and men leading the teams, and they proved that PI mode with a strong project manager can be done effectively. Yes, occasionally something breaks and things happen. But all of the Discovery-class missions, which include the two Mars Scout missions, Phoenix Lander and MAVEN, which Discovery just did targeted for Mars, have all been way beyond expectation in terms of science delivery.

JOHNSON: You mentioned that international element in some of these instruments, and like you said the one that didn't get flown, India, when they flew, it went on that. When we think about international cooperation between NASA and other countries everyone thinks of ISS [International Space Station]. They don't necessarily think of these kinds of missions. How important is that international cooperation to a program like Discovery?

GARVIN: I think international cooperation is always worth the sometimes-painful paperwork that is associated with it, which goes across different governments. Of course, ISS is a demonstration of how that can work with a lot of hard work by people, in all fairness. But in every case, I've seen the international collaboration, cooperation, contribution involved, it has added massive value and better results. That is true of everywhere, whether it's a little small element of a subsystem that an international partner donated, contributed, to a full payload that's international (as on DAWN and Mars InSight). The full payload on Mars InSight was French and German, and yet the spacecraft was built in the United States with leader [William] Bruce Banerdt of JPL, United States. Project management at JPL and Lockheed Martin. But yet the core payload, the seismometer, the heat flow probe, were built in Europe, contributed to the United States to fly to Mars. That's a good model. Everybody wins.

The lunar exploration neutron-detecting spectrometer on LRO was an experiment contributed by Russia with U.S. elements to help it calibrate the data and all that in the United States, I think in Maryland and Texas and Arizona. It was an instrument that could have cost five times as much were it developed in the USA. But by being partially contributed and partly American and other things, it was able to be done cheaper.

In every case I've seen including the newly selected VERITAS [Venus Emissivity, Radio science, InSAR (Interferometric Synthetic Aperture Radar), Topography, and Spectroscopy] mission to Venus where one of its key payloads is 100 percent German, the Venus Emissivity Mapper [VEM], beautiful experiment, something we've always wanted to fly to Venus. It's going thanks to the international participation and cooperation. In all the missions I'm familiar with those cases, including more expensive missions like Cassini to Saturn, great benefits have been realized. We have an international radar on the Mars Reconnaissance Orbiter known as SHARAD [Shallow Radar] contributed by the Italian Space Agency. Absolutely a critical experiment. Although there are some paperwork factors involved. The cameras on Dawn are contributed by Germany, the Dawn mapping cameras. This is a way to add value, to do better science, to bring in more people. To amplify the science footprint across. International science things are not paid for by NASA. We can't send U.S. dollars to other countries. But we get the value of us carrying them on a quality mission to do the work. That's exciting to me.

In the case of our own DAVINCI mission our tech demonstration instrument, while built in the United States, is led by an Italian woman, Dr. Valeria Cottini from Italy, and wonderful spectroscopist who understands Venus atmosphere. We're so happy to have her leading that experiment for us. Just a small example of that partnership. I think it's a value added. Sometimes takes longer, more paperwork. But in every case, I've seen, at least in the context of Discovery, better science, more people involved, better discoveries, and it fits in the Discovery mold.

JOHNSON: Speaking of DAVINCI, last time we talked about some of the people on your team and how you formed that team and how you've got those other two PIs that work with you and that whole group, and the importance of bringing younger people in too. We've talked about being the PI, but if you can talk about how that worked as far as from the AO to getting that team together and how the process worked for you being on that other side. Because you've been on both sides of it. But that point of view of going through the process.

GARVIN: I've been lucky because I've seen both sides of the equation. I've been an evaluation chairperson for NASA Headquarters to run processes that select missions and that select payloads on missions competitively (via AOs). That process is certainly rigorous and I would say comprehensive. Is it perfect? People can argue. But I think that the women and men I've worked with on the panels I've led have done great service to NASA. Seeing what people bid and their excitement in what they can put together, and penetrating how they develop their teams, ideas, science from the side of being, I hope, an informed evaluation chairperson and reviewer is exciting to me because it helped me see things to avoid, the things that work, the kinds of partnerships and structures that are effective. Some principal investigators operate like the top of the food chain. They are the general. Listen to them. They're going to do it. They have the experience. That has worked. Others are more democratic, more attempting to build a wider breadth of team, to grow a community. It's different styles for different folks.

For me I saw the value of having brilliant deputies and people in lead positions, our project system engineers, who are the next generation of leaders, because they're going to inherit all this "mess" and carry it forward. They'll make it better. They'll own it. They'll fix it. Those of us that have done it for 30, 40 years have seen it through multiple changes. The next 30 or 40 years are going to be just as dynamic and different. I think that's the beauty of having both sides. Not many people in the community have that, because how many people leave their science jobs to go to NASA Headquarters? A few of us have done that because we felt: (a) it was important to do for our community, and (b), because we wanted to be useful. Others would rather stay being a scientist. It's a lot of fun and often thrilling. You discover new things, write great papers, build great teams. It's up to the person. But I was lucky to have both sides and to learn from some great folks that taught me how to build a team and how to work.

I will say this. I can see people that are going to be natural leaders of the future. Some of the PIs that are being selected now are just off the charts fabulous. Lindy [Elkins-Tanton] on Psyche is just a fabulous PI, a model PI for all of us. Just a great learning experience. I've known Bruce Banerdt for 30 years. He's a fantastic PI on Mars InSight. Bruce [M.] Jakosky, he's just an outstanding scientist and leader and MAVEN has demonstrated that. You can go on and on. I'm just naming people I know. It's a spectacular thing to witness such talent.

In designing the team that became the DAVINCI mission [Discovery Program mission] that's now selected for launch in June 2029, I wanted to include one or two of the very best deputy PIs I could find, both because I wanted both to become PIs, as they should be, and so having two people of that caliber, it just makes the mission so much better. And DAVINCI has the best deputy PIs I can imagine in Drs. Stephanie A. Getty and Giada N. Arney. We're not single-point failure decision making. We talk about things so we can all understand each other's perspectives. Some of us have done a lot of work in one area and not in other areas. Other people are experts in this or that. When you're trying to look at an entire planet like Venus, which is poorly explored and complicated and hard to explore engineering-wise, you need all that expertise. Because what can you do when you don't have a lot of time or it's otherwise complicated? These inconvenient places to go explore need new designs of teams.

I think Discovery has bred that, namely the idea that teams grow a future leadership pool with connections so those people can take over and run the show, write the papers, lead the science team. On DAVINCI my condition for even working it going forward (back in 2018) with my leadership team at NASA Goddard was that I want to pick those people and see if they want to work with me. If they don't, of course I understand. I may be not the best person to work with and I get that. But the people we've managed to cobble together, and I think all teams have this story, I don't mean to be cliche here, have done brilliantly. We had COVID-19 on top of it, so we had to work remotely in unique ways writing a 1,500-page proposal, or Phase A concept study report [CSR], final proposal. That took interesting dynamics.

But we got through it and it shows the process can operate effectively when people work well together. Again, I think the message is very simple. There is no single person that is running the show on these missions. They are too complicated, too important. We owe the taxpayer to have a team, with a capital T. It could be three levels deep, that person is making the difference to make the mission work. That is why you have to build a team of people you trust.

I think all these Discovery missions that have done so well demonstrate that in different ways. Maybe the melding of them all, you can shake the trees and see oh, these are the special conditions that make things operate on cost, schedule, and deliver the science and the community impact that we want (and that the taxpayers deserve). I think that's something that as Discovery (as a program) looks back over 30 years it's thinking about.

JOHNSON: You mentioned some last time and you've mentioned some again today, but is there anything that stands out to you as far as the relevance and the importance of the Discovery Program? There's technological relevance in Discovery. There's science of course. But then there's other things like the international aspect of it or how it benefits the average person in the United States whose tax dollars help fund it. But is there anything that you haven't mentioned that you would you consider the most important part of that?

GARVIN: What makes the Discovery Program special, and it's grown into this, is a couple of things that all work together. It's innovation in exploration at every kind of target in our big solar system that you can imagine. If you can innovate what you do, even at those targets that are uncooperative, inconvenient, far away, that's going to open the doors to a better understanding at a price-performance point. Because we live on the beautiful planet Earth. But that's one planet in a massive solar system with all kinds of action going on everywhere, from the poles of the Moon to Mercury as mapped by MESSENGER [Mercury Surface, Space Environment, Geochemistry and Ranging] to what you can do in the outer solar system with missions that go out there. What Discovery did was open that entire frontier to whomever is interested. You can go anywhere you want within the cost cap and time or schedule. That I think was a stimulus, a catalyst to the community saying, “Well, we might be able to launch a mission that goes to Neptune.” There was one in the final four in this last Discovery 2019 [selection]; a brilliant mission called Trident. How do you get out there 40 times farther from the Sun, 39 times, whatever, than the Earth? But you can. It was credible and deserving.

The fact that we have grown that can-do attitude, which I think is endemic at NASA just from what I’ve witnessed over the past 38 years; I’m one person, so I should leave it to everyone, it’s a big Agency. But that can-do attitude of engineers saying, “We can do that for this money in this schedule for that problem,” is exciting. Before Discovery there were no programs like that. Every so often a “new start” (for a recommended mission) would be formed, there’d be a problem, and the National Academies said, “That’s a good problem. Go build a mission.” People would study it. There would be a formal selection of a science team. They would facilitize instruments. These places can build them [such as JPL], these can’t. Have a few little procurements. You go fly. That’s how the missions were done, the first wave of robotic missions to planets like Voyager and Viking. Some were done because we had to have a mission go map the Moon before Apollo. Others were done because we wanted to go look for life on Mars, etc.

The Discovery Program changed all that. It said, “Let’s bring competition with open frontiers to the table.” What does that do? Competition is good. We have competition in sports. We love it, it’s great, and inspiring. Who doesn’t love the Super Bowl and the World Series and all the things people love about athletics including the Final Four in basketball, whatever. Competition breeds creativity, innovation, training, growing a new community. The minute competition got involved things were good and getting better.

Now there's a downside to competition. You have to evaluate carefully and fairly because it's not a game you play in a three-hour football game. It's how do you tell people what you're going to do and prove it to them. The processes invented to review, peer-review, openly, fairly with no conflicts and transparency. It's taken time to make that. Discovery has proven you can do that. It takes individuals willing to work hard, but those that I've seen do it have done a marvelous job.

I think for the Discovery Program it's that open frontier opportunity through competition to catalyze ideas that wouldn't otherwise have existed. Before people would have said, "Well, we need a $3 billion mission to go to Neptune." Someone said, "Hold it, we can do it in Discovery, for less than one billion." Okay. It might be a 14-year flight where we're in hibernation for 12 of it. Okay. The Spacecraft doesn't care. It's not a person. It'll sleep kindly waiting for that chance to go do something. We can go into the atmosphere of Venus, which is very uncooperative, and measure things as if we're a flying rover "chemistry lab." We can do that. We can sit and listen to marsquakes. Or we can map Mercury, so close to the Sun that how do you even get there without ending up in our parent star? These are the kind of things Discovery has accomplished. Wow!

We can go visit asteroids, these small objects that are critical. They collide with Earth. They affect the history of life. We can go visit the parent bodies. I think the competed programs give us another element too. The Frontier, competition, which breeds good solutions, and it also increases flight rate. If you can control the program, you get more places to go more often, for more young people or anyone, early career people, whatever, to get involved. That grows the community. That inspires people. Every one of those missions, a discussion I've had with one of the Discovery Program scientists, also produces ancillary information, engineering data that relates to science that is in part the data for the planets that someday could be mined. There are all that ancillary housekeeping engineering environments data that is acquired to make sure the instruments are all working or they're calibrated. That's not the fancy stuff on the cover of *Science* and *Nature* when you discover a big thing. That's the secret sauce that lets that thing be proven. I bet a lot of our Discovery missions have these archives of things that could be looked through (e.g., ancillary supporting datasets) to understand more about our solar system, but it's a question of time and money to mine all of these things. Just like we relook at Apollo stuff and say, "Oh my God, look at what we collected in 1970, it was pretty darn good, let's go back and look at it."

Discovery, I think, breeds hope because every few years you can compete. Yes, the price of competition is not insignificant. But at least the first step is not limiting to many people—you often get 30 proposals for full missions to explore other worlds at "step 1." That's pretty dazzling. What's funny about Discovery is that because it was so effective early [1990s], the Earth science community started their own version of it called ESSP [Earth System Science Pathfinder] in 1995, 1996. I was actually the first program scientist for ESSP because we had lost a couple of Mars missions (on which I was a science co-investigator) and some of us needed a job.

It borrowed heavily from Discovery. What worked in Discovery, how do you apply that to Earth sciences? Now Earth is coming back with its own Discovery Program called the ESE [Earth System Explorers] Program thanks to NASA Headquarters, as recommended by the National Academies.

I think it has done its job better than ever imagined. In only 30 years, virtually all missions have demonstrated success. CONTOUR [Comet Nucleus Tour] had a failure, but I guess all others were successful and delivered thousands of times more than anyone would have ever expected. We have new kinds of PIs, new kinds of leadership teams, new kinds of instruments, new kinds of spacecraft, new kinds of partnerships. Everyone wants more. When the National Academy [of Sciences] says, "We want more of these per decade than we've had before, or at least as many, and that's something you can't cut," we got to do that. That's a pretty big testament to how important this is. I don't know. I've been bullish about these kinds of programs ever since they first appeared.

JOHNSON: I was going to ask you about that because your enthusiasm and your excitement about this program and the other programs like it and about exploration, you share your experiences often. I found some things on YouTube, and you've been on television. Talk about that and why you think it's important to do that for NASA, and maybe some of the fun things you've done and anything that sticks out in your mind that you really enjoyed the most.

GARVIN: As NASA people, I think it's part of our job, particularly in science. I'll say, "We serve really at the behest of the public to pay for us, to have the opportunity to extend our presence in this universe as per the [National Aeronautics and] Space Act of '58." Part of that job is communicating what we do. We train our astronauts to do that and they do a great job of course. They're very classy people, so we expect them to be great communicators. But I think all of us have a little piece of that to do. It's not just the social media things, it's communicating why this matters. Sometimes why it matters is lost on the esoterica of what we're doing. "Why are we listening to marsquakes?" people would say. Gee, another planet might tell us something about ourselves that we didn't realize was happening because we weren't smart enough to think outside of the Earth box for example. The way life works. May not work like it all happened here where we're so lucky to live. Maybe it takes another perspective.

I think communicating the excitement and passion for what we have done, can do, want to do within these envelopes. Someone once told me this. It might have been scientist-astronaut John Grunsfeld. Discovery missions are about the cost of a Hollywood movie, a big one. For the price of a movie that we're entertained by, oh, it's great, had a lot of fun. We're going to explore a new world for the first time ever. *The first time ever*! Whoo Hoo!. We remember the first time ever. Lewis and Clark traveled the West and saw places that other people had lived but no one had heard about in Washington. We can talk about that.

When you start doing that for the first time ever, you have to communicate that excitement. I think there's a lot of naturally gifted communicators. I call them *sciencecasters* instead of sportscasters. But those sciencecasting women and men, the ones I've been dazzled by and I've learned from, they're just natural at explaining what they're doing and why. Not in the way they could convey to their colleagues at a science conference. Here we are, we're at the Lunar and Planetary Science Conference and here's what we learned. You're going to talk with your science peers about the rigor of your result. But in the excitement of what did that mean to you and your team.

Just an example, our DAVINCI team will employ 1,600 to 2,000 people as we build our mission to Venus. Others may have more. I'm just telling you we have the workforce planning on our DAVINCI. We have to plan budgets. It's a lot of great folks. Every one of them have their story to tell of their piece of doing something that has not been done in this way ever before. That's pretty cool. When we were presenting DAVINCI to the selecting official, we made a set of selfie videos. We asked many people. We asked 40 or 50 people to each record a minute of themselves talking about why going to Venus might be interesting to their neighbor or their dog or cat or sister. They all came up with a different story. We pasted them together in a little video collage. To just see the excitement of people. It was tremendous!

One of our colleagues, our DAVINCI project scientist, was standing next to a babbling brook. She said, "Well, I like water. What happened to the water on Venus? I want to know. I have to go to find out. Because she's not going to travel herself across 35 million miles of space." Planets may be telling us "special things;" we just don't know. But you know what I mean. I think that communication element is an exciting part of it. I've taken it seriously, on DAVINCI we take it massively seriously. In fact, many people on our team are incredibly gifted communicators. One of our deputy PIs is one of the best I've ever seen. Literally *off the charts*. Could naturally do it anytime. I hope she gives most of our talks. Actually, our two deputies are both incredibly gifted in that regard because they can tell a story better than I ever could. Such talent is inspiring.

I like telling stories, because that's how we do things as people, I think. Whether it's your great sports story or fishing story or dance recital story or you had the best burger ever story, whatever it is, we have stories. I think we communicate that way. In my career I was lucky because at one point I was asked by Agency communication folks to appear on David Letterman's late-night TV show (January 2004). Now I was scared. My wife would say out of my mind. Went up to New York City. David Letterman, the host, he didn't even talk to me before the show, I guess because he was busy, and I was very unimportant. But it came out and we got to talk a little bit of science to the Dave Letterman late-night TV show audience on a national network. It was thrilling and scary and humorous. He was funny, I was not, because

I'm a NASA geek I guess that's incapable of being funny. But the opportunity to try to convey our story (about Mars) that way, imperfectly in my case, but at least was an exciting thing.

Those opportunities, giving TED Talks [Technology, Entertainment, Design] and things, are I think important. We need to tell people why it matters to us and maybe a little bit to them. Not totally. Everyone has their own thing to care about. If someone asked me why I care about Venus, I'd say, "Well, aside from the fact that she's right next door and we can't help but see her, the Moon and Venus, brightest things you're going to see except big comets, but anyway, she has a story to tell. It's a story perhaps of lost oceans. We need our oceans. They make us this wonderful livable "ocean" planet. That has saved us through a lot of human history and given us the capacity to travel, to eat, to learn, to explore. We're an ocean world. Venus may have been one for billions of years and then lost her oceans. We want to figure out why. That's a story for us to learn." If your neighbor builds a house and it burns down you might say, "Hey, Joe, why'd your house burn down? I don't want to have that happen."

I think we learn by those analogies. Communicating that in ways that people will see the relevance to themselves, to our existence thriving on planet Earth, and eventually across the solar system. It's dazzling. Science fiction paints a great picture of it in *Star Trek* and *Star Wars*. My favorite book *Dune* has another way of doing it. They paint that picture. But we're doing it now as we explore these worlds in the Discovery Program and others. Those stories need to be told too. They're not science fiction. They're engineering fact that produces science fact or interpretation, whatever you want. But those little pieces are the mosaic of how we get to learn our place in space.

I think the communication is part of the art of what we do. I can't paint a picture, but maybe I can talk a little bit about it "scientifically." Our colleagues, our women and men that are really good at it, they bring it alive and make connections. When an astronaut comes back from life on ISS or flying the Shuttle and they talk about it, just great. When we had our little experiment up on the Shuttle on *Endeavour* back in '96 [STS-72], I remember the commander talked to us and said, "What can you tell us?"

We said, "We'll give you your orbit good to 2 feet."

He goes, "That's pretty good."

I said, "We need to know exactly where you are if our laser altimeter is going to tell you the distance to the Earth good to 15 centimeters."

He goes, "That's pretty cool."

Then we said, "Hey, could you rock and roll the Shuttle a little so we can remove some biases over the ocean?" Totally loved it. There's the commander of the Space Shuttle doing things that of course they can do. It was just very neat to have that interaction because they got it. We were just a little fairly insignificant experiment called the "Shuttle Laser Altimeter" (SLA).

These stories, how people communicate through stories of things and relating them to who they're talking to, the public, their friends, neighbors, families, whatever, I think is part of our job. I think NASA does it pretty well. We win Web prizes, Webbys or whatever they're called, and oral history prizes and other ones. But sometimes just our people talking are worth it, whether it's in a little school or across the fence to your neighbor or standing in line to pick up food at a restaurant. We're an investment by the United States in doing things that have never been done before. We competitively earn the right to do them or run the competition to do them. Whatever we do, tell the story of the people that did them. That's a privilege and that story needs to be told in my view. It's not captured in an esoteric science paper even though that states the science outcomes. I think that's the beauty of these programs. We do have a communications outreach budget for these missions that engages people that know how to do this kind of communication really well. They know the mechanisms that work and I don't know them but they seem to all be good. Those moments are priceless.

I remember early. My Last story (I promise!). Early in the Discovery Program there was the terminal "impact" event of the Lunar Prospector mission where the spacecraft impacted the Moon. The communications colleagues at NASA Goddard said, "Let's do seven straight hours of live TV shots with a couple of people sitting in a chair bouncing around TV stations all around the country talking about why the Moon matters and what this could do, what this could mean."

I was one of the lucky guinea pigs, much younger then, no gray hair, all that kind of stuff. I could talk quickly I guess is why they wanted me to. I don't know. Whatever. They had a woman that was far better than I as well. We did it, literally sat in chairs with TV cameras on us, doing everything from stations in towns I'd never heard of to New York and Houston, Chicago, LA [Los Angeles], Washington, all the stations. It was amazing to see the interest. The weatherperson at station XYZ, I did one to Canada and we talked about the Moon and hockey, which is my favorite sport. But just to see the connections and how people made them, and how people do those kinds of TV live shots from their Web conferencing tools and their laptops on national TV. We did it during COVID. I think it's expanded the NASA reach for the things we do well. Yes, we have live stories from crew living on the Space Station. That's incredible. They call us in our schools. "Hey, Commander [Scott J.] Kelly, what's it like up there after 300 days? Don [Donald R.] Pettit was up there during the 9/11 [attack, September 11, 2001] and lived through that. Amazing, pretty much, to me.

I think that's part of our legacy, the stories we tell about the experiences we've had. Telling it to the people that have funded it and allowed us to do it is part of the game.

JOHNSON: As far as communication, you also have to communicate up the chain. I know you've briefed some Administrators about some different things. Maybe talk about that relationship with NASA Administrators. Some have more of a science or engineering background than others. There are different personalities involved. Talk about that for a few minutes and the different Administrators you've worked with over the years.

GARVIN: NASA has been gifted with a lot of great leaders. Lord knows, it's pretty stunning. I certainly haven't known many of them. But it's a privilege to have witnessed a few in action. When I was a youngster literally early in my career at NASA, I worked for Sally Ride and we outbriefed what it takes to be a leader in space after *Challenger* to Administrator [James C.] Fletcher, who had come back to NASA after *Challenger* to help get us back to flight and all the good things he did. It was thrilling and scary, but he was a very good listener and he listened. I had to give a part about how we define leadership across our agency. Actually, I presented the case for building an outpost for people on the Moon as a demonstration of leadership by the United States in 1988, because we weren't flying a Shuttle at that point, so the Moon looked pretty good. It had been a study that Sally and a bunch of us had done after Challenger. Just to talk through that with someone that asked these penetrating questions like well, so that's a great idea, Jim. I can't remember the exact line of questioning but it was penetrating.

Later I was asked to chair a special decadal planning team activity for Administrator. Goldin, who was a very technology-smart person. Understood science, passionate about Mars.

Big telescopes. He was a thinker. We used to say his hair would go on fire when he didn't like what you were saying. You could see it in his eyes. Very scary. But I remember one time we were outbriefing to him about the ideas of these meta-architectures to put people in new places. We wanted to send this message of going anywhere anytime as human explorers, sometimes ourselves, sometimes projecting ourselves into hard places would be the ultimate goal of exploration. We've got the solar system. He was asking questions and he said, "Well, we've already done Mars. Why?"

I was literally (and this is unfortunately rarely), but I was at a loss for words and I stopped. This whole team of people who I was working with, very smart, astronauts, others, they looked at me and I said, "Hold it sir, Administrator Goldin. We know almost nothing about Mars. Nothing. We are in a kindergarten level of understanding. We think we're a senior in high school. We're not there yet. It's going to trick us every time we go and it always has. That's why we have to keep going so that women and men can go."

He stopped and he looked at me and he looked mad. He said, "You're probably right. That's why we need a Mars Exploration Program. We need to sustain it so we can open that frontier the way we did the Moon very early with Apollo." He thought about it, had great ideas. I'm thinking this guy got it. He could have fired me on the spot for disagreeing with him. I was scared afterwards as all the colleagues on our team were that we would be sent to outside of the United States let's just say. But we kept our jobs and it was great. But I appreciated Administrator Goldin. He had an opinion based on a lot of good missions had gone to Mars. Lot of money spent. But he got it and we had a great Mars Program thanks to him and others.

I was fortunate to have known several other Administrators and had a chance to brief them. Charlie [Charles F.] Bolden was a wonderful guy, and he was very much in favor of making the Mars Curiosity rover and then Perseverance. Be that projection of robotic spaceflight. With Sean O'Keefe the idea of going back to the Moon and flying the LRO as a first step, loved it, and he was all in. It was great to see them excited by it.

I got to meet Senator and Administrator [Bill] Nelson right after he announced that he was selecting two Venus missions a year ago in June 2021. He came out to Goddard and we showed him our DAVINCI test gear that we would test for the Venus conditions of our spacecraft. Myself and our two young deputy PIs and other engineers explained it all to him. He was wonderful. Listened, asked great questions. He and Bob [Robert D.] Cabana were engaged with us. They were excited about what we were doing. To see that in the eyes of Administrators and senior leaders, and we can go all the way back, but I only had a chance to really personally talk with a few, was just unbelievable. I knew Fred [Frederick D.] Gregory very well when I was the Chief Scientist for NASA. He was an Acting Administrator. Then my friend Chris Scolese who was an Acting Administrator too and who I learned from at every step is an engineer who appreciated science, and values that interaction that they get from some of us very eccentric scientists, of which I am definitely one. My wife reminds me routinely.

Interacting with the big decision makers is exciting. Begging—not begging—asking politely to the Administrator to get the money to start LRO on the streets of New Orleans, which is a great town, I don't know what I was thinking, personally. But made it happen. The LRO mission is still flying. So, hat's off to him. I was just perhaps ill-advised to have picked that moment. But then again, we were walking to a restaurant. I think we all had a good time; it was great.

I was lucky that some of the other slightly less than Administrator leaders took the time to occasionally listen to people like me and others. Sitting in the Columbia Cafe on the ninth floor at NASA Headquarters saying, "We've got to do an LRO to the Moon. The President will like that. It's going to deliver for us." The fact that they went and energized it so we got to do it. That's pretty amazing. I remember vividly right after New Year's in 2001 the Office of Management and Budget working with the President, then President Bush, said, "We want to see your architecture for enhanced Mars Program."

We went over to the big guns at the people that make the budget for the United States. We briefed them and after a while they were confused. One of them said, "Why don't you go up on the whiteboard and draw me your vision of what that Mars Program is, Jim?"

I said, "Okay." I'm happy to go to the whiteboard. Not very artistic. I drew something that had reconnaissance, rovers, people, samples, looking for life. I said, "This is what we want. Some of the pieces we don't know how to do. We do want to get people there but it is a bit far. We haven't been back to the Moon yet and all that." We called it "Seek, In Situ, Sample."

They looked and they said, "Well, this makes sense. You do the recon. You send the rovers. You bring the labs with them. Then you bring the samples back. Then you send the people. There's the Mars Program." They gave us, not just thanks to me, lots of work by many people smarter than me. They gave us a budget plus-up to do the new Mars Program. Next day it was in the budget! We could start what become MRO and MSL [Mars Science Laboratory]!

People are willing to listen if you get the opportunity, and NASA I think has a great brand of delivery. We built a Space Station. We went to the Moon. We're returning samples from asteroids and someday from Mars. We built a telescope the size of tennis courts that can see back in time like no one will have ever imagined with the James Webb. Our Discovery Program has touched so many different kinds of objects it's not funny, from Mercury out to the outer solar system. I think if we were a movie-producing studio—we're not, it's all real—the engineers, managers, scientists, everyone at NASA has delivered on the promise of doing some of the stuff that I think in some sense is part of the American experience. Or so historians have said. Whether you believe the [Frederick Jackson] Turner thesis or not [the importance of the American frontier], that idea of the frontier percolating into how we think about things has been at least at times a part of the American experience. Comes and goes, I guess. Different flavors.

I think NASA has been the embodiment of that and people can debate, argue. That's why. I appreciate talking to big leaders because they often understand things far deeper than some of us, and they can tell us. When you're mentored by people of the caliber of a Sally Ride, my God, that was wonderful. Noel [W.] Hinners, who hired me right out of graduate school, I don't know why, but he did, and told me to go do Mars and Venus. Okay. I've actually been lucky enough to have those things happen. Flew experiments on the Space Shuttle. Oh my God, what a phenomenal thing to do that. These are things that 500 years from now if people said, "You actually flew a Space Shuttle? You did the first ever mission to do X? Why did you fly a camera that could see things this big on Mars back before we even knew where we were going? You used lasers to measure stuff? Why? Radars?" And yet this first wave of the first 60 plus years of NASA have done all that. I think 500 years from now we'll look back. Programs like Discovery and things we've implemented. They'll say, "Wow. That was pretty smart of those women and men."

JOHNSON: Considering your background, and because you've been in a lot of management positions, but right now as a PI, so you're getting to do something that you've wanted to do for a while, are there any other things, maybe some things that were proposed that didn't get picked? Or some things that you still personally want to be involved in going forward with Discovery?

GARVIN: First, my job now is to make sure we get back to Venus with DAVINCI in our June 2029 launch window. While we're doing paperwork now, it's going to get serious as we get moving and building things and getting all these people working. It's a privilege. I've dreamt of it since I was in grad school in the mid-1980s. Now the United States goes to do it. In 1983 I went to the Soviet Union after they had just landed on Venus with their Venera spacecraft. Now we're going with next-generation stuff. That's my job.

However, I've written a lot of proposals. There's a few things I touched that I would like, I think are important for NASA to do. They come and go because it's not just me who thought of them. But I think we need to fly an ice mapping mission to Mars that discovers what I call the "undermars", which would be the ice sheets that are buried under dust and sand and rock, because that is going to be a resource for science and human exploration like none other we're going to get to in the solar system in the near term as we go to the Moon and Mars. I think it's just calling us. It's been hard to do because it's sort of in that gray zone between science, human exploration. It's esoteric. What? Radars that use weird stuff to find ice? Who cares? But it's a necessary tool. It's like people didn't believe in MRIs [Magnetic Resonance Imaging] based on the technology they had until they started to show us things inside our bodies that told us, "Your knee is bad. You might have known that. But it's real bad, we're going to fix it." Good.

I think Mars needs its "knees fixed". In this case we need to find the ice that's lurking just below our rover's feet or wheels I guess, so that we can open that frontier. That may be where Martian life if it ever existed could have recorded its story. That's one thing. I've written proposals actually with the present NASA Planetary Sciences Director. Wrote a proposal called

MOSAIC [Mars Orbiter for Surface Atmosphere and Ice Chemistry]16 years ago to map the icescapes of Mars with a kind of radar and lidar. There have been 10 other proposals, some in Discovery, some independent. I think that's something NASA has to do. It's going to open the Martian frontier. Radars are unassailably good at doing certain things. They map the Earth. They can be helpful at the Moon. Mars is the perfect place to go. There's a little atmosphere and there's tons of ice under the soil. We can find it, so we have to do that. Someone has to do that kind of mission, an ice mapping mission to orbit, with partners, without. I think we know what to do. That will be a step. I want to see someone do that, so that's one thing.

I also think, and this is kind of crazy, but I also think that a mission to the polar caps of Mars, not that I've ever proposed one, to that big ice core record of the climate history of another world, robotic, maybe someday with humans, would be dazzling to do. There is a story. The science we do on Earth in the ice cores in Greenland and Antarctica tell us the climate history. We got to imagine how to do pieces of that at Mars, because it's going to be an eye-opener. Mars has a topsy-turvy climate history. That's two.

I had a vision to use Hubble to look at the Moon to do something beyond pure science, and it happened. I still cannot believe it. I pinch myself thinking that we took Hubble Space Telescope and took several orbits of it, nulled out all the guidance sensors, and stared at the Moon, and looked at ultraviolet light, and figured out how that could tell us about minerals that if we found them in that concentration on Earth, we would be mining them as ore bodies. We found them at the Moon the same way Dr. [Harrison H. "Jack"] Schmitt found them at the Apollo 17 site when he was there in 1972 with Gene [Eugene A.] Cernan. Oh my God, that was just the power of the telescope applied in new places. We used it to watch dust storms. Hubble watched dust storms on Mars. James Webb will look for organics in the plumes around Europa this year. These are things I hope that happen.

But the other thing that is a connection that I think NASA is particularly good at is we're sitting on this special planet Earth that's been impacted by asteroids and comets throughout our history, same way as the Moon and Mars, Mercury. That record of those impacts is our ground truth for the processes that we're going to live with when we go and live on the Moon and live on Mars. That Mission to Planet Earth that was first invented as a name in the late '80s to sell a program known as the Earth Observing System, EOS; I'm hoping that it will expand its sights and apply some of that planetary knowledge back to this aspect of planetary defense, understanding that impact history of Earth, which we know has affected the history of life. The association of the Chicxulub impact with the death of the dinosaurs is incontrovertible now with new work by Robert DePalma and others. They found the dead critters at that time with the stuff not from Earth in the ejecta. That raises the question. What if there's early Earth ejecta on the Moon? The Moon becomes the attic of the missing part of the Earth history that's gone. That's another opportunity for the Moon to shine in all the other ways it can.

I have my dreams. There are technologies I think would be fantastic in space. I think pushing quantum computing as a tool in space to come back is something we need to do as we use it for all the reasons on Earth we can use it. But I think space is a frontier where its application would be extending value if we can figure out how to do that. Of course, it requires certain things.

The final thing is I think sometimes we don't imagine enough what we can do with people in space. We're used to people as the kind of explorers that have done great on Earth. But as astronaut-scientist Piers [B.] Sellers and I were trying to talk about now 12 or 13 years ago, a human crew in Mars orbit operating surface robots that can go to places they would never let us go as astronauts or people. Climbing cliffs with cliffbots and sampling stuff and then blasting it up to our human-crewed Mars orbiting facility to study before we send it back home to Earth, or to make sure it's safe to send home to Earth. Sometimes we need to get just close enough to be dangerous. The way James Cameron dived on *Titanic* and filmed things. He didn't go down 12,000 feet. He had the ROVs [Remotely Operated Vehicles] go down. But he was there controlling them.

Sometimes that standoff nature can allow exploration, like we've done from Shuttle, like we did in the Apollo orbit of the Moon. Mars may be an application where that application of robotics, with people close by, computing assets, transfer of stuff could really shine. Because Mars is a big place. We'll go to some places at the surface, we'll set up outposts, and they'll be great. Someday whatever else. But it may be that the humans, the people, the women and men, in close proximity can do a lot. They could go to Ceres, which clearly may have an ice water salt history.[1] If you even go to Venus orbit and operate things that would have short-lived but directed application to places that are hard to get to, 11,000-meter-high mountains on Venus may not be a place you're going to risk a lander, but maybe a human-controlled system could get close and do other things.

In some sense projecting ourselves to being just close enough to do the work where we're not interrupted by light-time delays that are tens of minutes or more would extend our presence in ways that is a step toward the sort of *Star Trek* kind of thing. I'd be excited to see that. Not that I don't want boots on the ground wherever we can go. I know that's controversial, but I think we can probably do humans to Mars orbit before we know we could ever land people there.

[1] Ceres is a dwarf planet and the largest object in the asteroid belt between Mars and Jupiter

That may be incredibly exciting as women and men are living on the Moon. It's just a thought. Maybe the lunar Gateway will show us how far we can push that model as we go back.[2]

But anyway, there's a lot of things we can do. There's the unimaginable swarms of NanoSats and bots that can go and do things, and submarines on Europa [moon orbiting Jupiter]. There's too many for me to describe. There's a few that I think are important to do. They could be done within Discovery. They could be done in other ways, not necessarily with human spaceflight, but anyway. We have already done a lot. I think sometimes we need to pause and look back at the last 20-30 years and what we've done, and the last 60 as well, and then project ahead 60 and say, "What if the next 60 years is equally interesting? Where will we be in 2082?" Going to be a different planet and a different time. I hope thanks to our measurements and our understanding we'll make it a better place. That's why we do it, aside from being darned curious, and as engineers really wanting to build the stuff that no one else can think can ever work, and they do all the time by the way. If we didn't have the masterpieces of engineering we do, we wouldn't be anywhere even pondering the science. It's an engineering frontier made possible by some interesting science questions and some good managers that get us the money.

JOHNSON: Thinking about that formula for those great things with Discovery, if you had to pick three or four top lessons learned from the Discovery Program, what would those be?

GARVIN: Okay, that's a toughie. Of course, the Discovery Program has evolved. I like the fact that it was pre-seeded with missions like Mars Pathfinder and NEAR Shoemaker to get it started,

[2] The Gateway, a vital component of NASA's Artemis program, will serve as a multi-purpose outpost orbiting the Moon that provides essential support for long-term human return to the lunar surface and serves as a staging point for deep space exploration.

to prime the pump. That was a lesson learned that was positive. If you start a new program, test it with something that you've already thought about to get it going so that you have an existence proof. Then the first mission selected, Lunar Prospector, was modest but big in science. It fit the box. It didn't stretch the box and break and be delayed 10 times. Those were successes, the NEAR Shoemaker, the Mars Pathfinder, and Lunar Prospector, as the first missions out of the gate. I think they gave people the confidence we can do this. That's a lesson learned. If you start too big and you fail, they may not give you another chance. If you start carefully it's going to work. Then you'll be able to increase the scope and do missions that return samples, make craters, go to Mars, Mercury, now Venus. It's great. That's one big lesson.

The other one is I think we've learned that the evaluation process is not perfect and never will be. It's all about people. In the end the final selection can be also coupled to programmatic factors that senior people at NASA have to look at budgets and portfolios and decide, "Well, I can't have 27 missions to the Moon and none anywhere else, as much as I like all the bids. I can't; I have to spread the net widely." I think the lesson learned is not Discovery's fault. The community has to know that the factors that lead to selection—it's not like your report card in middle school math class. You got things wrong, there's your grade. It's more complicated than that. The lesson learned is tenacity in a program that has frequent opportunities is a good thing. Keep proposing. It might take you a few times.

Sean Solomon, the PI on MESSENGER to Mercury, said first time he thought he proposed a winner it didn't win. He proposed it again, he won and flew. He fixed it, made it better. He learned from mistakes. That tenacity in learning; sometimes people give up. We wrote a good proposal, they didn't like it, try again. We wrote the core of the DAVINCI mission proposal four times. We got good scores, many of those. Still didn't get selected. Okay, so we fixed it, did it better, finally got selected. A little patience and tenacity pays off.

The other thing is to innovate with people. Give people a chance on these missions. Some people said, "There's only one kind of person that can be a PI," and that's balderdash. PI is a tough job. It's a little bit lonely, but if you build a leadership team it's not as lonely. It's not even if the buck stops at the PI to make the final decisions where your tail feathers are on the line. It is a team effort. Team perspectives take a team, and I think Discovery has learned to build teams that are just that. That can be enhanced with directives in AO language.

Another lesson I learned, having done it way too many times, is that 1,500 pages for a final Phase A report that goes into final review is a bit much. Here's why. We all want to write everything down we think. The observation is that the review process can't handle it. You think you explained everything in the clearest language known to woman or man with the best figures and they probably only had time to read half of it. It's a lot of material. When you give them a 25-page science volume with dense figures and 500 references, if you don't attract them in the first page or two and then explain it in a good traceability matrix, you need to do all the rest. But I guess my question to the Discovery Program process developers now, having gone through this for 30 years, maybe there's a little correction, and the correction is that maybe it's at step one, doesn't have to be a step two, maybe we can templatize step one and say, "Here's a Web-based form. Fill it in. Here's your figures (or space for them). Here's your text (in a text box). Here's your tables of engineering stuff. Here's your cost. Fill it in. We're going to evaluate that as your first gate of entry." Maybe it's a pre-step one, just to see. You'll probably get more ideas. People don't have to get every partnership worked out with signed letters promising vast sums of money. We might see more innovation and maybe we won't get anything better in the end but maybe we'll see more possibilities, and that could trigger investments beyond NASA to bring value later.

One of the big things that Discovery has shown us is there's probably a sub-Discovery class of missions for planets that can use rideshares and other mechanisms of getting out there that are more focused, higher-risk, but can still do good science, and maybe they won't have the massively high nineties success rate. But maybe they'll be 75-80 percent successful and they'll cost 25 percent of a Discovery mission. We'll get to more places and try out more things and make more PIs, give more young early career people a chance to be involved. I like having everyone who wants to be involved in something, but you can't afford it in Discovery. I'd like to have a 50-person science team. But my budget folks say, "Well, you can only afford 20." Because that's the carrying capacity of the program.

A lesson is we want more people involved. Maybe Discovery can't afford that at present. Maybe a sub-Discovery program or an option that NASA could consider as a pilot, doesn't have to be part of Discovery, to do that. Yes, we've tried things like SIMPLEx [Small Innovative Missions for Planetary Exploration], and that's even different. I think Discovery has shown us things we want to do that didn't quite fit within its excellent framework. They didn't fit either because they were too hard, that's understandable, or maybe they could be broken up into smaller pieces that could be bid in different ways. That would give us more opportunities.

As the 2022 Planetary Decadal Survey just said the other day in their latest report, making more opportunities for people to be part of this, exploring our universe, our solar system, is the ultimate goal. More kids, more schools, more engineers, more public. Citizen science is good. Maybe we could even imagine Discovery missions that are 30 percent citizen science! You do what you're going to do and you send back a lot of data and say, "Hey, public. We're going to guide you. Here's some tools. Write your own programs. Let's see what you've got." I don't know. I think innovation is going to come as commercial space does more things, as access to space increases because people need it. Look at what Amazon is going to do with their fleet. I think that could also expand. There's a lot of other little things.

Discovery has been so successful that there's no major flaws because it's evolved with the times, organically. Yes, you have to be rigorous if you're going to invest so much money in missions. I believe that. But we haven't gotten it wrong, aside from a couple of things that have broken at the margins. The program has been magnificently successful. There's been one flight delay that was unexpected because hardware just didn't perform, and it was from contributed hardware from a foreign partner. Another one that had a failure with the CONTOUR failure, which is better understood now. We've learned from it. Hasn't happened again. We've done piggyback experiments in Discovery that were brilliant. The Moon Mineralogy Mapper that Professor Carle Pieters flew as a Discovery mission of opportunity (MoO) niche thing mapped the whole Moon. That's pretty good for $40 million. Good job, Carle. There's no complaint there.

Again, when something's really good, lessons learned are often just following up on things that people have already done. I don't know. I think when I look at the missions that have gotten to the final four, final few of the fully selectables, whatever they are, they're all worthy of flying. It's too bad we don't have more money. But if you want to keep the flight rate going and the competition rate as often as you can to get more people a chance, then you can only pick so many and fly them and wait for the next. How many teams win the Super Bowl every year in a row? Very few. Can't keep the teams together. It costs money. I think the flight rate of Discovery has been really good for NASA. That's I think going to be really important as something that keeps the spirit alive. I realize that's trite. But it keeps the energy going and people wanting to try new things.

Having things like TDOs where you can fly a tech demo as an experiment of opportunity is a great thing. On DAVINCI we bid four TDOs because we had four ideas that we thought were credible. They picked one. We turned others away. Because we had excess capacity on our spacecraft. I've rambled on a bit–sorry about that!

JOHNSON: It's good. It's all good stuff. I appreciate you talking to me. But I just had one quick question, and then if there's anything you wanted to add after that. But if you had to look at the work you've done with Discovery, is there anything about it that you think of as something that would have been your most challenging moment or the most challenging work that you had to do?

GARVIN: I think being selected as a PI on a Discovery mission is definitely one of the most challenging, because I feel a strong obligation and commitment to mission success on cost and schedule as per the promises we've made for our team in our proposal, for all the perhaps 1,600 women and men that will work on it. That's the challenge ahead. I think there were cases where we bid things, teams that I was a part of, not only with me as PI, but in cases where I had a role, which were a stretch technologically. I was on a team that bid a kind of exo-atmospheric kinetic landing system to go to Mars that would have used the techniques that are used to fly cruise missiles around to land on Mars. It's a great delivery system. It's really elegant. Obviously, our DoD [Department of Defense] knows how to do it. But applying it to planets is going to incur fear and risk. That would have been a challenge to actually deliver, just because we don't control that technology. It's something you gain access to through partnerships and then you fly it. Do I think it would be great? Yes, but landing on Mars is a hard thing, as most nations have discovered. I think that would have been tough.

But there's no real regrets. I think bidding and losing a lot is a learning experience. A lot of teams failed to win, but the ideas were good, the science was good, the engineering was good. The mission we bid to send a radar to Mars [MOSAIC, 2006] had a great instrument, a great science team, a great management team. We just didn't design our spacecraft well enough. I realize that. It's my fault, and I should have done a better job. The review process said, "Spacecraft might not be up to the job of generating 2 kilowatts of radio frequency energy out and sending back 50 terabits of data." We could have fixed it maybe, but we bid it maybe a little bit ahead of its time. I think there's things that I would have thought were harder than maybe we realized. Sometimes we have an aspiration for a mission and it's really a little harder when you get down into the details.

JOHNSON: Is there anything we haven't talked about that you wanted to add?

GARVIN: Sandra, I would just say this. Sometimes NASA fails to sell itself well enough. I'm not saying that because we're not trying to. Of course we are. But a program as rich in deliverables as Discovery across multiple teams, targets, processes. The fact that it's worked for 30 years and covers of the most prestigious science journals are littered with its discoveries is a tribute to NASA and the people that came up with that idea, who put it together, back there in the early '90s. Those were smart folks. I think Mark [P.] Saunders, Lisa Guerra, there are a bunch of others who were part of that early process. They gave us something that's a gift, and it's still going.

It's stood the test of time and gotten better. The National Academies agree. The latest Decadal Surveys say, "Keep doing it." Other programs in other areas at NASA say, "We want to do that." Sometimes we have to stop and celebrate a little bit the successes and look for what transformations can a program like this could achieve in the next 30 years. What do we do now to make those happen, even if they're not going to happen right away? Because it's working. I always believe for me personally I got my chance. I'm going to focus on it, but I also want to give back to all the people that are going to propose in the future in a few years.

I hope that the Agency will use us folks that are going to be around for a while. I've got 10 plus years till we finish DAVINCI, let us help in ways that are constructive. There's no self-interest I have except flying DAVINCI. I'm not in conflict with anyone. All targets are good for the best science and engineering that can do the job. Grow a new cadre of PIs who can go do great things. There's a lot of exploring left to do. Space is a big place, and it's a happening place. I hope all of us—maybe someday a gathering, as COVID-19 gets better (or is eradicated), of the PIs and the Discovery Program could all get together for not so much a formal thing but more a fun gathering to just celebrate, maybe after Psyche launches in 2023, and say, "We've done all this stuff. Who would have thought we would have gone to all these places with all these missions with all these discoveries?" It's almost unimaginable. That's my final one thought.

JOHNSON: Okay. I appreciate you talking to me and giving me all this information.

[End of interview]