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 February 9th, 2022. This interview with Dr. James Garvin is being conducted for the Discovery 30th Anniversary Oral History Project. The interviewer is Sandra Johnson, and Dr. Garvin is in Columbia, Maryland, and talking to me today over Microsoft Teams. I appreciate you taking the time to talk to me today and for this project. We really appreciate your participation. I want to start by asking you to briefly describe your background, your education, and your interest in geological science and how you first got interested in working for NASA.

GARVIN: Thank you, Sandra. It's a pleasure to be here. I'd like to start with saying that I am sort of "*NASA by birth*" as my mother would say. She passed away a couple years ago. I think that's a good intro to me. I was fascinated and beyond idly curious about the universe, the Moon, rocks, and all things like that ever since I first started getting dirty as a young person (as far back as 3 years old!). I think that was a lead-in for me, with encouragement from family and friends, to pursue my lifelong interest, which has been to work for NASA, where I've been for over 37 years, plus 5 years in grad school, so for quite a while.

My background, Sandra, is broad. I'm interested in science in all 360 degrees of what makes pursuit of curiosity-driven research possible by women and men, and through the lens of doing that as we explore space, which I like to call "the forever frontier," not the final one, but that's just because I think it is, and just my personal viewpoint. My interest in that then comes from seeing the world around me as this fascinating masterpiece of the underexplored, perhaps not completely understood things that are the myriad of our lives. I think NASA embodies that by bringing that picture broader than our own backyards, our neighborhoods, all the good stuff we like as people, by putting it into bigger perspective. *What is our place in space?* I liked that ever since I was as old as I could read a Quiz-Me book. I used to look up and say good night to the Moon, but wondering who the Moon was, and wanting a piece. Now we study Apollo samples, which are greater than "science" gold as many would say.

My background became focused on pursuing the natural world here and there. I grew up in the era of Apollo, was absolutely thrilled by it as a kid, seeing the Apollo 11 landing, and actually being thrilled over the Apollo 8 voyage to the Moon as well. Really evocative and spiritual and scientific all at once. I think exploration does well with that. In fact, right now I'm the principal investigator [PI] on a Discovery mission to the planet Venus [DAVINCI: Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging], named for a great explorer known as Leonardo da Vinci. I think of da Vinci as that kind of person that aspired to use art, science, technology, math, people, humanity together to solve problems and see the world differently, and that's what I think we do at NASA, and that's what interests me and has kept me motivated for 45 plus years.

My background. I lived all over the world as a kid, spent three years in the Middle East in Beirut, Lebanon. Saw the deserts of Upper Egypt as an impressionable child, went into King Tut's tomb[1] when the walls were still covered with gold leaf, which was *kind of wild*. Saw the big, beautiful rocks, Libyan Desert glass, of course tektites, and things of interest. But was able to travel there to see history as it was, then went to Australia, lived there, loved Australia,

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[1] The burial place of Tutankhamun, pharaoh of the Eighteenth Dynasty of ancient Egypt (ruled c. 1334–1325 BC), located in the Valley of the Kings, near Luxor in Upper Egypt.

another dimension of our planet. Stopped at tropical islands, visited the volcanoes of Hawaii, the wonderful volcanoes of New Zealand. These things just enraptured me. It was beyond captivation!

I remember my grandmother describing the eruption of the island off the coast of Iceland known as Surtsey that erupted in the ’60s when I was a little guy. I was like, “Oh, is this dangerous?” She seemed just intrigued by it as she lived to be over 100, as a little woman who was interested in people, places, and family. That caught me too.

I managed to go to school and was motivated by science, and whether I had talent or not, I was passionate. I think that’s a big thing for young people. I was lucky enough to end up in a school system when I was in my formative middle school and high school years in the town of Westport, Connecticut, where there was an incredibly encouraging cadre of teachers who gave me an opportunity to try to learn new things. I didn’t always succeed, but I loved the chase and the learning and the spirited teaching and the colleagues around me, many of whom were brilliant, and they challenged me. I did experiments in high school that I look back and think kids nowadays would never be allowed to consider, to set up 1,000-volt generators, to scrub the burning leaves in a burning leaf experiment in a chemistry lab, which we did. I mean the ionized air. We had large cloud chambers with high voltage using radioactive materials. We did things that I’m sure nowadays would [not be allowed]—safety first. But we were able to be curious with few boundaries in my science experience in the Westport School system. Wow!

I experimented with aquatic insects, the largest water bug (aka “the Giant Water Bug”), which is about the size of a cockroach. It’s a rather fierce beast and will suck a frog dry in about a minute, common in ponds where I lived in southern Connecticut, and was fascinated by these voracious predators that large.

I luckily managed to get into a university situation that also brought the open-ended encouraging education that gave me a chance to pursue my dream of working at a place like NASA. My parents were nonscientists, and it was interesting to see them allow me to be or try to be a scientist. My mother was especially encouraging. She went out to acquire for me blocks of dry ice to do experiments from begging local pharmacies for them. I don't know how she even got them. Big blocks that now I guess they would ship food in. But whatever, she'd drop me off at swamps where I was trying to discover certain things about the swamps and aquatic insects and liverworts, and would sit there in the car for three or four hours while I mucked through swamps looking for the wonders of nature. This was all by way of background.

I ended up at a university notable for a very open curriculum. It's Brown University [Providence, Rhode Island], and a lot of NASA folks had been there and went there. When I was at Brown the person who became the leader of the Viking [Program] lander imaging investigation on Mars was a professor there, and I took a class from him as a freshman. The class was about exploration as a mode of thought, not as science or history. That theme I think is the theme that is suffused in NASA's competed Discovery Program for exploring the planets robotically, of course with humans separately within Artemis and other programs.

For me that was a hook. While I loved math and wanted to engage with advanced computing, this was cool, because it was exploration by people, and how it worked, how it was going to work as we were going through Apollo, post Apollo at this point; but anyway, and thinking about what was next, dreams of humans on Mars, space stations on the Moon, all these things that came out of Apollo with the hopefulness as we were building the [Space] Shuttle, all those things captured me as an undergraduate. So, I took a myriad of classes, studied computing, and was hooked on aspects of geology that could be applied to planetary [exploration]. I took I think the first class ever given at Brown University on the geology of Mars, and thinking that you can actually do that in the ’70s as Viking landed on Mars, to look for back then putative signs of the kind of microbial life we know on Earth.

I was bedazzled by that, and ended up going to Stanford [University, California], got a master’s, working in computing, but applied to planetary, and then came back to Brown to do my PhD at that point with the scientist who was the leader of the Viking Lander Camera Investigation, who ended up being an Associate Administrator [AA] at NASA Headquarters. While he was being an AA for Science [then called OSSA, Office of Space Science and Applications] as we say, I was one of his last students starting my PhD work. It was then that I really was captivated by connections at human scales on planets, the third dimension, the rock scale, what makes that tick. It’s kind of like a Sherlock Holmesian Victorian novel—how do forensic techniques let you put it together, but quantitatively. That’s how the water flows and the wind blows and the craters form and the rocks move. That was good to me.

I’m sorry if I’m rambling a bit here. For me this got me going. When I was finishing my PhD, which connected landing panoramas of the planet Venus collected by the then Soviet Union to the connections we’d made with our Viking Program at Mars and to some extent what we saw on the Moon at Apollo, but less so, because of course the Moon is an airless natural satellite and Mars and Venus were different—I had a vision of interpreting these human-scale views of other worlds to our own. So, my thesis was about those connections geologically, using techniques of geology and radar remote sensing, and putting those together to set a framework for exploration. I was very lucky because when I was finishing my dissertation, I got an opportunity to come and work for NASA, which I never thought I would ever have. Most of us go off to postdocs, great things to do. I just got lucky. The Center Director at NASA Goddard

[Space Flight Center, Greenbelt, Maryland], Dr. Noel W. Hinners, hired me as he was a geologist; he had been an Associate Administrator in the ’70s, and helped the Apollo Program go to the Moon. He hired me and said, “Let’s do Mars and Venus, Jim.” I thought hey, pretty good. That got me going.

Then fast-forward. While there I realized there were huge measurement gaps. The connection between engineers who build great things, those women and men, scientists who think about the problems that they can’t solve or would like to solve, and the programs that get us to do those things in space brought me the so-called perfect storm in my career. In the late ’80s I realized we needed to measure the third dimension of the Moon and Mars (and Earth). The landscapes at the scale you and I would drive our cars, walk our kids over were not measured. That’s the landscape that we see and experience. The third dimension matters at local and big scales.

I went on a crusade to develop new measurement tools with engineers—I hardly developed anything, but told them what I wanted to measure. But promoted the development of the idea of measuring the third dimension using techniques involving lasers. I was told, “This is dumb, silly, forget it.” But actually, one senior guy [William A. “Bill” Quaide] who had been a key player in Apollo said, “Jim, pretty cool, we should probably give you a chance at trying this.” They gave us some funding. I’ll never forget when we got all these negative reviews and this gentleman said, “Let’s go do it, give you guys a shot.”

We within a year were flying it over the Grand Canyon at 40,000 feet showing we could measure every little crevice down the walls of the canyon and up by bouncing laser beams off of them. In fact, one time, a story I love to tell, the terminal control area [TCA] of Los Angeles International Airport, LAX, was saying to our little NASA [T-39] plane, “Hey, what are you guys doing at 40,000 feet going back and forth across the Grand Canyon above the terminal descent area for all those flights coming into LAX over western Arizona?"

We said, "Well, we're NASA, we're doing our thing." It was exciting. That gave me a chance to propose with a team to fly an experiment on the Space Shuttle, which we did twice, the Shuttle Laser Altimeter [SLA], which was really Discovery-class science in action with human spaceflight. We took spare parts and flew a next-generation kind of instrument for a few hundred thousand dollars, other than the price of being on the Space Shuttle, which is priceless, to measure the relief of the Earth at foot scale.

I'll never forget on STS-72 on the Shuttle *Endeavour* talking to the captain and saying, "We're computing the orbit of the Shuttle good to about 2 feet now, so we'll know where you are, good to 2 feet, with our laser altimeter and other solutions."

He wrote back and said, "Well, we've never been better than 1,000 feet, how do you do that?" We were tracking the Shuttle and other spacecraft and doing things, and it was just way cool to see how engineers and scientists could do that. Of course, we do that now on the [International] Space Station [ISS] with the GEDI [Global Ecosystem Dynamics Investigation] experiment, and we map Mars and the Moon that way.

For me that journey was connecting my curiosity and questioning how things work, the physics, the chemistry, I love the biology, I'm not a biologist, so the rocks, I like to tell the kids, never really lie, so it's cool. Life is tricky. But connecting those to the measurement gaps, the things that are unmeasured, making them measurable, so they become useful as we explore other worlds, Moon, Mars, Venus, Jupiter, wherever, small bodies. That really has driven me over the decades. I think NASA's Discovery Program is an embodiment of that, and here's why, and then I'll turn it back over to you.

After the *Challenger* disaster [STS-51-L, January 28, 1986], I was very fortunate that NASA asked me to be a member of Sally [K.] Ride's team that was asked to reassess leadership in space [*NASA Leadership and America's Future in Space*]. There were 10 of us. We were the younger NASA people from across the Centers brought together with Sally, who was of course an incredible inspirational person beyond words, just a joy to work with, to ask the tough questions. What is leadership after you've had a horrible setback, a calamitous one, that none of us will ever forget that time in '86? I'd only been at NASA a year at that point and couldn't believe it. But to work with these colleagues, and I was the lone scientist on Sally Ride's committee other than Sally herself, who of course was many things, an astronaut, scientist, whatever. To think about what it would be to establish leadership.

At that point in the late '80s we [Sally's Task Group 1A team] said actually having an outpost on the Moon where the little kids can look up and say, "There's Mommy and Daddy there living on the Moon," as a natural space station was very much in the spirit of what we thought might be one of those leadership frontiers. The other one was big telescopes like the James Webb [Space Telescope] that we would eventually maybe have crews, human beings, servicing. The others of course were getting people to Mars and other very big important things.

But working for her I saw NASA writ large. We briefed the Administrator about some of these leadership ideas with Sally and others. It was amazing. Talking about where we can send people, what's coming after Shuttle, how we're going to build what became the ISS, back then it was still Space Station Freedom. All those things. It gave me an opportunity to think about so how do we do the next-generation science—what's the business model? The thing that Sally liked was it's great when people compete, like the Olympics, it's cool, like in whatever you compete in, music, the arts, whatever. In some sense Sally's idea about competing the action amongst teams of women and men through science, even the robotic science of exploring planets, started ideas like the now 30-year-old Discovery Program.

We went to her testimony to one of the congressional committees, it was circa ’88, late ’88 I think. She testified and said, “We have to compete.” Not everything, but the more competition we get, the better the teams will be to do the jobs we need in scientific exploration. Science is always competitive, we compete through peer review, we compete through getting things published, we compete for lab space, for experiment space, for money, for what we learn. When you put that together it’s going to give you better value.

That was somewhat heretical in a sense. We had small competitions at NASA, we’re going to do this mission and we’ll get some people, and those will be sort of competed. But competing everything, an entire mission, the rocket, the spacecraft, the instruments, the science team, management team, that was still not yet in vogue. Sally’s catalytic listening to what leadership meant gave us the ability to start programs like Discovery, programs like Explorers to send little spacecraft to achieve big science. Of course, Explorer 1 being our first science mission back in the ’50s was a little different. But that was a big change. It went from an era where we had new starts, smoke-filled rooms, people behind closed doors, like let’s do a mission there, and then stuff happens and lots of scientists meet, and engineers said, “We can do that, not this.” Boom, we’re doing missions. That worked. We flew Voyager and Viking, Galileo that way. But the future has changed and the Discovery Program 30 years in now is showing the value of that competition.

It’s tough, it takes time and energy and money. But in the end the products are just spectacular. I was lucky to see that as it happened, as it came out of Sally’s wisdom, and to start pushing for things that were part of my career. I’d wanted to observe the Moon with Hubble

[Space Telescope] in 1991, when Hubble was just being discussed to be repaired for its spherical aberration. I wanted to send a laser altimeter to Mars. I wanted the Mars Program to eventually look for things not directly life but that would support the idea of there being life (now called "habitability"). All those things happened, thanks to the NASA we have, and lots of amazing people. I've been lucky to know some of those great people that have made those stories happen. And now thanks to the Discovery Program and many attempts, I will admit, we have a mission to Venus that will return the United States to the atmosphere and the surface of Venus for the first time in 50 years, by the time we fly [launching in June 2029]. As the principal investigator on that mission, having gone through the Discovery lens, it's exciting to have a team of many many brilliant young people, thank goodness, to work with to do this mission across many NASA Centers, including teammates from JPL [Jet Propulsion Laboratory, Pasadena, California], JSC [Johnson Space Center, Houston, Texas], Ames [Research Center, Moffett Field, California], Langley [Research Center, Hampton, Virginia], Goddard, and many universities and Lockheed Martin [Corporation] to do a mission like this, which the last time one like this was done was in the 1970s.

My background, it's a checkerboard, a mosaic of stuff (perhaps like an impressionist's artwork). Comes together, and I like to tell my wife, "You're stuck with me because I'm NASA for life." But that's okay, and it's been good to me. And she understands and puts up with me!!

JOHNSON: Sounds like you were definitely in the right place at the right time and got to do some things that were pretty amazing, even growing up. But when you were only at NASA a year when the *Challenger* accident happened, and then you ended up on Sally Ride's team, how did you end up in that position? You were relatively new, relatively young at that point, how did you end up on that team?

GARVIN: I was lucky. Once the *Challenger* event happened, I was hired by the Center Director of the Goddard Space Flight Center, who had also been a leader of Project Apollo and also Associate Administrator for NASA, and a geoscientist. I think in some sense he and I, Noel Hinners, were like-minded. He was a very encouraging individual. I think he wanted new people like me back then in the mid ’80s to start transforming into other things that the Agency could be, because he was a visionary. He hired a lot of us in that period. But he hired me with this planetary bent. I think when the *Challenger* blew up—and the Teacher in Space by the way was from New England, where I ended up after living abroad. I even got to brief Christa McAuliffe before her ill-fated flight (about geology from space). We told her about planetary geology, guess what, and the Moon. She was a fabulous teacher.

I think he recommended me through his role on what was then called the NASA Strategic Planning Council [SPC] to bring in a visionary science perspective. I wasn’t afraid of saying, “Let’s build a telescope the size of James Webb,” which would have been considered crazy at that point. Or send women to be in an outpost at the Moon, to use the Moon as an actual spaceship and a laboratory for studying the world, the planets, the universe. The other colleagues on the team that I was lucky enough to work with with Sally Ride were also of that broad vision type. I think all of us were selected with that idea in mind. That was different.

Now I think this is common, we’re much more connected, we have social media, e-mails, continuous connectivity. Back then finding those kinds of people, I really give NASA credit, because I think many of those folks on that early team, we were called *Task Group 1A,* not sure what that meant. But anyway, we helped Sally write *Leadership in Space*, and one of the chapters was the consummation of the work we did with her that was briefed to the Administrator. I think I was in the right place working for the right person. I was pushing back right before *Challenger* to fly laser altimeters to map the Moon, to get back to Venus with American landers, not Soviet ones, and to think about how we could live on the Moon back in '86, '87. We had done the Moon, and people were thinking about other things. I was one of those hereticals. A lot of people said, "Well, Jim, but you study Mars. Why not the rush to Mars?"

I said, "Well, we have this beautiful natural space station with a rich history unique to anything [the Moon]. Why not start there? We've done it in some sense."

That was one of the ideas we floated with Sally, which is ironically now what we're doing with Artemis, but which we thought might be a leadership position for the Agency in 1988, not that we have to do everything, it takes money and people. I was just very lucky to have that opportunity to be there on the ground floor.

It's funny, as a related thing. In the late '90s I got another call like that, from Administrator [Daniel S.] Goldin, who said, "Well, we want to reestablish exploration with people." He had a passion for enabling people to go to Mars. Smart Administrator. He said, "We're forming a decadal planning team, a secret team to look at strategies for putting people and technologies together to get us to the Moon and Mars." He asked me to chair it, and I thought he was kidding. Mr. Goldin is a great guy, very inspiring, because I thought, "Well, I'm just a science guy writing proposals, I had a laser altimeter in orbit around Mars, we had flown the one in the Shuttle, what do you want me for." But I think they wanted the vision element that sometimes is valuable and sometimes is suppressed, because it's sweeping and it's big. That's great, but when you have to do something, as my engineering colleagues will tell me, you actually have to write down what you're going to do and do it, not visioneer it. I was lucky to do that, and perhaps it was linked to working with Sally, or not. Literally after that, I was asked after two setbacks in the Mars Program to come back and be the first NASA Chief Scientist for Mars to help develop a new Mars Exploration Program [MEP].

JOHNSON: I was reading about Discovery and how it came to be. It was talking about the Space Shuttle overruns and then the *Challenger* and the fact that there had been no planetary spacecraft launched in a long period of time, late '70s to late '80s. But Wes [Wesley T.] Huntress was very involved in that, and wanted to get that going, and I think when Mr. Goldin came in with his idea of faster, better, cheaper, it all just kind of came together at that point. If you don't mind talk about that and how you first heard of them actually going ahead with an actual program that was going to encourage that kind of competition that you had already been talking about on Sally Ride's team. Talk about that beginning, and how you got involved pretty closely after that with the NEAR [Near Earth Asteroid Rendezvous] Shoemaker.

GARVIN: What happened after Sally's impact and changeover at NASA in the aftermath of *Challenger* and the long gap in planetary missions, we had waited forever for Shuttle to launch what became known as the Magellan [Mission] to Venus. Many of us waited a decade. Magellan partly funded my graduate career, graduate school, so Viking and Magellan were my funding sources in Mars and Venus.

There was this gap and this recognition as new leadership came to NASA including Wes Huntress as the associate administrator, Len [Lennard A.] Fisk, who was also involved I think as the Chief Scientist at one point in those early ’90s. How do we increase the pace of flight and the idea space of our Administrator, who was a brilliant technology person, Mr. Goldin, how do we do that? Instead of 10-year cycles of development, why don’t we get this turned around more quickly? Small programs like the Explorers, which are for astrophysics and heliophysics, had already started with that idea. But they were fairly modest, one experiment on a small sat [satellite] goes to do something scientific. Changing that scope to doing things to go study other worlds like Mars or asteroids or near-Earth objects was big; a leap. I think it took the combination of an implementing enterprise such as that Wes Huntress had in the space sciences enterprise back then to so-called Code S as it was called in the old NASA Headquarters code days, and with a Mr. Goldin who wanted to do things, to get missions to Mars, and to get to other places.

What was brilliant about the fledgling Discovery Program in that time was they did a couple of things really well. They developed a competition that was structured around the science merit, what’s cool about the science, how you’re changing state of knowledge, and the technical feasibility and risk of doing that within an envelope of cost, time, all those parameters that we value as we fly missions with whatever. They separated the variables well with those early architects led by Associate Administrator Wes Huntress, who’s an old colleague of mine, and I think the world of him, but also others who implemented the program. What they did was they decided to prestart, prime the pump. The first two Discovery missions were not holistically competed. They were pre-designed to have science teams competed, and so the excitement of those missions, which included NEAR Shoemaker and Mars Pathfinder, gave us something to start with.

We knew that the Jet Propulsion Lab could do a Mars Pathfinder lander with a new kind of airbag landing system, even with the first ever un-tethered microrover, Sojourner, which flew on that in ’96. We knew also that these larger small objects [Near-Earth Objects, NEOs] like asteroid Eros were fantastic objects of discovery with microgravity, all kinds of cool stuff, and origins, compositional source of hypervelocity collisions on planets, and we had to get to one, and not just fly by it. Get to it, go into orbit, understand it, and eventually come to rest on it, which was an amazing endgame. Those pre-seeded things, preseeded, not preceded, and gave the program a start. While the newly minted Discovery Program leadership was figuring out how to actually compete something there was a workshop in San Juan Capistrano. It was in California. I remember I went. There were 50 ideas that were all presented, long-lived stations on Venus, nuclear missions that used small radioactive power sources, little ones, little eraser pencil head ones. Missions to asteroids and Mars. Ones that would return samples of the solar wind. They were all debated and discussed as the science idea with not a lot of details of the implementation. That primed the community; everyone was excited, writing their little mini papers, white papers, to that. That got the community excited, while we were starting NEAR Shoemaker and Pathfinder.

What that gave us was the opportunity to know the program was starting and then to start the competition. Ironically Pathfinder and Shoemaker both brilliant, totally successful, great teams, at JPL and the [Johns Hopkins University] Applied Physics Lab [Howard County, Maryland], with colleagues at many other centers. The first competed and then selected mission, the Lunar Prospector [low polar orbit investigation of the Moon], was exactly the embodiment of Discovery. It was faster, better, cheaper. It was small, focused, great science. The Moon was something where we had samples. But yet it picked up where we didn’t know what the Moon could do. That's where Discovery came in. It changed the game, instead of waiting a decade for the next big, large spacecraft to the Moon, we had a little one to the Moon, and then we had a sample return to the solar wind, and then we had the sample return to the tail of a comet. All these things were changing the equilibrium.

That was really where Discovery came in. By the way, right about the time those first two Discovery missions launched Earth sciences at NASA led by Charlie [Charles F.] Kennel at that point, all of a sudden said, "We have to do this for Earth. We have our big Earth Observing Systems and Landsats and critical things, geosynchronous satellites for NOAA [National Oceanic and Atmospheric Administration]. All great, but we need to compete Earth science. I was lucky enough to be the first project scientist for the Earth sciences analogue of Discovery called Earth System Science Pathfinders [ESSP]. We took the lessons of Discovery and said, "Let's compete Earth science missions."

The first of those was GRACE [Gravity Recovery and Climate Experiment], which revolutionized understanding on heat flow in the oceans and gravitational structure of the Earth's crust (and mass storage of water). Its sister mission, GRAIL [Gravity Recovery and Interior Laboratory], 15 years later went and mapped the Moon, which was a competed Discovery mission. Those connections, competition, opportunities, frequent opportunities, challenged by the limits of resource caps, schedule caps, allowed us to do more quicker, while we then looked at the bigger program and said, "Okay, but we still need to fly a Hubble Space Telescope (as a Great Observatory). We do. We need to build a space station [ISS]. We do. We need so-called flagship frontier missions to do the things that we're not ordinarily doing." Cassini to Saturn and Titan. Missions of that scope.

While we were learning from Discovery, NASA in the late ’90s, when I came to NASA Headquarters as NASA’s first Chief Scientist for Mars, which is something Mr. Goldin and the Associate Administrator for Science wanted because Mars was important at that point to all of us, we changed the game and said, “Okay, we’re also going to compete even bigger missions. The New Frontiers class. These will be more narrow scoped to specific destinations; you have to go here, here, or here. Those missions, 40 percent bigger than the Discovery envelope of scope, cost, schedule, have also been wildly successful. They’re more difficult to implement, they’re more challenging problems. They’re not as focused.

I think the outgrowth of all this, in the past 30 years of Discovery, is that open competition works, it’s a lot of work by the people that run those competitions, but the benefits of frequency of flight, new ideas, pushing the envelope, getting people excited by the competition has really changed the game. This new business model of space with entrepreneurs and NASA and internationals and new partnerships is going to just open the doors. We can fly CubeSats [nanosatellites built to standard dimensions] to planets now as we’ve demonstrated. We’re going to the Moon with one called Lunar Trailblazer. Just amazing. A mission that would have cost hundreds of millions of dollars now whatever, 60-70 million dollars. The price of not even a blockbuster movie.

This is a game changer in how we do things, and sometimes revolution comes in steps like that that you don’t realize is even happening. The Discovery Program started it at a scale where it made a difference. We saw samples of things that changed how we see the universe, how we see the solar system. In the later Discovery missions, we had Deep Impact that made a cratering process and observed it. We had Mars InSight, which has measured the pulse inside Mars of another silicate planet, like we did with Apollo on the Moon and Earth. Nowhere else have we ever done that. This is heretical stuff. Now two missions to Venus that will change our sister planet forever. Once they've flown VERITAS [Venus Emissivity, Radio science, InSAR, Topography, And Spectroscopy] and DAVINCI, Venus will come more in the spotlight, I think. We've been waiting. We think she has a lot to offer as we look back at our own history of Earth.

JOHNSON: Let's go back to when it was started, and how it was received in the scientific community at different universities, even internationally. How was that competition model received? Previously, like you mentioned, you had to wait a long time, you got something on a flight, and it may be delayed. NASA was promising something different for scientists like you that wanted to get things out there and get them going. Talk about that excitement or how it was perceived at that point. Then I'd like to talk about the basics of the competition and walk me through what it took to get something launched.

GARVIN: I think when the first idea for competing whole missions came out, there was a natural division and resistance. There were the old-school folks who said, "Hold it, that's not how we do it. We have a process, it goes through committees, they rise up, there's big senior folk meetings all behind closed doors, outcomes, the bushes are shaken, and there's a new start, it's in a NASA budget, that's how it works." That had worked. Of course, we had a long hiatus in planetary as we waited for Shuttle to be developed, first launching in '81, and then becoming a workhorse, and then realizing it couldn't be the entire workhorse because it was busy eventually building a space station. That realization changed the game.

Then the delays during that period from the landings and the launches of the '70s into the launch of Magellan on the Space Shuttle in 1989 really got the planetary sciences community, which is very multidisciplinary, got them thinking, "Hold it, what's wrong?" We had lost the connection to Mars. Project Viking ended and we were supposed to have rovers and sample returns and we got one mission which ended up failing, the Mars Observer, in the early '90s, which had 11 instruments on it; we had a laser altimeter on it called MOLA [Mars Orbiter Laser Altimeter]. People started to realize that putting all the eggs in one basket once a decade does not grow a community, doesn't engage people at all the different levels. How do you get an opportunity unless you have a connection? How do those young early career women and men plug in? Now there's mechanisms. Back then there weren't. It was who you know, how you know them, where you were educated, whether you worked close to a Center. I think there was initially some resistance. But the younger generation thought this is the way it should be, that's how we write proposals. We write a proposal, it gets reviewed. We don't always like the answer but that's how papers are reviewed.

The idea of doing that review was accepted by some, who saw it as a mechanism to do more for less more frequently. The more you do, the better chance you have of eventually doing what you might want to do. It also starts to allow you to demonstrate technologies and approaches that otherwise might never be done. By the way, the other benefit of it was it told people, "Well, maybe we should compete instrument investigations on big missions." Instead of just saying, "Well, let's call up a NASA Center and have you build instrument X," why don't we compete that investigation at the level of a woman or man PI who builds the instrument, how it works, how scientists come together? That's what we've done too.

We expanded competition. The initial reticence I think was somewhat ameliorated by the fact that the first two Discovery missions were preprogrammed to what they were doing. There was going to be a Mars lander, Mars Pathfinder. It would measure environments, do some geology, and demonstrate technologies. There was going to be a mission to an asteroid, NEAR Shoemaker, that was going to explore small bodies, how they work, how to go explore them. That was what they were going to do. The competition levels that came were for participating scientists, a 15-page proposal to say, "I want to be on that mission." A lot of people wrote those for those two missions. It allowed people to connect to them. Some got selected, some didn't. That was exciting to see that happen. It was a way of engaging differently than the old way where for Magellan, for example, there was a core team of scientists, great leaders of radar and Venus and science. Then after the mission launched and the Shuttle got it going, the IUS [inertial upper stage] got it to Venus, there was a call for guest observer scientists, more like we do in astrophysics with big telescopes.

But Discovery and then its Earth analogy [ESSP] changed that. It got more people involved more of the time in more different ways. Now what it did do was explode the number of evaluation processes that had to be generated. That I think allowed the community, having written and participated and led several evaluations that led to missions that flew myself, learn how to do them better. While there's more work maybe, we sharpened the approach, so the evaluation process is more open, understood, objective. The measurements, people don't argue. If you don't get selected because of reason X, I think there's been much less worry about it because the process is understood. It's taken us a while.

Discovery, because of the magnitude of the commitment, which was bigger than a small single instrument thing doing one thing for science, started to show how it could work. I think it gave the optimism to those naysayers. I can be involved. More people got involved. I ran the first competition for the "Discovery-like" Mars Scout Program, which was the analogy for Mars of Discovery, focused only on Mars, after the setbacks in the Mars Program in the late '90s, the loss of the Mars Climate Orbiter and the Mars Polar Lander, when we restructured the Mars Program and a lot of us old Martians came back we said, "We're going to have our own program just for Mars." We did that for two cycles, and then we put it back into Discovery because it made sense. But we ran it the same way. Those first selections for Mars, the mission known as Phoenix [Mars Lander] and the mission known as MAVEN [Mars Atmosphere and Volatile Evolution], were run exactly like Discovery. I chaired the first one, and we felt like we got fantastic mission bids, and we could have flown them all, quite frankly. But it takes money.

I think the connections showed people how it could work, and while there was some initial oh no, it started to increase flight rate, it started to produce funding lines for technologies that could fly not only on once-in-a-lifetime flagships but on things that might actually happen. Flying more stuff more often by more people and spreading the wealth across the community, especially in planetary sciences, where I was most engaged, was really exciting. To be honest with you, after working Sally's program and being a part of the Mars Observer with our laser altimeter known as MOLA, which was competed, when we lost that mission a lot of us said, "What are we going to do now? What is the planetary program? It's two little Discovery missions and Cassini, the big mission to Saturn and Titan. What is it?"

I actually was asked to be the Project Program Scientist for the Earth Science Program ESSP, the Discovery Program analogy, because they needed someone, and I was familiar with the competition idea. We ran the Earth Science Program that way and led to missions like GRACE and CALIPSO [CloudSat and the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation] and others.

There was a lot of cross-fertilization across the themes and NASA's leaders recognized that, and Mr. Goldin, it wasn't just faster, better, cheaper, it was more science by smarter technology as often as you could, regulated by money and risk of course. All those things were good. When we did the decadal planning team [DPT] for Mr. Goldin in our first meeting we asked, “Well, Mr. Goldin, why don’t we compete human spaceflight completely? You pick your astronaut team, you pick your vehicle, you pick your heavy lift launch vehicle.”

He said, “Well, let’s not run a marathon before we’ve walked a mile here. We’re learning to do that robotically. People’s lives are involved. Scope is bigger. Investments are bigger.”

In some sense we’ve learned how to do that as we’re going into the Artemis Program with more levels of involvement and competition and partnerships, as we learned from the International Space Station. You have to learn. In robotic spaceflight we took this other approach, and it’s been wildly successful. I think that’s the message here. Sometimes you try something, it’s not perfect, but it’s a living process. It evolves. It’s better now. It’s still hard. As a recently selected PI (for DAVINCI), I spent two and a half years of my life focused on one thing and our final proposal was 1,470 pages of material plus another 2,000 pages of spreadsheets of masses and budgets and schedules. That was before we even did site visits and briefings to the selection officials and all that. That’s a lot of work by a lot of smart people. But in the end the people that do the evaluation have a lot of information. I think it works, is my bullish answer.

JOHNSON: You’ve been on both sides of it, and if you don’t mind, because I’ve never been through that process, and most people reading this will never have been through that process, describe that process, from the first idea that someone has, to putting a team together, how big of a team, how does it work, and what kind of people do you have on that team, and then actually creating the presentation or the proposal that you want to do, then going through the selection process. If you can just walk us through each step and give me an idea of how that works.

GARVIN: The Discovery Program process is a competition at the mission level driven by the science questions (and priorities), the measurement technologies, the spacecraft, and even in the early stages the kind of launch vehicle you're willing to pay for out of your budget to solve a scientific problem that has been in today's environment vetted by the National Academy Decadal Surveys or equivalent kind of framing documents, NASA strategic plans, road maps, in the sciences. The first step is the idea, what's the problem you're solving. It depends on the timing of how that happens. When Discovery first started, the kickoff conference in California was designed to ask, "What is the space of questions you might solve with missions of this price, performance, schedule, cost envelope? What could those be?" We didn't know. We honestly didn't know; there was no Planetary Decadal survey back then. The community came together and there were lots of ideas. They were sorted and binned and prioritized and stuff was done, but no one knew for sure.

When the first wave of proposals came in for the first Discovery in the mid '90s, while NEAR Shoemaker and Mars Pathfinder were happening, the evaluation process was tested. A lot of very smart people worked on that. I remember Mark [P.] Saunders was one of the early colleagues who helped develop that whole evaluation cycle of the risk, which we call the technical management cost [TMC] part of the evaluation, the separate science peer panel of nonconflicted scientists. Let's go through the process as a pipeline. You're a scientist. Maybe at a NASA Center, but often not, perhaps at a university. You're a woman or man, you have an idea, you know the community and your colleagues, you go to conferences. Lunar and Planetary

Science Conference in Houston. Conferences in American Geophysical Union, whatever, wherever you go. You talk to your colleagues, you write papers, and they say, "Well, there's a competition now, you can bid an entire mission in Discovery, anywhere in the solar system, with a price cap, a launch date window, and a development schedule that you should meet."

What many people do is they have internal prioritization processes. At a NASA Center we might say, "Okay, let's get all the ideas in a room, have a couple of maybe more experienced colleagues say yep, nope, yep, nope, yep, and then we make an investment." Writing a proposal now in the 2020s is thousands of pages and millions of dollars of investment. It's not for the faint of heart. But by partnering now, which is the key to everything, a university scientist who wants to be a PI, principal investigator, and in Discovery it's *PI mode*, the principal investigator signs the contract with NASA to deliver the mission! That principal investigator, she or he, is supported by a project management team on the mission who is peer-reviewed as part of the process to be able to execute that with partners, and those are all evaluated. Cost, risk, schedule, track record.

Unfortunately, the training of the PI is a process that I think initially we hadn't quite realized was going to take a certain kind of person. It's not just the smartest scientist that can write the most papers. It's perhaps the scientist that pays attention to what you have to do to not overrun (the budget cap), to make your launch date, to deliver, so your team can deliver the great results, and the data is archived for generations to come, as we're learning is so important, because 20 years from now we may look at the problem differently.

The idea then gets shaken down through whatever filtering process is at hand. It could be locally at a university, it could be at a NASA Center, it could be in industry, to here's what we want to do. We might want to land on Mars and measure something within ice in the ground, hypothetically, the Mars Phoenix mission did that on Mars, for example. That's what it is. Why do you want to do that? What's the change, the delta, in knowledge? You have to know that because that's going to drive the science question to the measurement to the functional requirements that say, "Okay, my question is ice on Mars, I want to do that in the ground, I want it to be as clear as possible, as definitive as we can do." It's like going to the doctor. They say, "Well, you're sick." You go, "Well, I knew that. How am I sick? What do I need to do? Do you want to cut me open? Do you want to?" It's like that.

Whatever the problem is, and there's many, and I'm oversimplifying, take that problem and cut it into pieces (divide and conquer). What is the big driving question? History of water in the solar system. Big question. It matters to life, it matters to climate, it matters to volcanoes. So why do you care if it's in ice on Mars? Maybe it's a climate cycle thing that's important because we have climate cycles on Earth.

Where do you have to go? Where the ice is. How do you know where the ice is? We sort of know from missions XYZ. Now you have to land on Mars, because otherwise it's going to be indirect, and remote sensing is only so good. Now you're going to land on Mars. Now you need a team that can build a lander. There haven't been that many landings on Mars. Most successful ones are by the United States, until the recent Chinese lander/rover. You got to partner with people that know how to do that. What instruments will tell you about said ice? But hold it. Maybe the ice is under some soil. Now we have to get at the ice. Maybe you have to heat the ground, whatever you have to do.

You start to build a framework. The question, the measurements, the vantage point, where you have to go, how you would go there, the functional requirements, and what would be the minimum set of things you could do to answer the question so you've advanced knowledge and that change in state of understanding will have made a difference. It means the next thing can be better. We know there's ice, maybe we want to go and do biology in the ice. Now we have to do planetary protection, we don't to contaminate the biology in the ice, because blah blah. That kind of process happens organically.

In the early days there weren't a lot of people that could do these things, so you had to sort of know who might actually be able to build a spacecraft. There were only so many aerospace firms that were willing in a price performance zone that fit within Discovery. Only so many people that were brave enough to be a PI and worry about money, management, cost, schedules, risks, engineering, what you can do, what you can't do. You might not get the science you exactly wanted. How far low can you go and still be okay, still learn something? These are tough things. I think the community has learned from workshops, successes, storytelling, oral histories about what it takes. The first steps, it was a frontier. It was like the wagons across the plains of the West. Where's the water? We don't know. Hmm. The horses need to be—whatever.

The process is organic. There's a lot of creativity in the science community, but that creativity has to mesh with engineering reality. What instrument can you fly? How much is it going to cost? A lot of the smartest scientists haven't ever thought, "Oh my goodness, most instruments that do good work are $30 million or $50 million. Ooh, and I only have so much money. When I build a mission, I need to have reserves in case something breaks. They're not going to give me more." What's the business bend strength of your idea if all of a sudden you have to use all your reserves? Now you're at the pad, you have no money, who's going to pay the scientists? The mission operational folks?

It was a learning process. But the pipeline goes from the idea to a framework for a proposal with a science, why we're doing it, how it traces to the goals that the community has stated, to the measurement systems, the instruments that do the job, to why they're doing the job well enough to make a difference, to how those instruments can actually be flown on a spacecraft to do a job. How the spacecraft gets the data back to Earth. Because my goodness, it wouldn't be any good if you don't get it back. How we can do that in a schedule cost envelope that's not elastic, there's a cap.

While occasionally that cap has been changed because the mission had to be delayed because a rocket wasn't ready or an instrument from a European partner had a problem, we still have those things. Discovery has held to the fixed cost caps except in, I think, one and a half cases. One because a French instrument had a developmental challenge on Mars InSight, we had to slip to fix it. We did. Everything's great, it's working fabulously. Another one when there was some issues with launching, I think it was Kepler and they had to delay it until they fixed those, got them right. But all the others, phenomenally successful, on schedule, on time, recent launches of things like Lucy [first mission to the Trojan Asteroids] demonstrate that brilliantly. Even during COVID [-19, Coronavirus disease] we launched on time a mission to visit multiple Trojans.

The pipeline ends up producing a proposal. The first step proposals are about 100 pages plus another multi-hundred pages of ancillary information. Up front, 20 odd pages are the science story, with connectivity to the community goals and why you need to do it and lots of references. It's like reading a science paper. Then the next section is what we call science implementation. It's how those science goals can be met with these instruments, making these measurements at this quality that will change what we think we know. In some cases I call it, "the one over zero." We don't know anything, so anything we measure has a lot of value. Other cases, we know too much, so how can you polish that apple?

Then the next part is the technical flight system story. How are you going to get it there? How are you going to get the data back? How are you going to calibrate it, test it, etc.? Then there's the management section which talks about how your project manager [PM] is going to work with your PI and the PI team, and the science team, and all the engineers building instruments (project systems engineering team), how those colleagues are going to do this job for you. In many cases those management system people might be new to this job. They might not have done a planetary mission. They've been wildly successful, so they're fast learners. But that's something.

Then finally the cost and schedule parts. Then there's literally abundant appendices. One of the big things that's now a part of the equation is heritage appendices. Showing proof that you have the piece parts that have demonstrated they can be built on cost and schedule for a given real dollar value that will make your mission work. In the case of our mission known as DAVINCI, we had heritage tables that showed the key instruments which are derivative of those that have been working for 10 plus years on Mars and could be built and fit in a mission to Venus based on that track record. We have the numbers, what it costs to build these instruments for Mars, which are working right now on the Curiosity rover. We take those and we scale it to our mission, our spacecraft. How is that going to work? You can do that for everything.

Those things get you in the door. Final steps now. You've written your proposal, but there's two steps. Step one is the scientific "beauty pageant." No offense meant in that terminology. It's emphasis is on the science, prove it feasible, and have a cost that's not crazy and that no one's going to say, "There's no way." And the cost-risk evaluators know if it's like right, "Yeah, I bought a bridge once and it was not there." Those kinds of things. That process is very tough and usually out of it comes a few finalists. It's like the final four in college basketball tournaments. Out of that typically NASA picks one or two then for flight. In the first Discovery it was only one [Lunar Prospector]. Eventually the leaders of NASA science have decided it's better to pick two. Sometimes one is a backup to the other, sometimes they're both developed on a staggered development cycle.

But once you get onto the dance floor, after step one, you've gotten what's called a Phase A study (concept study report or CSR). NASA gives you money, a couple million dollars, to write your Phase A study. That's your mission concept called the concept study report that has all the gory details.

Now you sold the science, great. Now tell us how you're really going to implement these instruments with this mission with that team with these people. Show us the details. Expand on the issues you had. That takes a lot of work, and those things normally are a one-year process from being told you got the Phase A, money flows to your team. Then you deliver a massive report, and you go through a—it used to be in person, now it was all virtual this last year—the Site Visit. The Site Visit is an in-person evaluation from a board of up to maybe 50 women and men who've evaluated your proposal against standards. But they're told you got to meet those. They can ask you anything. That's usually a two-day, plus two-week period. Two days in person, two weeks to get written answers back to them. That then allows the evaluation team formally posed by NASA with no conflicts, and they're all checked, to then score you in terms of risks, strengths and weaknesses, fatal flaws versus non-fatal weaknesses, cost risks, and those things then bubble up eventually to the selection official, who is usually the Associate

Administrator for Sciences with his or her board. They then evaluate and then they make a selection. Then you sign a contract with them after being selected to deliver.

Nowadays, with two Discovery missions being selected, sometimes the exact launch date based on planetary windows is a little bit flexible because they don't know NASA's budgets are going to be able to support certain burn rates and things. But anyway, the process starts with the ideas and science, the measurements, the vantage points, the teammates you want. At NASA Centers, we have internal competitions that are formal, so we can't just pick our best friends. We have to go through processes to be fair and open. Universities applying with other people don't have to do that. They have different legal things. But in the end, it all comes down to that. I've been on the selection boards, helped select the payloads for multiple missions. It's an amazing process. A lot of work. It's kind of like the Olympics for engineering and science. If you get the gold medal you get to fly. If you don't, well, you try again.

JOHNSON: You mentioned the principal investigator. I can see where that would be a very unique person for this type of situation because you have to have the budgets and also the project management, all of that in mind, because this is a different kind of project. Like you mentioned, they may not have that experience. Maybe those roles have evolved over the last 30 years and people have figured out how to fit those roles a little better. Talk about that relationship between the PI and the project manager and how that breaks out as far as managing the missions. The principal investigator, as you said, is responsible for keeping all aspects of the project in mind, that he's going to have to stay within budget and everything, what does the project manager do, and vice versa, when they're working together?

GARVIN: In the Discovery Program, we call it PI mode, or PI-led. The principal investigator, typically a scientist, who's responsible to deliver the science or the measurements that support said science to NASA, to the public, to the taxpayer, they're the kind of overseeing agent of reality for the mission. When you sign the contract and say, "We're going to understand why small asteroids are made of the stuff they are in the history of the solar system," that's a big task. The PI, woman or man, their job is to make sure we do that. They have to battle against the pressures of resources, schedules, technical failures in testing and scope, to still deliver a mission that is worthy of that investment by the American taxpayer through the lens of NASA Headquarters program management. What ends up happening, it's changed. I think NASA has learned that not everyone should be a PI because it is not without tension and conflict and churn as people say. The PI has to be beholden to her or his science goals and objectives, which flow down into things we call Level 1 requirements, things you better do or you will be considered not successful or only partially successful. It's like the skating competitions in the Olympics, they judge technical, artistic, other things. I don't know what they are. But they're there. They put them together to get a big score. The PI has to worry about all that.

The project manager is the PI's agent of managing those programmatic details that allow you to do the mission that the PI is responsible for. She or he, the PM has to say, "Okay, I know the budget. If my PI says, 'Well, I want three widgets,' and I can only afford one, I have to tell that PI, 'You can only afford one, is that enough? Is that too risky? What are you going to do?'," and forge a relationship and understanding that you can't have all the science all you want all the time. You can't have none of the science you signed up to do none of the time. There's a balance. The PI-PM teams that work best understand that. There's a give-and-take. They have an elasticity of understanding to make sure they deliver on the promise of the mission as defined in many documents.

I think that is a beautiful thing because it's evolved to a point where the really good PMs, those people are agents of constructive help to the PI and the PI teams. On DAVINCI I insisted on developing a management plan where I have two absolute brilliant world-class deputy PIs, one an early career rising star who should definitely have her own mission as soon as she feels like it, and another a midcareer absolutely brilliant management scientist person that has vast technical strengths. I look at ourselves as a triad of management as PIs. I'm responsible, I'll sign my name in blood to do the DAVINCI mission, my colleagues in arms in that are two brilliant people who I can always use as sounding boards and we work together on all major decisions, as we relate to our project management team.

We know what we want to do collectively. We understand each other. We've been working together for years on this. I see my job as a *not young* PI to make sure that I'm giving them the chance to shine, to grow, to be the PIs of the future. In some sense the training and baptism under fire to be PIs are to see this whole process. Because that future generation is what's most important to sustaining what we do at NASA, and not just waiting on our competition, we'll fly in 10 years, mission is over. Find someone new. It's grow with the system. It's a learning experience.

The PMs as well with the deputies and the other elements of the project management team, which are a deputy project manager for cost [DPMR]. That person manages the books. One for technical [DPMT]. Make sure that our PM sees the technical tensions globally, not just in the science instruments, that I might care about. Then we have a payload manager that makes sure everything fits. On DAVINCI we have two flight systems and a big aeroshell [Entry

System]. Lots of stuff that flies with stuff in it. Those all have to work. They have to work together in a symphony.

What we've learned over 30 years is not everyone fits all the different roles. It isn't that there isn't a place for everyone, it's that the PI has to have a tough enough backbone to be willing to bend to still get the mission done but also to work as a team player with the rest of the team, which is often 400 to 500 women and men, and across the different partners.

That ability to bend and compromise and still keep your eye on the ball is essentially a part of these PI-mode missions, because the PI is <u>not</u> the autocratic head, the enlightened despot who's leading this, the czar or the emperor. It is the person that makes sure science comes out of the mission that's worthy of an American taxpayers, in the case of NASA, investment in that. For Discovery so far, over 30 years, knock on wood, right there, it has been. The return on investment has been enormous. Some of these missions, like Lunar Prospector, the first small mission we rediscovered the compositional properties of the Moon and it led to other great missions, and now going back.

Likewise, missions to Mars like Mars Pathfinder and Mars InSight [Interior Exploration using Seismic Investigations, Geodesy and Heat Transport lander] and MAVEN, which has been mapping the interactions of Mars and the solar wind. These are amazing things. Had we not had Discovery, we could not have in program lines flown all these missions. Now with two new Venus missions, we have a virtual Venus exploration program for the first time, with two missions complementing each other beautifully, synergistically. Had you crammed them into one it probably would have been too big. It wouldn't have fit the competitions. We would have waited forever for it. Now we have them in pieces, and different teams get to look at problems in their ways. That partnership, coming back to your question, of individuals or small numbers of teams in these leadership PI team management team is where the action is. Because when things get tight, you have to make the tough decisions. Ultimately in PI mode it's the PI's. But the PI can choose to listen to people in making those decisions, and I think that's the beauty of the partnerships that have worked. Some of our PIs have been totally off the charts brilliant and delivered way beyond the scope of expectation. That was good.

Remember, the first two Discovery missions, although PI mode in principle, did <u>not</u> have PIs. They had project scientists and project managers. Because they weren't competed at PI mode. The next one, Lunar Prospector, did. Then Genesis [to collect solar wind samples and return them to Earth] and Stardust [to collect samples of a comet and return them to Earth] and all the others in the list have all been that way. [W.] Bruce Banerdt on Mars InSight is the PI who keeps Mars InSight delivering the incredible Martian interior structure measurements that he's doing for example. Does that help?

JOHNSON: Yes, it does. It's interesting because people do have to work together for something as massive as these kinds of missions. Have there been instances in Discovery that people didn't work together so well, and problems had to be resolved? Would those be handled where it's happening, at the Center level or Headquarters, or would it depend on the type of issue?

GARVIN: I think what happens is the process is somewhat self-correcting. A PI knows she or he has to deliver on a signed document. It's a program-level commitment agreement. You sign it, and it's signed by the Associate Administrators. That will influence your career if you don't deliver. You need your team to deliver because it's not one person. Some people think it's all about the one. These are not. **It's all about the team with a capital T.** The better that team is in working together to solve problems, the better everything is. You can see that happening in these very intensive site visit processes at the end of the step two competition, where you have to answer questions. We had hundreds of questions, detailed ones, with just a few days to have them all written down, answered, presented, articulated, all done virtually, which is very tricky. You see how people have to operate even in a COVID-19 context.

I don't know of any instances where big, massive changes had to be enacted from on high. There were descopes that were required where the PI was told by Headquarters, "We don't think you're going to make it with this payload at this cost level. We can only grow you based on extra funding elasticity in our program. We're going to ask you to make a descope. You tell us what you're going to do." The PI had to make those choices. There was a descope like that made, I know for example on the Dawn mission [to study two protoplanets: Vesta and Ceres]. A couple of instruments had to be deselected, and not for any reason I know. I was not part of that process. But they had to be deselected to fit the mission in a cost budget schedule. There were launch slips that were due to other problems, sometimes not due to the PI. But the PI has to live with those, and the management team.

There was a launch slip on MESSENGER [Mercury Surface, Space Environment, Geochemistry and Ranging] to Mercury. It was a very complicated, wonderfully successful mission. Some of the earlier Discoverys did have greater cost growth that was allowable by the kind of reserves that the PI/PMs carry. We've learned that those have not happened recently. It's been wonderful. The PI teams, when they launch on time, have been able to maintain their cost profiles.

There's more creative management by NASA Headquarters to assign launch vehicle classes to missions, to keep launch vehicle costs in check, and to also maintain the part of the mission called Phase E, once you've launched, when you're doing stuff away from Earth. A lot of the early missions had very large growth in the Phase E costs. Now there's caps on those so you can't just bid something and say, "Oh, we'll figure it out once we're out there." Now you have to know what it's going to cost to fund your operations team, your engineering team, your science team, your communication team.

I think what we've seen is there've been a few cases where the PI was maybe not as bending. In those cases, some NASA Headquarters leadership from the top came in and helped the problem. In other cases, the NASA leadership said, "Well, this is what you have. Make a descope. Make sure it's above the threshold that you establish with them. If the mission goes below this, we're not going to fly. It's not worth the investment." All the missions that I know that have been selected by Discovery, aside from ones that had failures due to whatever process, have all launched in the idea of being successful.

Some had issues. The CONTOUR [Comet Nucleus Tour] mission being one. But they were not particularly the fault of the PI or the PM. Others had other issues that come out with not understanding. One of the instruments on Mars InSight could not operate as intended because Mars did not cooperate. Even though we had the best models of Mars to do that, it just wouldn't. Now we know something new about Mars that unfortunately didn't lead that instrument to do everything that we wanted it to do.

JOHNSON: Yes, it's science, right?

GARVIN: Right, it is. Sadly, but it is.

JOHNSON: There are so many working parts to make anything happen. We talked about the PI and the PM. But engineers also enter into this discussion. They're a major part of the team. Talk about that relationship between a scientist and their engineers and how they make that work, because you can dream all day long, but if they can't make it, it's not going to work.

GARVIN: My viewpoint, having been at NASA my whole career, is scientists dream and the engineers produce the masterpieces that enable the dreams to become real (or realized). NASA is an organization that produces masterpieces of engineering. Driven by ideas, in many cases by the wisdom of scientists. The science gives you the "why," the engineers tell you whether you can do the "how" you think you want to do. That partnership is critical. In my case in my whole NASA career, just having lived this, my dreams were dictated by what engineers said we might be able to do in the context of science. The more I pushed to do a little more, they would tell me what's that strength. It's a cooperation. I don't think any of our missions have been successful without the absolute brilliance of these engineering teams, whether it be new instruments that people said would never work, to missions that have landed in places that seemed, "Oh my God, how did they ever do that?" Or new ways to everything.

The fact that so many of them worked. Look at James Webb, as an extreme example. Look at landing Mini Cooper size cars on Mars. These are not something you buy at Walmart. As much as Walmart is a great consumer buying place. They're not. They take engineering magic to happen.

I look at the leadership team we have, that I have on DAVINCI, as a PI team, myself and two deputies [Stephanie A. Getty and Giada N. Arney], who worry about that science, because we got to deliver on that, and make sure the community delivers with the measurements we provide, it's not just us, it's everyone who wants to be involved. We look at the management to make sure we have the money and schedule to do it. Then it's the engineers. The project system engineer and her or his deputy, they're the magic agents that say, "Okay, we can do that, we can't do that. We can turn this dial; we can't turn that dial." When we get to missions that's so important. How much data can you come back?

When we first bid DAVINCI we didn't know we could get enough data back from our flybys to do enough science to be worth it. Enter the engineers, saving us by coming up with a new solution, so now we can get the data back. We hoped for it, but we didn't know. They told us what we could do. Those are the things that change the gain on how we do these missions.

Landing on Mars with airbags. People said, "It's never going to work." It did work. We did three missions that way, and it saved a lot of money, and it was a little scary, but it was an engineering solution to a hard problem.

The engineers are like the master artists that take the vision that someone says is great, and they turn it into something you can actually see and touch and feel and cost and build. The ones I've worked with, the engineering folks across the NASA Centers I've been lucky enough to work with, have just been dazzling. The NASA spirit that I find so invigorating is the can-do spirit that says, "Okay, we'll find a way to do that, Jim." It's not, "Oh, forget it." It's, "Okay, let's see how far we can stretch to do it." I've seen that multiple times in my 37 years at NASA, from the first laser altimeter where I said, "I want to know the distance from a screening spacecraft to a foot." Every football field along the surface of the Moon or Mars.

People said, "Well, you can't. There's light and path, you got to perceive it that fast." It all worked. We have maps of the Moon and Mars, asteroids that way. We could land a robot on them that way.

The engineers have solved some of these problems, and when they're given the opportunity to have a seat at the table to work with the scientists and managers with the constraints, I have never seen them not solve the problem. That's really encouraging. It's an optimistic view. I know maybe I'm being naive a little bit, rose-colored glasses. But in the context of what I've witnessed in my career at NASA, it's been remarkable. We actually pointed Hubble at the Moon through complicated orbital things, and did remote sensing for resources from a telescope designed for the universe to measure the Moon. Who would have thunk that? Just unbelievable.

The engineers that enable these things to be accomplished, the operations managers that figure out the engineering solutions to do them with the spacecraft we have, unbelievable. That's the hallmark. A lot of those stories aren't told. Paper comes out. There's an answer. It's a great paper. The mission keeps going. Great. But the engineering solutions that made it keep going, often people forget those things. Sadly. They're lost in the glow of the success of what you learned.

JOHNSON: As you said, the missions can't happen without engineers. They also can't happen without funding. The budgets have to be approved. Talk for a minute about the various Discovery missions that you know of or that you've worked on. How important is that public perception of what NASA wants to do for these types of missions? Because not everyone always knows what NASA is doing. But I would think to get the funding from Congress, from the places you need to get that funding, there has to be some kind of desirability about these missions. We mentioned Mars. People think of Mars, that's really cool, because going to Mars is going to another planet. But how do you sell going to an asteroid or Venus for these other missions so that NASA can keep funding the Discovery Program?

GARVIN: What NASA has learned, which is really phenomenal, is the why we do these things matters. It's not just about spin-offs, Teflon, whatever we like. Those are great things. Personally, love my Teflon and my Velcro. But it's about connections about what we learn out there to come back and benefit us here by improving lives, improving what we can measure, making things more autonomous or safer, and ultimately displaying a leadership that gives people the confidence to do other things. Whether it's to develop a vaccine in a year that saves the country or understand the climate future of humanity over generations, not just our kids.

NASA has learned I think after its early days where it executed brilliantly with Apollo into the transition how to explain that at least from certain colleagues, often at NASA Headquarters, sometimes PIs on missions. How to explain those collateral benefits, those benefits beyond just the science question. Because let's face it. Science is great. The average person who needs to feed their family and do things may not care about the origin of the universe, the timing of the inflation from the big bang, or why it's so salty on Mars. They probably say, "Well, how does that affect me?" But the Earth lives in space. It is affected by space. The History of life was probably controlled by asteroidal impacts that changed the scope of how life filled the niches on this great planet of ours over time.

We're affected by the ability to have water as a liquid state variable in our planetary history, our climate history, our evolutionary history. So those variables, those history variables, we would not be able to understand if we just looked at Earth alone. It would be like looking in your basement saying, "I'm going to figure out history of the United States in my basement."

The house has been around a long time, they’re going to get back to those founding people. I doubt your house was around 200 and some years. But if it were, great. You probably don’t have the records from [Thomas] Jefferson, [James] Madison, and those dudes back there in your basement. So, you might need to look outside.

In exploring “why.” we do what we do with this investment that NASA takes for the American public, which is appreciable, these missions in Discovery are the price of [producing] a substantial Hollywood movie, as a good ballpark. That’s equivalent to taking your kids to the movies a few times a year as your contribution to that part of the budget. That’s about the level of all the stuff NASA does. There’s also jobs and other things.

I think the equation has been learned. NASA presents the case in strategic plans in communications by our Administrators and leaders of the why, what the benefits will be at high level, and lets the experts several levels down explain them more deeply. For example, people asked me when we were restructuring the Mars program 20 years ago, “So why should we do this?”

We said, “Well, people, life may be a cosmic imperative, but we just don’t know it.” We’ve got to get our minds off what fantastic living things are here, us, all the things we love, and think about it out there. What if the record out there is different and it will inform us about destinies here, future courses of action, and how we can learn to live with that life that’s out there that we have yet to discover because we’re not that far advanced?

Where’s the first good place to look? The Moon is not so good because it is an airless object riddled by space radiation and all that. It’s a great place to learn about the boundary conditions but not a place to have teeming life as we have on Earth. Mars may have been the one place we can get to start looking at that question with things that we can bring home, sample return. Things that people could touch if they go there. Crews to Mars. Things we could do with remote sensing, find the ice, find the record of the chemicals. Look for biochemicals. All that kind of stuff. So, it's a good test case. If we can do it at Mars, we can look in other places where it may be harder, beneath the ice crust of Europa, in the ancient records of things on Venus.

Those questions flow down to a bigger question about investments in the country. We invest to keep ourselves healthy, survive pandemics. Keep ourselves safe. Okay. The infrastructure so we can have jobs and have families and do things we like, get food, watch movies, whatever we like. We invest in those things. Some of the tools that allow those things to be possible actually were energized by the need to try them in space, in very challenging environments, or the engineering was just not going to happen.

The Apollo Program kick-started first generation integrated circuitry that had to make things small enough so they would work in a little capsule with a few dudes. Otherwise, we weren't going to take giant vacuum tube computers up to the Moon and have them break upon launch. Wasn't going to happen. Someone had to say, "We got to make them solid-state, they got to be small, radiation-tolerant." Fault-tolerant computing. It's got to work in space. You're not there to fix it. Maybe we fixed Hubble all those brilliant times and we did. But it was designed that way for crew and robots.

Some of the things we do in space have natural feedbacks to how we live on Earth, understanding things that we didn't even know happened on Earth. We actually learned by looking at the Moon and Mars. We said, "Holy gosh, there's a volcano 90,000 feet high. It has giant cliffs all round it. Wonder what that means. Oh, gee. Most of those big ocean islands that pop their heads up above and people go to have giant cliffs under the water. One just blew up in

Tonga. Hmm. Interesting." Which I happened to have been studying. Ironically. Talk about good luck.

But we learn by looking at another world to come back to understand ourselves. The history of life. What it could or isn't. We can't just do here, because it's everywhere. We need to go there to test that.

We can go to the International Space Station, do some of it. We can look at the records on other worlds in their history books. Those things promote the stories that we use at NASA. For the price of a movie like *Waterworld* or the new movie that's an Oscar candidate, *Wag the Dog* or whatever it's called, we can do a mission to understand the climate history of Mars, or to bring back a piece of an asteroid, like OSIRIS-Rex [Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer], that might contain carbon-bearing substances that were the early building blocks of what became the predecessors of life on Earth. Because there was a lot of that stuff left over when our solar system formed. We can go to Venus and measure the chemistry of the atmosphere and say, "Oh my God, maybe Venus had oceans for billions of years, like ours, and then they disappeared. Holy crap, what does that mean?" How might that hopefully not happen to us?

Those are the kind of big things. These programs, while they're not everything to everyone, and they're not all the time, start to chip away at that bigger question, how we can learn to thrive and be alive on our spacecraft Earth, which is what it is, as we look at the bigger picture. Because eventually people are going to leave this planet and go to the Moon and live, great, space stations, fine, hopefully Mars, and wherever else. Maybe main belt asteroids like Ceres would be a good place with frozen water, I don't know. Wherever it is, not for us. But we're just in the very early kindergarten steps.

So, in answer to your question, the why is an investment in the technologies and the capabilities to do tough things that broaden how we understand where we live and bring tools back to us. The laser altimeter we used to map Mars so we could land spacecraft robotically there autonomously is now the basis of laser hazard avoidance system that cars use so they can autopark. Thirty years ago, when we said, "Let's do it to Mars and the Moon," people said, "Well, that's never going to work. Oh my God." Now you can buy one and have it in your phone in an iPhone to tell you how to take a better picture.

Yes, our national security seeds some of those things, obviously. They have a big investment to keep us safe. But some of it has to enter the civilian sector in the way we benefit. That's one of the things NASA has done very well. It pushes us to capabilities. Some of the streaming technologies for data, when you're at Mars you can't send back Super Bowl quality digital video of every event, so you learn how to send it back in pieces and recompile it, reattach it. These are some of the great things that NASA has been able to catalyze. The Discovery Program does it in a cost price performance that doesn't cost so much that you can't do it fairly frequently. We'd like to do it even more often, with piggybacks on the launches, add-ons, missions of opportunity, small CubeSat-like things. The more kids and young folks are learning to do things in space, the better, and of course entrepreneurially too, which is another economic factor.

I think in answer to your question with a very long answer: we do it because fundamentally we live in space. Our planet does; we do. We're protected on spaceship Earth by many great things, big magnetic fields, big atmospheres, lots of water. All great. But the history of those variables that make our planet livable is out there telling us why other worlds aren't the way we are, or aren't now but may have been. With James Webb Space Telescope we'll be able to see if there's other Venuses that are big hot gassy planets near their parent suns, and compare those Venuses to our Venus. That's going to be important. Eventually telescopes beyond James Webb will be able to see other Earths and spectroscopically look for oceans and things that will allow us to make those comparisons. While we won't go, at the speed of light we can see the light from those systems tens of light-years away through the lenses of these incredible time machine telescopes. Think of that. The generation of today's kids will see that through Webb. They'll grow up with it as part of the same way they see the Internet and social media and electric cars. I don't know if that answered the question very well.

JOHNSON: Yes, it did, and it brought up another point. The involvement of younger people and students in school, even high school, junior high, younger kids, getting a chance to be involved with Discovery, and to get to see things that they've wanted to see on some of those flights. NASA is very involved with STEM education, so talk about that educational aspect for a moment.

GARVIN: First, education in the pipeline, growing the future people that can do this better, smarter, maybe faster. That's why we do this. It's a very Renaissance kind of thing. It's why I always like to go back to Leonardo da Vinci, who kind of did all those things. He was an artist and a scientist and wrote things down as one person with true "vision." We want all kids to have that opportunity. That's STEAM education. It's STEM plus A for Art, so they can bring it all together. There's no reason why any girl or boy who is interested or might be exposed might get interested as part of their lives, even if it's not their job. Of course, the job is their choice.

Let's talk about it. NASA's Discovery Program has opportunities for engagement of students in many ways. The first opportunity is student collaboration experiments. On DAVINCI we have one called VfOx [Venus Oxygen Fugacity]. It's an experiment where kids from regular universities and underserved underrepresented ones will build a small sensor that will fly into the atmosphere of Venus. They'll build it; they'll test it. They'll run it; they'll write papers about it. They'll learn about it; they'll learn about the mission it's flying on from all of us. They'll be guided by a few professors and other students. Hundreds of students in the end will be involved in that journey through cycles, because it's going to take a while for our mission to launch because of budgets. It's not like one year we're here and the next year we're launching. Those cycle times are normal.

That will fertilize those kids with a spaceflight experience of something never before done by humanity. Their experiment is the first ever one that will measure the partial pressure of oxygen near the surface of Venus, which will tell us how the rocks should react or not. We've always wanted to know that number. Their experiment will do it. It's a student experiment.

There's a student experiment on OSIRIS-REx called REXIS [Regolith X-ray Imaging Spectrometer] that has been doing measurements of the asteroid, did measurements of the asteroid Bennu, designed, built, engineered by students. The students as engineers, as scientists, as project managers, as kids taking classes, doing seminars, being interns will participate in that whole process. Lots of the Discovery missions have had different variants of that. They're encouraged. You can propose them to your mission. They're very exciting. That's one vehicle.

There's lots of other encouragement through the communications and outreach plans that we have built with our missions. There used to be a special budget that you proposed a whole engagement program with our missions. Now that's more globalized across NASA and applied to the missions based on what you recommend, and you do it in a partnership with NASA Headquarters, where the money comes from. But it's designed to have, what should I say, different engagement mechanisms for students through participatory learning, social media, tweetstorms. All the different things we do. We're going to take your art to Venus competitions inspired by Renaissance artists. But we'll let kids be the artists. Events coupled to critical events in our missions where we bring students in to participate. In our mission with DAVINCI we'll have a flyby of Venus with tons of new data (30 Gigabits or more), six months after we launch.

Getting kids involved at the earliest stage they could even be interested is one of our goals, particularly with Venus. It's a place we want to have a lot of women involvement all the way down to young girls (possibly in middle-school). We think it's very important. For many reasons, also just the goddess of love theme makes sense in the way Venus is. But that's been endemic and part of many of the competed program elements in NASA.

Not just in planetary with Discovery but in Earth science, heliophysics, and astrophysics, that engagement of the kids, that next generation, is critical. I believe what we're going to see is whole early career opportunity spaces for people who are in college and beyond and even special postdocs will ultimately be funded. We can fund NASA postdocs to be part of missions, and that's happened before, something we're very anxious to do. We want to have collaboration kids at colleges and universities that plug into our mission. We've given ability to interact in different ways. One we'd like to do through art departments, some of our partners for DAVINCI. We have the local MICA [Maryland Institute College of Art] group here in Maryland, but we also have the University of Michigan art department interested in space art. I know that's happened on other missions through connections at JPL with local art institutes and likewise in New York and Houston and other places. I don't know them all.

In answer to your question, I think that engagement as part of education and just connection, doesn't have to be part of a curriculum in your school, it can be part of an opportunity to be an intern, to be a junior intern. One of our project scientists on DAVINCI is going to cultivate young girls coming out of middle school to be involved as we get closer to time of flight. They'll be able to participate as very young people in mission stuff. While you can do that on a little mission, on a CubeSat that might operate for a month, having the big mission when you're up in space for years, you're doing things. You have events, planetary entries. We haven't had a NASA planetary entry to Venus since 1978. The kids of today haven't seen it. We want to make that part of their learning experience as we go.

Most of the missions take this on in different ways, student collaborators through different institutions, international partners bring students in through their own mechanisms that don't cost NASA a dime, which is great. We have multiple international co-Is [co-investigators] on DAVINCI who are going to have their own students in France, in Italy working with us. They get the benefit.

This is one of the things NASA is really learning to do better and better. In fact, in the Science Mission Directorate, the Associate Administrator, Dr. [Thomas H.] Zurbuchen, is really gung-ho about expanding engagement, diversifying it, being more inclusive. Anyone who wants to be a part of it. There used to be missions that held on to their data really tightly forever. The idea of getting the data out there that can be shared, as long as it's not uncalibrated meaningless stuff, is something we all really believe in. There's no reason if you can process something to a point where the public could be interested as citizen scientists or just consumers of it that they shouldn't be part of that. Sometimes there's so much data, what would you do with it? But just a radar map of a piece of Venus will be tens of gigabytes. You might not have it on your iPhone or your laptop. But nonetheless those kinds of connections are something we all believe in a lot. I personally believe in it. I think I was given the opportunity to get engaged indirectly with things young, with encouragement, and it changed everything for me. Every kid out there that has a vague interest in what we do across all the spectrums of what NASA does, but in Discovery with its competed missions, there ought to be a mechanism to do that. I think that's the intention of the program architecture.

JOHNSON: You mentioned sharing it with the world, the results. How important is that for NASA to do that internationally? Because as you mentioned we've had other countries that have landed, on the Moon, Mars. We may not get all that data back from them. But NASA is willing to share that, and Discovery, those missions are willing to share that.

GARVIN: Exactly. I think what we've learned since the '70s and '80s with the first missions to places, the more we can make at least the data that we think is valid and useful, the more we can make that accessible to anyone interested, the better. Even the higher-level data products, the stuff that's processed to be useful as a map, or a boundary condition for engineers. Those are important. Our colleagues in other nations use our information that have mapped the Moon and Mars to land on Mars, to land on the Moon, to know where to go, to be safe. We're not holding that back. We have a global image mosaic of all of Mars on a 6-meter grid. That's better than we have for all of Earth. Of Mars. It's going to be even better for the Moon thanks to the Lunar Reconnaissance Orbiter [LRO].

These are foundational data sets for humanity. It does take money to put these things together to be useful, it's NASA's job to make those available. In cases of our mission like DAVINCI, we'll be collecting a lot of data on flybys of Venus before we take the plunge and do our entry, descent, and science mission phase within the atmosphere. Our job is to get those data processed, out there, available to people, both in science archives where you download them and work, but also in publicly accessible formats that people can look at and marvel over. The images of Jupiter by one of my best friends, Mike [Michael A.] Ravine from the Juno mission, show these beautiful tapestries of upper atmosphere cloud patterns. They're artistic and appreciated not just for the science, which is stunning. When we get to Venus and start to look at the Venus cloud deck in the ultraviolet, which we'll do on DAVINCI, we want the people to see that and think about it.

All the Venus missions and other missions really have that intention. The quicklook images from our descent imaging of Venus, which will look weird because there's no shadows, the Sun when we land will be at high noon, so it will look different than you're used to. We want to make those available. Our job I think is to share what people have paid for and also to write the research papers quickly to get what we think is the story out and then challenge others to do better. Because it's not just about us writing a few papers, it's about producing information and capabilities for the community. One of the things on DAVINCI we're doing is we want to establish a twenty-first century planetary probe architecture that other people could design to fly to other worlds. Saturn, Uranus, Neptune. Worlds with big atmospheres where you want to probe them with chemistry. We haven't done that at NASA by a NASA spacecraft since Galileo and Pioneer Venus in the '80s and middle '90s. We might as well have that capability to go to places where that kind of mission makes sense.

In a sense, Discovery opens the doors to that in a price performance class that's not so formidable that you'd only do it once every 10 or 20 years. I think that will carry over as human spaceflight gets the women to the Moon. We'll have more opportunities for people to be involved. Not just waiting once in a lifetime to have a crewed mission go somewhere, but to have people actually participate, whether with payloads, with instruments, with talking to the astronauts who are living there, to other opportunities that we didn't have in the first generation of those things. Like we do on Space Station.

JOHNSON: We've got just a few minutes left. I do want to talk about the LRO, but that's going to take some time to talk about that. But thinking about Venus, one of the questions I have, I guess it's very simple, but why Venus? Why do you want to go? Why personally? What's attractive about Venus to you?

GARVIN: If you look in the sky tonight, this morning, actually, you'll see this big bright thing, it looks like an airplane coming in to land. That's ***Venus***! Our nearest planetary neighbor other than the Moon, which is a natural satellite of Earth. Venus has been a mystery. In the '60s people thought Venus was the swamp planet, even in TV shows. There were crazy science fiction things with people living in these jungly swamps. Then we realized ooh, they can't be swamps, because the surface temperature is 950 Fahrenheit. For me, the Venus lure is because there's so much we don't know. It's like the puzzle pieces of a masterpiece all mixed up and not all there. But you know there's something good. There's a pony in there. But you don't see the pony yet. But you suspect there's a pony.

For me, I see Venus as a tale of an evolutionary path. It grew up and evolved differently than our beautiful home planet. Why is that? Because Venus was born and raised in the same neck of the woods of the solar system. One of my colleagues on DAVINCI said, "What if you had two cities ten miles apart and one where you lived, it's green, and everyone's happy, and dancing, and doing whatever they like, and the other one is like a graveyard and it's polluted and everything, and you never went out and looked at it? Then one day you did, and you said, 'Holy goodness, that's our neighbor and we didn't realize, we didn't know, why did it get that way, we don't want to get that way. What can we learn?'"

The Venus of today is not the real Venus. There's a story there. To read that story, we need tools that we've learned to use on Moon rocks, on Mars rovers, that we can apply to Venus. We didn't have those tools in the '70s and '80s. We didn't. We flew radars to orbit, Magellan, they did great. Mapped the whole planet. Brilliant brilliant brilliant. But they didn't tell us that story over time.

Some of us suspect, and this is what gets me, that there's no reason why Venus might not have had global oceans of liquid water, hundreds of meters deep, for maybe billions of years, and then something happened. Venus went away from that state into a state, it's called a greenhouse state, which is climatically what it is today. Hot surface, swirling clouds 30 miles high. Not a place where the kind of life we have on Earth would be survivable.

But something triggered that. We think in the record books of the chemistry of the atmosphere, in the record book of the rocks we're going to see that story. It's like the Dead Sea Scrolls as a unique preserved record. We didn't know they existed. But if you find them and start reading them about people that lived 2,000 years ago, you see what it was really like in those critical days of that part of the world, a lot happening.

We want to read the Dead Sea Scroll records of Venus with our mission and with all the missions going to Venus to tell us about our own destiny. Because Venus should have grown up Earth-like. It's in the right neck of the woods of the solar system. Bouncing around the so-called habitable zone, and yet something changed. Can we tell what changed? Was it the role of water? Was it the role of its crust shifting around? Was it the role of volcanoes? Was it rapid loss of said water, producing a runaway hothouse that was not sustainable? We don't know.

There's a lot of enigmas about Venus. Why is the record of impact craters on the surface of Venus so small, 950-odd measured impact sites? Heck, we have 200 on Earth, and we know two-thirds of the Earth is resurfaced every 200 million years, so we're obviously missing thousands. If you take the Earth record and just project it back a couple billion years, you'd probably find 5,000. Why is Venus 950? We don't know. Was it because oceans precluded the preservation? Was it because of global volcanism repasting over the entire place like the seafloor does around our divergent boundaries? We don't know.

Venus is a puzzle. It's a puzzle that's worth solving because clues from what happened on Venus may tell us about our own destiny, and we know that we can see exo-Venuses with the astrophysical telescopes that we now fly like the James Webb Space Telescope. Around those smaller suns, those M-class stars, if there are Venuses, exo-Venuses, which we predict there to be, because we sort of sense that from what we can tell around other stars, the James Webb Telescope can make spectroscopic measurements of those and tell us about exo-Venuses tens of light-years, trillions upon trillions of miles away.

But if we don't know our Venus, her upper atmosphere down to her surface, that big, huge, massive atmosphere hundreds of times more thick than ours, then we won't be able to understand it. So, what if we see all these exo-Venuses? There's a Venus. There's a Venus.

We go, "Well, hold it. We don't know our sister." I like to tell schoolkids, "So do any of you have a sister that you don't know?" All the kids go, "Oh, we don't like our sister." Whether it's a couple sisters or a brother and a sister, leave it to the kids. But we have a sister we don't know. She grew up with us, she's next door, we see her. She's a magic crescent. She has a big voluminous atmosphere. Roaring winds in the mid-cloud deck, strange mystery absorbers when you look through in ultraviolet light. Swirling areas that could be continents the size of Africa. Yet, we don't know her story.

We sort of know the Mars story. Of course, the Moon story we brought back with samples from Apollo. It's great. They're archived. We'll do more with Artemis. We don't know Venus. Now is the time to bring Venus into focus as we move out with astrophysics, as we go back to Mars, to the Moon, go to Europa to understand subocean worlds. I think Venus is the example of an ocean world planet that lost its oceans.

Now we're an ocean world that kept its oceans. Europa is an ocean world that hid its oceans. Mars is probably an ocean world that froze its oceans. If oceans are important, and a lot of people think they are in science these days, then we have an ocean world next door whose record may be lurking in the chemistry of the atmosphere. What we will do with DAVINCI is measure that chemistry with instruments as good as those we've been running on Mars that have found records of carbon-bearing molecules recently in the rocks on Mars, and Curiosity that can tell us about prospects for life or not. We're going to do that throughout the Venus atmosphere and measure the record of what might have been the history of water from the top of the atmosphere to the surface in ways that would be equivalent to bringing a sample back to an Earth lab and measuring it. But we're bringing the lab to the sample because it's too hard to come back, quite frankly. It's a bit of a trip. We'll get there but not yet.

Venus, I think, will be this special Rosetta stone that will all of a sudden open our eyes to things we had forgotten to think about. That's why I think it'll be tantalizing. The missions that have been selected, our DAVINCI mission, the JPL-led VERITAS mission, the European [Space Agency] mission with the U.S. instrument [Venus Synthetic Aperture Radar (VenSAR)], known as EnVision, those three missions plus others that people are talking about in India, in Middle East, even by commercial, they're going to paint a picture of a new world. I think the kids will wake up 15 years from now and say, "Oh my God, why didn't we think of that? Why didn't we?" That's the way it was with Mars after Viking. People said, "Well, it's a sterile cold desert. Too hard. Let's go off and do other things." Then we did the Mars Program that restarted with the Mars Pathfinder and then the Global Surveyor and then other missions, Odyssey and all the others. We said, "Oh my God, this Mars was a formerly habitable world with water and lakes and rivers, seas, frozen glaciers, buried ice, carbon compounds. Holy crap, why did we give up so quickly?"

Venus is hard, surviving on the surface for more than an hour or two is a thermal nightmare. But we can learn a lot by just getting there, making measurements through the entire atmosphere, touching down on the surface, and doing that in the context of what we know will change everything. We can also map its surface with next-gen radars that will see the surface in 3D. Those things our missions will do in the next 10 years. It'll be stunning.

We're going to wake up in a decade and say, "There's a new Venus." It's important to us. If you took the water away from Earth, take a look at what the scientists say our planet would be like. It'd be a very different world.

JOHNSON: That's exciting.

GARVIN: It is. We can do it and I think someday we'll have astronauts come back from Mars by way of a Venus flyby. They'll drop off big payloads. Because you can actually get a great gravity assist from Venus if you're willing to spend a month going a little closer to the Sun. It will help us reenter with bigger masses back on Earth, something we studied with colleagues at JSC. While it's maybe not the safest, it'll save developing gigantic heat shields that are twice the size of those we've been using to bring people back from space.

Venus may be even part of human exploration someday.

JOHNSON: It's interesting.

GARVIN: Yes.

JOHNSON: All right. That's a good place to stop.

[End of interview]