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RICHARD R. VONDRAK
INTERVIEWED BY SANDRA JOHNSON
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JOHNSON: Today is June 8th, 2017. This interview with Dr. Richard Vondrak is being conducted for the NASA Headquarters Science Mission Directorate Oral History Project at Goddard Space Flight Center in Greenbelt, Maryland. The interviewer is Sandra Johnson, assisted by Rebecca Wright.

I want to thank you again for joining us today and agreeing to talk to us. I want to start by talking about your educational background, and how and when you first came to be interested in working for NASA.

VONDRAK: Thank you Sandra, it's a pleasure to be here this morning. I grew up in Chicago [Illinois]. My parents were the son and daughter of immigrants from Central Europe. I was raised in a blue-collar neighborhood. But I liked to read, and I used to love reading the stories of the early explorers, particularly the polar explorers, and also a lot of science fiction.

I was interested in history. When I got to high school I wanted to be a history major, but then Sputnik [Russian satellite in October 1957] was launched in my freshman year in high school, and I became very interested in science at that point. I guess you would say that I'm a child of the space age, and that the space age really took off when I was young. I was good at math, and the good thing you could do for your country was to become a science or math major.

I was very interested in physics, and I decided to major in physics in college. I was still torn a bit between history, psychology, and ended up getting my bachelor's degree in physics from the University of California at Berkeley, where I met my wife Mary. When I was at Cal I talked to the professors there and I said, "Gee, I'd really like to go into physics for graduate school, and I'm interested in space." I took one of the first courses they had in space physics that they taught at Berkeley. They said, "Go to Rice University [Houston, Texas]. They're just building up a big department because the space center is going to Houston." Rice was getting a lot of money from NASA, still in its early days. They had the first space science department in the country, and they had a lot of experimental space science. So, that's what led me into NASA research.

When I was in graduate school I got affiliated with a professor at Rice who had a rocket program. It was going to study the aurora, the northern lights, and for the first time try to measure the electrical properties of the aurora. In addition to the charged particles from the sun that produce that beautiful northern lights, you have the electric currents that flow along the Earth's magnetic field into the upper atmosphere. These electric currents produce magnetic fluctuations on the ground, and they're key to understanding the processes that form the aurora borealis.

I built a rocket payload and we brought it here to Goddard in 1968, so I'm approaching my 50th anniversary of my first trip to Goddard. It was a little Center out in the woods here. We calibrated the rocket here at Goddard and then brought it up to northern Canada, to Hudson's Bay, where NASA had a rocket range and the [U.S.] Air Force had a rocket range. We fired the rocket over the aurora, and were able to get enough data for my thesis—even though that was quite an adventure, because the rocket payload didn't work exactly as we thought it would. I had to spend a long time sifting through the meager amount of data before I knew I had a good measurement.

That was my first NASA science program, and that's the history of my educational career through my Ph.D. thesis. When I finished my Ph.D., the theory of the aurora had been done by the group in Stockholm [Sweden] at the Royal Institute of Technology, Professor Hannes [O. G.] Alfvén. I had talked to the people from Sweden and I got a postdoc [postdoctoral fellowship] there, so I went over and spent an academic half year—one semester—at Sweden and then came back to Houston.

JOHNSON: Talk about when you came back to Houston. I was reading your resume, and that you worked on the suprathermal ion detectors deployed on the lunar surface for some of the Apollo missions.

VONDRAK: Right. To be very candid about the situation, I graduated in 1970 with my Ph.D. It was a year after the first Apollo Moon landings in '69. The NASA funding at that point was in a sharp decrease. NASA funding went downhill at that point, and NASA was withdrawing support from a lot of its research activities. It was impossible to get a NASA job. NASA was not hiring. It was very difficult even to get a postdoc position in space research, much less a faculty position, because the academic departments that NASA had been funding in the early '60s—like the ones at Rice and elsewhere in the country—NASA started withdrawing its support from them.

One of the professors at Rice, who I knew well, he had an instrument that had been selected for Apollo. It flew on Apollo 12, 14, and 15, and it was called the Suprathermal Ion

Detector Experiment [SIDE]. It measured, essentially, the plasma environment from around the Moon. The Moon is exposed to the solar wind—this is the outer gases of the Sun that are electrically charged—and they flow at very high speed into space. These gases, called the solar wind, interact with the Earth's magnetic field and form what's called the magnetosphere, the trapped radiation belts, and the aurora. They also interact directly with the Moon, because the Moon lacks a large magnetic field. The purpose of our experiment, or Dr. [John W.] Freeman's experiment, was to measure these charged gases that come from the Sun. It was deployed on three missions because it was viewed as a very high priority to understand this interaction.

Dr. Freeman—when I came back from Sweden it was very fortuitous, because he was looking for someone to be a postdoc to work with him. Actually it was a research position, but it was what we would call today effectively a postdoc because it was a nonfaculty position, a research position. He needed help in understanding the observations, and also he had a chance to go to Sweden on a sabbatical to the same place where I came from, the Royal Institute of Technology in Stockholm. So, I basically was responsible for some of the science operations, along with Dr. [Howard] Kent Hills, who had arrived as a postdoc a few years before me.

That was a wonderful opportunity, because first of all I could broaden my experience from more than just the aurora and the northern lights and the polar atmosphere to understanding the Moon and its environment. Also it was exciting to be part of the last three Apollo missions, because the astronauts were going to deploy the third of our instruments at the Apollo 15 site. I was able to participate in some of the training activities for the Apollo 15 crew.

Then, more importantly from a personal point of view, because we were able to monitor the exhaust gases from the Lunar Module, and also from the activities of the astronaut on the surface with our instruments, we were turned on for the last three missions in real time. I was working during those missions in the Science Operations Center, also known as the Lunar Operations Control Room. Everyone knows Mission Control and the big screen and the banks of specialists monitoring all the Apollo subsystems. Right around the corner, down the hallway, was the Science Operations Center.

In this room, at one end were the geologists who were looking at their TV screens and trying to get information up to the astronauts, and back down about what the astronauts should do in their EVAs [Extravehicular Activities]. At the other end of the room were the Apollo Lunar Surface Experiments Package teams, the ALSEP teams as they were called, for each of the instruments that were going to be deployed, and also our instrument because we were doing this real-time monitoring. For example, when the Lunar Module took off, we could measure the gas cloud that was released by the Lunar Module. Even with Apollo 15, since SIDE was right near the 15 crew when they were on the surface we could see them open the door, and the gas coming out of the Lunar Module, and even the gases from their life support systems.

That was a wonderful experience, and we all said, “Gee, this is really great. It’s got to keep going.” I remember the Apollo 17 departure from the Moon, December of ’72. Everyone remembers July of ’69 [Apollo 11 Moon landing], but not many people remember December of ’72 when we left the Moon for the last time nearly 45 years ago.

I remember sitting in the control room of the Science Operations Center with some of the other scientists, and we were saying, “Gee, I wonder when we’re going to go back.” Some of the optimists said, “Oh, four or five years.” Some of them were, I think like me, more realistic. I said, “Maybe 15 or 20.” I don’t think anyone said “never.” Some people said, “It’ll be a couple decades.” But it’s been 45 years, and it’s been far too long. I think future historians will wonder why there was this long gap before we go back to this wonderful place right next door to us.

JOHNSON: The information that you were gathering then, did you have to come back and analyze that information?

VONDRAK: Oh, yes. Not only did we do the operations, but we spent all of our time at Rice working on reducing the data, trying to understand it. Probably one of the things I'm most proud of in my career is that I looked at the observations and I said, "The lunar exhaust that we see"—there were measurements made soon after the Lunar Module left and then a few months later, and we could see a large decrease in the exhaust gases around the Moon.

Basically what was happening was the solar wind, as it blows past the Moon, it picks up gases, the ionized plasma around the Moon, and then carries it away. It's a very rapid cleansing mechanism. If you artificially add any gases to the lunar environment, it won't linger there for years or decades. It decreases with a half-life time of about a month, the length of time it takes to photoionize these gases and for the solar wind to pull it away.

But then what I did was I thought about it more, and I said that there's other planets like Mars and Venus that have dense atmospheres that they haven't lost that quickly. The reason is that as the atmosphere becomes denser it becomes thicker at higher altitudes, and the solar wind is not able to penetrate down to the surface. On Mars, for example, it gets stopped about 60 miles up in the atmosphere. Because it cannot penetrate to low altitudes, it cannot clean the lower altitudes. I did a calculation that said if we take a lunar atmosphere and we increase its density by about a factor of 1,000, then the solar wind will not be able to go to the surface, and the atmosphere then can keep building up.

For example, if you had a volcano or a factory or heavy traffic to the Moon, that would build up a dense enough atmosphere to stand off the solar wind. I made that prediction, and made that point that the lunar atmosphere right now is very very thin, and as a result it can be rapidly cleaned. But if we build it up by about a factor of 1,000, then you have a transition to a different state.

I remember Dr. Freeman was very nervous about this paper because it didn't look like pure Apollo data analysis. He said I could publish it by myself, and so I sent it off to *Nature* magazine, which published it, which was quite nice for someone of my age to get a paper like that published. At that point it actually had a fair amount of notoriety, if you like. It was viewed by a lot of people as significant. In any case, I showed that one Apollo mission basically doubled the density of the natural atmosphere. The atmosphere is only about 10 tons of gases, the natural atmosphere, and each mission of the Apollo Program put about 10 tons of exhaust into the lunar environment.

JOHNSON: That's interesting.

VONDRAK: Yes. That was a lot of fun, very satisfying. But I had to find a real job, because by this point even our funding at Rice—because the Apollo Program was over—they wanted to shut off all our instruments, which they eventually did after a few years. That's another thing that I think future generations will regret, because we have this beautiful data from the surface, like lunar seismology, lunar moonquakes, and the lunar environment. That record starts from '69 and ends into the late '70s when NASA, just to save the money required to record the data, decided to shut off all the instruments. They were powered by small nuclear sources, so they could have operated for decades, but NASA just lost interest, needed to save money, and they shut them off.

We'll eventually get more instruments like those left on the lunar surface, but there's going to be this 50-year gap of data. People say, "Gee, it's regrettable we didn't have a continuous record." Because the Moon has a dynamic environment, and it's important when you have a dynamic environment to have a continuous record so you can see trends, you can see variations, understand them better. To have 10 years of data and then a gap lasting decades is going to be hard to understand the processes. I'm sure future scientists will say, "Why did they do that?"

JOHNSON: Can't imagine the funding would have been that hard to find.

VONDRAK: It was, it was. Actually it was running I think about $1 million a year, and they decided to shut them off. But in any case I had to find a real job, and fortunately a colleague of mine recommended me to Stanford Research Institute [Menlo Park, California]. This was a group in the Radio Physics Laboratory who was doing studies of the upper atmosphere and the ionosphere with basically electromagnetic radio wave systems.

This was quite different than what I had done, because the rocket payload I had for measuring the aurora were these charged particle experiments measuring electrons and protons, and then we also had a vector magnetometer. This Stanford group was using high-powered radio waves for remote sensing of the aurora. SRI as it's called, Stanford Research Institute, operated a very advanced high-powered radar system in northern Alaska. This was a really neat observatory, because it was a large dish, over 100 feet in diameter, that was rapidly steerable. It was designed to be portable, because it had been funded by the Defense Department as part of the nuclear testing readiness program.

Earlier the U.S. and other nations had exploded atomic bombs in the atmosphere. There were a lot of puzzles as to what the effects of these explosions would be on the upper atmosphere and on the ionosphere. The ionosphere is the part of the upper atmosphere at about 100 miles up that gets ionized or electrically charged. It affects radio wave transmissions, so your AM radio bounces off the ionosphere. That's why, especially at night when the ionosphere is up higher, you can pick up radio stations that are far away. It also affects communications from space to Earth, and intelligence gathering systems with radio waves from space to Earth and back.

The question was if you have a nuclear weapon exploded at high altitude in the atmosphere, can you communicate through it, can you see through it with radiowave techniques. There were some clues to how that may be, but no real solutions. The U.S. had wisely decided in the early '60s never to explode weapons in the atmosphere because of the harmful effects on the environment and on humans. So we went to underground testing. But Congress had said, "If any other nation does aboveground testing, we will resume aboveground testing, and we will have to be prepared to do that on short notice."

So the Defense Department had paid for this very neat, elegant radar system to be built at Stanford [University, California] on the campus and be deployable—could be airlifted to the South Pacific on short notice—to get the information needed to understand the effects of nuclear devices on the upper atmosphere. Now there was an absence of atmospheric testing—and fortunately no other country has ever done so since the '70s. Since France stopped and China stopped in the early '70s, no country has done aboveground testing. So the radar wasn't needed for that purpose.

But in order to understand how good the models were—and the software, the codes for understanding weapons effects—they decided to study the aurora. So the SRI system was moved from Stanford up to northern Alaska to near Poker Flat where the University of Alaska [Fairbanks]—under NASA funding—has a rocket range to study the aurora. We were right next door. What we did was study the aurora to measure with radio waves, remotely, all of the effects of the aurora on the upper atmosphere, the electric currents it produces, and then how you could study it optically from the ground. I was hired—I wasn't a radio wave person, but I had done this work on the aurora. My postdoc on the Moon was irrelevant.

I spent about seven or eight years at SRI, would go up to northern Alaska for many weeks during the winter and sometimes in the summer. I never got tired of seeing the beautiful aurora. Because we were near the rocket range, there were other scientists firing rockets over the aurora, so we would make measurements in coordination with them. There were satellite overflights for both NASA and the Air Force and other agencies, and we'd do measurements with them. It was very nice. I was very happy because I was able to introduce new analysis methods and new operational methods with the radar. So, I basically could answer some of the unsolved puzzles from my Ph.D. thesis, and do from the ground with this system some of the things I'd hoped to do in my Ph.D. thesis. That was very exciting.

People say, "Why do you like being a scientist?" I say, "Well, I've always liked puzzles. I'm good at math, so that's not an obstacle. When you have something you don't understand and you try to understand it, the beauty of being a scientist, the greatest joy, is when you can say, 'Ah, now I understand it myself. And you know what, no one else knows this, but I think I have the answer.'" Sometimes you're wrong. You discover that was the wrong answer. But the best times are when you do discover that "I know what that is" and you can persuade other people that you're right.

When I was at SRI—I really enjoyed those years, particularly the opportunity to go up to northern Alaska to study the aurora, and to other places in the Arctic. I was very happy because even though I was very junior, I became the leader of that project. I became in charge of their radar system.

Then the Defense Department was losing interest. They had received all the data that they were interested in getting. So I somewhat led the transition to funding from the National Science Foundation, where the National Science Foundation took over support of the radar. I worked with NSF and other scientists, the community around the country, to get the radar moved to Greenland. That radar now sits in west central Greenland to study the aurora at a higher magnetic latitude.

Most projects have a finite lifetime, and it's hard for scientists to accept that because you'll get great funding initially, or when you're in your prime phase, and then the funding goes away like it did for Apollo. But you have to be agile, and you have to either find new ways of getting support with the same system or move on to a different project, hopefully building on what you already know.

I was doing really well at SRI, and working on getting funding for the radar to move to Greenland, when some of the managers at the Lockheed Palo Alto Research Laboratory—which was only a few miles away from where I worked at SRI, but on the other side of the Stanford campus—they wanted me to come work for them. This was an opportunity to get my first supervisory position. I became the group leader in Electrodynamic Processes in the Space Environment as it was called, and had a small group of about 10 scientists. We were working primarily on satellite interactions with the environment and how the upper atmosphere, the ionosphere, and the magnetosphere affect satellites and the measurements made by them.

There was a combination of funding for the group from the Defense Department and other government agencies, as well as some NASA funding. When I was at SRI I had got my first NASA research projects. I became a participating scientist on Atmosphere Explorer and Dynamics Explorer, two Goddard missions. I didn’t have an instrument on those missions, but I was funded by NASA to work on analysis of data from several instruments on each of those missions.

When I moved to Lockheed, it was a combination of management and personal research. Then just a few years later, when the head of the whole laboratory there, the Space Science Laboratory, was moved to a different position, and I was selected to become the manager of that laboratory. So this was about 1984, and I suddenly had 100 people working for me, all of them on what we call “soft money.” I then discovered “Well, it’s fun being a manager because you can enable other people to do great things.” If it’s a research organization you can still do research on your own, but you spend a lot of your time worrying about people problems. I tell people it’s not just 100 people, it’s that 10 of them at any time have some serious problem. You have to sit in your office with the door closed and work on those problems.

But the joy comes when you see what the organization accomplishes. There’s only so much you can do as an individual, but by leading an organization you benefit from the work they do. You get some satisfaction from it. I forget who, but some baseball manager said, “The fun of being a manager is getting credit for the home runs your players hit.” Science management is very much like that, although scientists tend to be introverted. They often are difficult to work with. They have problems communicating on their own. It’s a challenge.

JOHNSON: I was going to ask you, did you get any training? You were still relatively young at that point to be managing 100 people. What type of training did they give you?

VONDRAK: As I mentioned earlier, when I was an undergraduate I wasn't sure whether I wanted to be a physics major or something more people-oriented. I took courses in psychology, interviewing, counseling, and abnormal psychology, so I effectively had a minor in psychology. I've told people that the courses I had in abnormal psychology and interviewing and counseling were more useful to my career than the courses in quantum mechanics or stellar evolution.

At Lockheed, one of the good things was that the company did have a culture of having professional managers. Unlike NASA, where often you'll take a scientist, put them in a manager position with very little training, and they'll take specialists—perhaps they're an engineering specialist—and put them in a management position, and sometimes these people almost resent their managerial responsibilities. So it's important that if you're going to be a manager, to view it as a professional calling, if you like, and try to focus on what you need to do as a manager.

Lockheed sent me to various programs at the University of Santa Clara [California], programs they'd have at corporate headquarters where you'd spend two weeks there with other people from around the country and get professional development in essentially managing. Then they even sent me for a full summer to Penn State [Pennsylvania State University] to their executive management program.

It was clear that I was doing well at Lockheed, but then I was like 50 years old and I said, "Do I really want to rise up the ladder here at Lockheed and get further away from research?" I decided I really liked being a scientist, and I liked being manager of a science organization.

When I was at Lockheed, I was promoted to a division director. I had three laboratories and several hundred Ph.D.s working for me. But I was one step above the front line, if you like, back in mission control rather than where the action was. It was lucrative to do that, but it wasn't very satisfying.

Then I was told by some friends that the position of lab chief—which was the term they used then for what we now call division directors—opened up here at Goddard. I was encouraged to apply for that position, and was very happy I was selected. NASA offered me the position of Chief of the Laboratory for Extraterrestrial Physics here at Goddard. So, I decided to come to Goddard, and I remember my bosses and mentors at Lockheed saying what a stupid decision that was because I could make more money, and they thought I could rise to even higher levels at Lockheed. I actually had to take a substantial pay cut to come out here to Goddard.

I decided I wanted to spend the rest of my career in science. Even if it's science management, it's still a science position. That's what led me to Goddard was just that opportunity to stay in science, and the decision that if you've still got 20 years in your career you might as well do something you really enjoy.

JOHNSON: It was a leap of faith, because you're going from a corporate environment into a federal position.

VONDRAK: It wasn't that much of a leap of faith in that I was very familiar with how NASA works. By that point I had been on several NASA projects, both for project formulation teams and also Headquarters advisory teams. For example, I spent many years on the Space Science Advisory Committee, SScAC, which was the highest level NASA advisory committee for science, reporting directly to Wes [Wesley T.] Huntress [Jr.] at that time. I would come out to [NASA] Headquarters [Washington, DC] four times a year, typically, for various advisory committee meetings for SScAC and then some of the magnetospheric advisory committees and other activities here.

I knew how NASA worked, I knew NASA Headquarters well. Frankly, it was frustrating trying to help NASA from the outside, because NASA doesn't respond well to external advice. If you're going to make change at NASA or develop new things at NASA you're far better off working from the inside. I had a particular liability in that I was the only non-academic scientist on SScAC. I worked for Lockheed at the time. Even though it was Palo Alto Research Labs that did wonderful science, we were still part of Lockheed Corporation. And being a contractor, it was typically hard to give advice to NASA as a contractor, because they think that you're just looking for work.

JOHNSON: That's true.

VONDRAK: That's true. I thought that coming to Goddard—which I have always respected because I know what great work is done here from a science point of view—that being part of NASA, with a NASA badge, would help me to be more effective in giving NASA advice, starting new programs, starting new projects. So I came here with the objective of trying to do that.

This worked out well, although there were challenges. The people who worked for me in the Lab for Extraterrestrial Physics—that lab had about 100 civil servants—were working on projects like Cassini. The lab built the Cassini infrared spectrometer, a beautiful instrument that's still today measuring Saturn and all of its moons, and other missions to the planets and to geospace, the Earth's magnetosphere, and the solar wind.

Those scientists were very dedicated, but they weren't very interested in the process of getting funding and selling things. I came from a soft-money environment where we were always dependent on getting funding and we were very customer-focused, to a Goddard environment where the scientists here were more research-focused—as a federal laboratory, I think, should be.

When I arrived, full-cost accounting was just being introduced. I had to work with the scientists to make them more customer-focused, where the customer is really the taxpayer, the stakeholders, NASA Headquarters, the science community. I told them, "You have to go down to Headquarters and talk to the people who fund your programs." It was difficult for many of them to accept that transition. They had a culture of, "We are working for the government. Government positions are not as lucrative as private industry, or academia even, but we don't have to worry about funding. We just work on projects that we find important." Some of them were very important, and those people could find funding easily. Other people were doing the same old thing they had done maybe even in graduate school, and they had a very tough transition.

In any case, I went to Headquarters and I told the division directors down there that they should look to Goddard to be their help, and we should try to work as a stronger partnership. That was very successful. For example, when I talked to Wes Huntress, who was the AA [Associate Administrator] for Space Science at the time, the problem we were having in magnetospheric physics—which was called Sun-Earth Connections [SEC] at the time, and today is called heliophysics—was getting new starts for new missions. Wes said we could try to devise a program line.

I worked with some colleagues at the [Johns Hopkins University] Applied Physics Lab [Laurel, Maryland] and with people at Headquarters, and we started two SEC program lines called Solar Terrestrial Probes [STP] and Living with a Star. Solar Terrestrial Probes studies the Earth's space environment, and Living with a Star studies the Sun and interplanetary space. The idea of a program line is that Congress funds this continuous line of missions and you don't have to get a new start each year. It'll be funded at a continuous level. At that time, the Solar Terrestrial Probes were about $150 million a year. It's probably twice that because of inflation. By working with Headquarters and the science community, we came up with a strategy whereby we have this continuous string of SEC missions.

The Solar Terrestrial Probes and Living with a Star programs were modeled after the Mars Exploration Program. Earlier Mars had all these individual missions like Viking and others, which had to get a new start for each one. They had difficulty getting enough funding, and that led to some of the problems they had with Mars Polar Lander and other missions. Then they moved to a program element where they would have constant funding, or guaranteed funding, and they could optimize the strategy within that. I worked hard to bring those two SEC program elements here to Goddard.

JOHNSON: How long was the funding for, if the Congress approved it?

VONDRAK: Congress generally every year will say, "STP or, comparable, Mars Exploration Program, we're going to fund it for $300 million next year and for the following years." Then

NASA has to, in the president's request, go in with what they consider to be a reasonable viable amount. Congress can approve it without saying, "Okay, we're going to approve [Parker] Solar Probe Plus," for example, the next one in the Living with a Star line. They don't need a new start. The new starts typically would get stalled in Congress. So that was a new way of doing business, and it's been very successful and very healthy for those communities.

In any case, the other thing I tried to do was to work with Headquarters on their education and public outreach programs, because Wes Huntress at the time—strongly endorsed by Ed [Edward J.] Weiler after him, Wes's successor—was to have a very active outreach to the public, to educators and students. We use the umbrella name of Education and Public Outreach, EPO. They said, "Okay, every new mission, you have to set aside typically 2 percent of your funding for communicating with the public and public engagement." They had a plan where each of the major science themes in space science—like planetary science, and what we now call heliophysics, which was then called Sun-Earth Connections—would have an organization that would coordinate all of the education and public outreach activities across the country for that discipline, and develop products, and have events.

Jeff [Jeffrey D.] Rosendhal was the manager of that at Headquarters. He came out here and said, "We'd like Goddard to lead the Sun-Earth Connections activity"—it was called the Sun-Earth Connections Education Forum—"but we also have a group at Berkeley who would like to lead it. So can you form a partnership with the Berkeley people?" I said, "Oh yes, I know Berkeley, it's a good place. I graduated from there and they have good people."

The challenge though was the fact that they have a different culture. We're a federal laboratory with scientists. Goddard has an engineering culture. They're an academic institution.

It would involve working with their preservice teachers, their education department, as well as their scientists and their space science department.

In any case I said, "That'll be fun." We formed a very effective group, but the fact that we were bicoastal had advantages and disadvantages. Also the fact that they approached the goal in different ways. I think it made us better, but there were some real management challenges working with them. The problem I had was I wanted some of the scientists to take on the responsibility, but the ones who were really good didn't want to do it, they'd rather do other things. I ended up being the co-director with the co-director at Berkeley, so I spent a lot of my time making sure that the partnership was successful, and it was. We formed what we call Sun-Earth Day where every March, at the March equinox, they have outreach to teachers and students. We did webcasts of eclipses, webcasts from eclipses around the world, and for the one coming up in August.

There were many other educational activities, because I do think it's extremely important for NASA at all levels to be devoted to education. I was very disappointed when we had a change in command and the new NASA Administrator said, "Oh, we're not going to fund any education because that's the role of the Education Department." He said, "Gee, I decided to be a scientist or an engineer in fourth grade. I was inspired by my mother. We don't need any significant amount of NASA funding for this."

I don't know if he really believes that or if he was misquoted, but certainly I think we do great things at NASA. We are the agency that can inspire the youth to go into technical fields and engineering, math, and just even to have scientifically-literate lawyers. We need lawyers who understand technology and appreciate science. You don't have to be a practicing scientist to be inspired by NASA. I think it's an important role for the Agency. Everyone in the Agency should participate in that. I think missions need to educate the public as to why NASA is studying Mars, or why we want to go back to the Moon. It's important.

JOHNSON: Especially right now with some of the political atmosphere. Evidently people still think there's a debate about science. It's interesting. I think, as you said, it's important, especially in times like this, when NASA has to take that role.

VONDRAK: You have to be open-minded. You have to get information. You have to understand processes, whether it's regarding climate or pollution or extraterrestrial resources, whatever subject might be important to society. It's necessary to have an understanding as to what are the issues, what are the facts, to try to make intelligent predictions.

If you don't fund research, you won't know enough to even know what's happening today, much less be able to predict what will happen in 50 years from now. The difficulty is you may discover that you forced society into a state where it's too late to make corrective changes or it's too late to do the right thing. You have to have foresight. Just ignoring a subject doesn't provide you the opportunity for accurate foresight.

JOHNSON: Is that still in place, that two percent?

VONDRAK: No.

JOHNSON: Was that Mike [Michael D.] Griffin that you were speaking of, the Administrator?

VONDRAK: Mike Griffin is the one to whom that quote it attributed. I hope it's a misquote.

JOHNSON: All the Administrators had different perspectives. That's one of the things with NASA, they all bring something different.

VONDRAK: It was very confusing. The SMD [Science Mission Directorate], what's now called SMD, had formed this beautiful system whereby we had distributed EPO activities around the nation, assisted by centralized coordinating groups that made them more effective. NASA dismantled all that about 10 years ago. But they said, "We can't do education and public outreach, but you have to do communications and public engagement." I thought to myself, "Okay, well some of the things we do now we cannot do in the future," like educator workshops that were so effective. We had to change our approach, but we still have made significant efforts to reach the public and students.

For example, we had quickly learned that doing missionary activities, as I called it, to schoolrooms, were very effective with the 50 students or 25 students you talk to. But that's a small group for the amount of time you spend. We discovered it was far more important to find interested teachers, bring them to Goddard, or go to where they are, and have a one-week summer session. They would get credit for professional development, and we would spend a whole week telling them about lunar science, space science, whatever. Then they could go, and they would understand the material better so they could use it in their classroom.

We had discovered that some material we were developing for educators they were reluctant to use because they didn't think they were qualified to answer questions from students. So by raising their level of understanding, giving them a deeper knowledge, they could go to the classroom, answer questions, work with other interested teachers. By doing that, we could multiply the effectiveness of our programs.

JOHNSON: Like you mentioned, sometimes scientists have trouble communicating. Did you have trouble finding people to lead those workshops? Or enough people came from an academic background that that was something they did well?

VONDRAK: We have many skilled people who work in education and public outreach now. They started their career in science. Most of them got through the Master's degree, and then for various reasons they didn't go on to a Ph.D. They still want to do science, and they're very effective at working with students and the public and educators.

These are the people who when NASA decided not to fund these programs, they're the ones who suffered the most. The educator workshops—it was decided by Headquarters that that does not belong in SMD, it belongs in the Office of Education. Then the Office of Education now may not have continuous existence at NASA Headquarters. There's a lot of confusion. But at the local level—at the mission level, at the scientist level—I still encourage people. The two percent requirement is no longer a requirement. At one point they took away funding from missions that had it as an identified budget, and they consolidated it, and then it disappeared. In any case, it's an important activity. I tell people, "Find a way to fund it, and do it."

JOHNSON: I've heard that from a couple other people that have mentioned that education is still going to go on. It's just not going to be, like you said, under that title. It's not going to be there.

VONDRAK: We have to communicate to the public. They said, "Engage the public, communicate, but don't educate them."

JOHNSON: A little hard to do.

VONDRAK: Yes. Anyway, I think it's very important.

JOHNSON: You were, as you said, the Lab Chief for Extraterrestrial Physics for about 10 years. Then you moved to Program Director for the Robotic Lunar Exploration Program.

VONDRAK: Right. What happened was I'd been here at Goddard from '95 to 2004, I was still the Lab Chief here. We had the [Space Shuttle] *Columbia* [STS-107] accident. Then to recover from the *Columbia* accident and that tragedy—the effect it had on NASA was that NASA needed to have a destination identified. The *Columbia* Accident Investigation Board said, "You not only have to change the culture at NASA, have people speak out more, but you also have to have a direction to where NASA is headed."

That led to President George W. Bush going to NASA Headquarters, announcing in January of 2004 the Vision for Space Exploration, saying that "Okay, we're not going to keep staying in low-Earth orbit. We'll finish [International Space] Station, go back to the Moon, and then on to Mars." That was very exciting. I think all NASA employees welcomed that. They decided that the way you go back to the Moon is to fill in the knowledge gaps from Apollo, decide how to go back to the Moon in a better way than Apollo, and then go on to Mars. They quickly formed a team called the Objectives and Requirements Definition Team, led by Johnson Space Center [Houston, Texas]. John [W.] Young was one of the principals there.

They brought together scientists and engineers to come up with a strategy for how you would do that, and what information is needed before you go back to the Moon. Apollo showed you can go to the Moon, you can visit it. But the purpose is not just to visit the Moon for a few days, but to learn how to live and work on the Moon. I felt very pleased personally, because I think other than Jim [James B.] Garvin—who was at Headquarters at the time and is now at Goddard—I was the only other Goddard scientist invited to that strategy session in Houston. I was invited because of my experience on the Apollo Program and the human effects on the lunar environment.

We came up with a strategy. We said, "What you need to have is a set of very prompt robotic missions." What they would do would be to map the lunar environment well, search for resources, and then also measure the radiation environment and some things that we didn't know concerning human effects at the Moon. The Apollo Program was incredibly successful. I'm a big fan of Apollo. I've read a lot about it, talked to many of the astronauts. It's incredible what the country did in just a few short years to actually put someone on the Moon, and return those 12 people back safely from the lunar surface.

But Apollo, those missions were clustered around the equatorial region. They were short stays. To go back to the Moon, what you'd like to start with are maps of the entire Moon, particularly the polar regions. The polar regions are important because they have resources. We expected the polar regions to have water and other volatiles. Also, they have sunlight. The Apollo astronauts, when they landed they came in right after sunrise, when the shadows would be long, so they could see obstacles. The temperature was fairly benign at that point, but if they had tried to stay longer it would have gotten very hot during the daytime. Then, if they had stayed more than two weeks it would be night on the Moon and it would get very cold. They would have to depend on their battery power to stay warm all night long. If you brought solar-powered systems, they wouldn’t have any sunlight to charge their batteries or run their electrical system.

An important resource at the Moon is that if you go to the poles and you pick a high place at the poles, the sun shines there all the time—or nearly all the time, 98 percent of the time—so you can run solar electric power systems. The temperature isn’t as extreme, doesn’t have extreme variations like you have at the equator. That’s an assured resource, and so we need to identify what parts of the lunar poles have near continuous sunlight. The other thing we were trying to do is to do an orbital mapping of where the resources might be in terms of water.

The highest priority was given to a prompt robotic mission, that was going to be called Lunar Reconnaissance Orbiter [LRO], to seek out that information about the Moon, and also carry a radiation sensor to see how much radiation the astronauts would get. That was a concern even during Apollo. Apollo was fortunate in that it occurred at a time of an active sun, and there were some major solar flares, but none of the missions was affected in any significant way by a solar flare.

I was on that team that helped identify the strategy, and then they said, “Okay, that will be part of the Vision, to have a prompt orbiter followed by a lander.” Because we said it would be important to put something on the surface to search for water, but in order to know where to put that lander you needed the orbiter first. This was a high-profile set of missions, and they had formed, in addition to the HOMD, the Human Operations Mission Directorate, they formed a separate directorate at Headquarters called the Exploration Systems Mission Directorate, ESMD.

It was led by Admiral [Craig E.] Steidle. ESMD would be responsible for this line of robotic missions, but since it was brand-new and they didn't know how to do robotic missions, they made a partnership with SMD. Ed Weiler was the AA at the time. So the missions would be implemented by SMD with funding from ESMD.

In fact, these were measurement investigations, not science investigations, on LRO, because ESMD did not do science. But all of the instruments were selected to be science-quality measurements. It was going to be high visibility, it was going to have a program director, like the Mars Program Director, under SMD, and they needed someone to run the program. I heard this, and so I talked to the people at Headquarters. Orlando Figueroa was the head of the Planetary Science Division, and he wanted me to take the job. He talked to Ed, and they called me the very next day and said, "If you want the job, you can have it. Come down here to Headquarters, and be the Program Director."

I was an SES, or Senior Executive Service, so they could do that without competition, just reassign me. It was very interesting because Al [Alphonso V.] Diaz, who was the Center Director, didn't want me to leave Goddard, but I worked out a deal. I'd do it for six months and keep my Goddard position, and then come back to Goddard.

So I went down there, and the first job was to get out the announcement of opportunity [AO] for LRO. I worked with Jim Garvin, who was the Mars Program Scientist at the time. We copied the AO after MRO, the Mars Reconnaissance Orbiter, which had just come out, in order to save a lot of time. We got the AO through Headquarters in record time because it was the highest priority, because President Bush had said in his speech, "We're going to do an orbiter in the next four years, followed by a lander." Everyone at Headquarters had to give it highest priority. It was tedious but very satisfying, because we got the AO out in record time, and we got the instruments selected in less than six months. Typically, an AO takes years to get to the start of a program. We did it in just a few months.

What happened while the AO was out on the street was that Sean O'Keefe, who was the NASA Administrator at the time, decided to reorganize. He took Ed Weiler and sent him out here to Goddard, and moved Al Diaz, to Headquarters. There was this big reshuffling that some of the people involved found very painful. Also ESMD was growing, and they were looking for things to manage that could be near-term successes. They wanted to take LRO and move it closer in to their organization, away from SMD.

Also it was clear that the Vision for Space Exploration was underfunded. They wanted to build the Ares rocket and their launch systems, and they were desperate for money. So they took all the forward funding for the Robotic Lunar Exploration Program and reduced it to where they couldn't do anything beyond LRO. The only way they were able to fulfill the presidential mandate to have a second mission to land on the surface was to add to the LRO launch a sister mission called LCROSS [Lunar Crater Observation and Sensing Satellite] that [NASA] Ames [Research Center, Moffett Field, California] would manage and Tony [Anthony] Colaprete of NASA Ames was responsible for, which was a lunar impactor experiment.

It did great things. It aimed the Centaur [upper] stage [rocket] into Cabeus Crater, measured the plume ejected from the surface with their instruments. We also measured them with LRO, and we showed that there's a substantial amount of water in the lunar subsurface. So that was very important, but it wasn't what was originally conceived, a soft lander. But it accomplished what the president said, and it did wonderful science at an affordable cost.

It was clear to me at that point that the Robotic Lunar Exploration Program [RLEP] did not have a bright future. Simultaneously, when Ed Weiler got sent out here, he decided to reorganize Goddard, which did not have a strong planetary division. It had planetary elements in the Laboratory for Extraterrestrial Physics, and it also had some elements in Earth science. He decided to organize a separate Planetary Science Division here. Ed called me up, said, "Can you come out and talk?" I came out and talked. He said, "I want you to be the new Division Director here at Goddard."

JOHNSON: Hard to say no, right?

VONDRAK: It was a great opportunity. I could see that it again would be a little bit of a managerial challenge because I'd be taking elements from space science, elements from Earth science, trying to bring them together in a new organization. Get people who weren't used to working together to work together. But it was a great opportunity, so I immediately said yes.

Then Al Diaz, who didn't want me to leave Goddard, now he was at Headquarters, and he didn't want me to leave Headquarters until I had identified a successor. I went through a tough period where I was trying to do the RLEP Director job at Headquarters, the Lab Chief for Extraterrestrial Physics here, and also create the new Planetary Science Division. Over a four-month period, I was constantly running back and forth between Headquarters and Goddard.

In any case, that all worked out well. Goddard won an instrument, the laser altimeter for LRO—which was actually out of the Earth Science Division here, but then became part of my new organization—and then also some roles in the Russian neutron detector experiment that was looking for subsurface water.

I had no individual role on LRO for several years. The LRO spacecraft was built here at Goddard. It was scheduled for launch by the end of '08 is what President Bush had said. At that point it became clear that we weren't going to go back to the Moon very quickly, so it wasn't as urgent, and there were issues with availability of launch vehicles, so our launch slipped until June of '09. It was still extraordinarily fast for a planetary mission, but we came in actually under budget and right on schedule. Launched in '09.

In '08, because it was such a high visibility mission, I was asked whether I could become the project scientist on LRO. I said, "I'd love to do that, and I'd like to be the project scientist," because they wanted someone more experienced who could work through the ESMD-SMD partnership and the public interactions to get LRO smoothly through its launch and one-year mission.

I said, "I would do that, but I cannot be the Division Director and the LRO Project Scientist because they're both full-time jobs." We worked out an arrangement where I had recruited Anne [L.] Kinney, who had been the head of the Universe [Division] at Headquarters. She came out here to Goddard, then I asked her to be my Deputy, which was wonderful because she was a very experienced, very capable person. I worked out with management here an arrangement whereby I would become the Deputy to Anne, and Anne would be the Division Director. So we could continue to work together, but she would have the lead role and would do all the heavy lifting for the Division, and I would do the heavy lifting for LRO, and that worked out very well.

I became the project scientist, and worked on getting it through all the different approvals at Headquarters for launch. The original intention had been a one-year mission for ESMD. They wanted all their maps, all their measurements, the requirement was to do them in a year. But the intention had been to see if we could convert it to a science mission. So I had to work with SMD and prepare a proposal to convert LRO from an ESMD measurement mission into an SMD science mission. That led to a very interesting summer, because I thought it would be a smooth transition, but I had to go through an incredible number of reviews in ESMD to get the assurances that we had accomplished the ESMD objectives, all the way through Doug [Douglas R.] Cooke, the ESMD AA, and then persuade Ed Weiler and SMD that we were a capable science mission even though we weren't initiated as a science mission, even though we weren't initiated as a science mission.

Everyone believed that we were doing the right thing, but it was just going through all of the requirements needed and preparing the incredible number of charts and reviews at multiple levels to persuade everyone that yes, we could do that transition. I think today we are the only major mission that has made that transition between AAs and mission directorates at Headquarters, where we moved from ESMD—now HEOMD [Human Exploration and Operations Mission Directorate]—into SMD.

With LRO, the project scientist, as you know, is responsible for the scientific integrity of the mission. The project scientist doesn't have any instruments of their own typically, because for a multi-instrument mission we have to be fair and equitable and not biased. But we have to assure Headquarters and the relevant Center that the mission is performing as it should and is performing at a level that is accomplishing its objectives. We were accepted by SMD for a two-year science mission. Since then, every two years we go through an extended science mission proposal. Right now we're in our third extended science mission. We were launched in June of 2009. A couple weeks from now we have our eighth anniversary of launch. We've been at the Moon for almost eight years, making beautiful maps of the Moon, understanding the scientific history of the Moon, the processes that occur on the Moon.

JOHNSON: I was reading an article and they quoted you as saying, "We're rewriting the textbooks by showing that the Moon is not a dead object." I thought that was interesting.

VONDRAK: That's probably the most important general conclusion we've made of the Moon, that it's a dynamic body. It's not isolated in space. It is changing. It's shrinking. We've discovered cracks and ridges on the Moon that are globally abundant, and we can tell the rate of shrinkage. It's like an orange. I tell people you take an orange or an apple, you put it out in the Sun. What happens, it gets dried out, and it starts to shrink. It develops cracks and ridges. That's what the Moon is doing.

The Moon isn't drying out. It's always been fairly dry, but it was hotter inside. As the interior cools it develops wrinkle ridges that they call scarps, and cracks called graben. Geological terms. I tell people, "It's just cracks and ridges on the Moon." That's a process that wasn't appreciated before LRO. But, the important thing is, first of all, we're making maps of the Moon. We have this beautiful laser altimeter built at Goddard that we were concerned whether it would last six months or a year. It's been up there eight years. It's still working.

We've measured about 7 billion points on the Moon where we know the elevation of each of those points, so it's a topographic map. It's like when you go hiking maybe in a national park and you get a topographic map showing the contours of elevation so you know where the hills are, and the valleys. We know the topography of the Moon better than we do any other object in the solar system, even the Earth, because the Earth is about two-thirds covered with water. The undersea portion of the Earth, the hills and valleys there are very poorly known. On the Moon we can give you a topographic map that has centers that are only tens of meters apart, and give you all the contours of the Moon because of these 7 billion measured points.

The laser altimeter fires out 140 laser beams every second and measures the returns. They go out in groups of five, then we measure all of the length of time for the return. We can measure all of those points, their absolute elevation and also their relative elevation, so we can measure slopes. The Apollo missions had to land on flat areas, because if the slope was more than about 15 degrees it would tip over. I believe it was Apollo 15 that landed on top of a small crater, and there was concern that its engine had been damaged when it landed and the legs were tilted. We can give you slope maps, roughness maps. Just incredible accuracy.

Then we have temperature maps, from a thermal infrared system. We measure ultraviolet so we can see in the dark in the polar craters. The craters that are in permanent darkness, we can now give you maps of the interior. We have image maps down to 50-centimeter resolution, typically. We flew in low over the Apollo sites, brought down the spacecraft as close as we safely could—only 60,000 feet above the surface, 20 kilometers—so we could image the Apollo landing sites with very high resolution. We can see not only all the hardware, the lunar rover, the backpacks, the ALSEP sites, take pictures of the instruments that I worked on sitting on the lunar surface, and we can even see the tracks they left, their footprints and the rover tracks. It's so satisfying to be able to do that.

We were launched in 2009, which was the fortieth anniversary of Apollo 11, and we went into orbit in early July. Naturally there was a lot of pressure from Headquarters, "Give us an image of the Apollo 11 site." We have to depend on the lunar rotation and the lighting in order to get a good image. The LRO Camera is managed by Mark [S.] Robinson, the scientist at Arizona State [University, Tempe] responsible for the LRO Camera. They'd get the data down and they would analyze it at night at Arizona, and first thing in the morning I'd go to my computer and turn it on at home to see what we had from the Moon.

I remember saying to my wife Mary, "Come see this." This, I believe, was the Apollo 12 site. I said, "Do you see those lines on the surface?" I said, "Those are the astronaut tracks." We never expected to see them because the astronaut footprints are too small. We can measure an object that's like a foot or two across, but not a shoe print.

What happens is the Moon is covered with dust, and as the astronauts would bound across the surface—they'd almost bounce across the surface—they would kick up this dust. It's like walking across a sidewalk that has a layer of snow, of dusty snow on it, fresh snow. As you walk, you kick up some of the snow. The astronauts do the same thing. You would see what I call their track. Not individual footprints, but you could see the path they made as they walked across the lunar surface. This is one of the joys of science. People at Arizona State saw the images first, but you can say, "Gosh." Come to work and say, "You won't believe what I saw this morning."

JOHNSON: So few people have had the opportunity to see that before you saw it.

VONDRAK: Correct, correct. We've been mapping the Moon with great detail, and finding resources, and preparing the way. The beauty of LRO is we have a very high data rate. The Moon is close enough, it's not like Mars where you can only send a little bit of data back from Mars. The Moon is close enough that you can have a high data rate. What was decided early in LRO, with the encouragement of Ed Weiler, the Center Director, was to build at White Sands, New Mexico a tracking antenna that would be just for LRO. Every time the Moon is above the horizon in New Mexico we download an incredible amount of data.

Right now LRO has accumulated more than 750 terabytes of data. People say, "What's a terabyte?" You say, "Well, a terabyte is 1,000 gigabytes." The high density DVD that you would use for data storage or a movie has about five gigabytes, four and a half gigabytes, so 750 terabytes is 750,000 gigabytes. We have the equivalent of nearly 200,000 DVDs' worth of data.

I tell people if you wanted to put all of the LRO data on high density DVD disks, if you took those disks—without the plastic box, just the bare disks—and you piled them up, you'd have a pile that would be bigger than half the Washington Monument. It's an incredible amount of data. More than half of the data in the Planetary Data System is LRO data.

Because the Moon is close it's easy to get data back, easier than getting it from Mars or Saturn. The Moon is a wonderful neighbor. If we wanted to explore space and being a spacefaring nation, if God wanted us to do that he would have given us a Moon, which we have. So the Moon is a great neighbor.

JOHNSON: Preserving that data is important.

VONDRAK: There's the Planetary Data System, which planetary science has, and we have to make sure that the data is preserved because there's no need to repeat it, and also you can look for changes. One of the surprises was that we expected to see in the LRO data changes from the Apollo era. In fact, Mark Robinson had a project very early to look for changes between the heritage Apollo imagery and the LRO imagery. He found some, but it was hard because they were taken with different cameras under different lighting conditions.

What he wisely did was set up a program where he would reimage places we saw with our Narrow Angle Camera and reimage them under the exact same lighting and viewing conditions, and therefore any fresh impacts would be easily seen. The surprise was that there's many more impacts than had been predicted. Also, each of the impacts produces a lot of secondary impacts.

The Moon is more dynamic than expected. Impacts are infrequent, so you could put an outpost on the Moon and you don't have to worry about your dome getting punctured very often. But the number of impacts, number of micrometeorites striking the Moon, is very abundant, it's very high. That's one of the surprises in the Moon, are the changes in the Moon. Not only the thermal contraction but also impacts, and the fact that we had thought that volcanism on the Moon, volcanoes, stopped a long long time ago. But in fact it may not have stopped a long, long time ago, just a long time ago, maybe tens of millions of years.

JOHNSON: We've talked about technology. Definitely technology has changed since you first were working on your Ph.D. The terabytes, and the amount of data that is being preserved now—just the ability to get that technology, and the technology that it takes to build the instruments to go into space. Sometimes there's delays of 10 to 15 years. Talk a little bit about the technology changes with science at NASA and how that's affected or aided the work that's being done.

VONDRAK: The sensors are certainly far better than Apollo era or early NASA. The instruments on LRO—the laser altimeter; even the Camera with the number of pixels in the readout, the resolution; the thermal infrared; we have a compact radar system. All of the instruments would not have been available 40 or 50 years ago. We can make measurements in far better ways than we ever expected, even that we didn't expect. Certainly not even what was practical at the time.

The other thing is the data volume and managing data volume. The data used to be very primitive with the ALSEP experiments, when I worked on the suprathermal ion detector. Our data came back through a teletype machine. There were just rows of numbers, and we had poor graduate students trying to analyze these by looking at microfiche and staring at numbers in order to see if there were anomalies. We used strip-chart recorders that were analog devices.

When I was an undergraduate I took a course in computing, and it was all analog computers. We had to take essentially a circuit board and use discrete circuit elements—no integrated circuits. We used resistors and other circuit elements to build up what would be like a differential equation, then run a clock and a strip chart and plot out the voltage we got. That was the way you solved an equation using a system like that.

Then when I was at Berkeley, my last semester as a senior I took one of the first courses they offered in digital computing. Although that used all punch cards, and we had only one computer on campus for students. We had to go there and run the programs, turn the punch cards in, and get the answers back much later. It was just so primitive doing software at the time because we didn't have the diagnostics. My rocket experiment, I did most of the calculations on setting the trajectory with my slide rule. Did not have an electronic calculator because they didn't come out until afterwards.

I tell people the invention that I found most breathtaking in my career was the Xerox machine, because when I was in high school and as an undergraduate you'd have to go to the library, get a book, hope someone else hadn't stolen the book. You'd have to wait in line to put your name on a list to get access to the book, and then you'd have to copy out by hand whatever you needed. I remember at the Berkeley library when they introduced a Xerox machine that was coin-operated, it cost like 10 cents—which is probably $1 or $2 a page nowadays—and you could actually put the book on there and make a Xerox copy of the page.

If you can imagine a world where you didn't have digital systems and you didn't have Xerox machines and you didn't have electronic calculators, that's basically the technology we had. Certainly for early science at NASA, and for the Apollo Program.

JOHNSON: We put a man on the Moon using slide rules.

VONDRAK: Yes. MIT [Massachusetts Institute of Technology, Cambridge] had some beautiful computers they used, but they were few and far between.

JOHNSON: And large.

VONDRAK: And large. They weren't distributed. They were all mainframe, so you'd have to wait your turn in line to get to use them for a little bit of time. Analyzing 750 terabytes of data would have been just incredible.

My rocket experiment, I got what we say right now a few kilobytes of data. It took me six months to sift through that to make sure that I had made a valid measurement because of problems with the payload and the rocket and the aurora not cooperating. So times have changed. I tell people that they're lucky because the tools are better, but you still have to be clever. The one tool that people haven't invented is a machine that's more clever than a human.

JOHNSON: Even though they try, don't they.

VONDRAK: They claim they have. But most of them aren’t as clever as they claim they are.

JOHNSON: There have been a lot of things—like you said, the Lunar Reconnaissance Orbiter, the amount of work that that was able to do. There’s a lot of things in the news also with Cassini because of the Grand Finale and everything that’s happening there. Also a few weeks ago Jim [James L.] Green and NASA Headquarters announced the findings from Saturn’s moon Enceladus.

So there’s a lot of very exciting things going on right now, with these announcements and some of the things that are coming back and the information hopefully that’s going to come from that last Grand Finale with Cassini. Talk about some of the information that’s coming out, and maybe hopefully where you see that leading to.

VONDRAK: Sure. We do have here in the Solar System Exploration Division here at Goddard many scientists who are interested in what we call the outer solar system, the major moons associated with Jupiter, Saturn, and distant reaches of the solar system.

Enceladus is an exciting world, and I think the recent news you’re speaking about just all falls under the general category that Enceladus is a dynamic place. It’s a dynamic moon. It has vents where there’s places that gases and liquids are flowing out of, plumes on Enceladus. Enceladus has cracks, it may have reoriented after a major collision. So it’s not a static world.

In my career, one of the things I find most satisfying is that when I was young and in school and would read science books they would just talk about Saturn and they’d say, “Okay, there’s these little moons.” Or the Galilean moons around Jupiter, they were just dim objects.

Now we understand these dim objects as worlds in their own right, as places. They have structure, they have dynamics. So if we want to understand the story of Earth we have to understand the story of the solar system and how the solar system has changed.

As recently as 10 or 15 years ago we thought that the order of the planets and their basic location in the solar system had been static since the solar system began. Now scientists think that there was a gravitational interaction between Jupiter and Saturn that caused Saturn and Uranus and Neptune to move farther out, and Uranus and Neptune to exchange their locations in space. This resulted in a huge upheaval to the smaller objects in the asteroid belt, in the outer clouds of icy worlds beyond Neptune. This led to a bombardment of the early Earth and the Moon.

One of the most important findings of the Apollo Program was that the basins formed, some of them, soon after the Moon formed about 4.5 billion years ago. But then around 4 billion or 3.9 billion years ago, there suddenly was a cataclysm of objects coming in and striking the Moon and forming the face of the Moon as we see it today.

The fact that that cataclysm, or what's called "late heavy bombardment" of the Moon 500 million years after it was formed—that was the first clue that there might have been some upheaval in the outer solar system. Now scientists are saying the solar system isn't a static place. It's changing, it's evolving. That appreciation is a real shift in the way we think about the solar system.

That's probably going to be one of the more important durable legacies of the Apollo Program, dating the history of the Moon, which we could not have done by just looking at the Moon through telescopes. We had to go there, we had to have astronauts pick up rocks, bring rocks home, so that important information could be obtained.

JOHNSON: Things change for NASA when we get new presidents and new administrators. Of course, like you said, the soft lander for the Moon, with the [President Barack H.] Obama [II] administration when that decision was made not to do that. But now there's talk that we may be going back to the Moon again if that budget gets approved. There also seems to be less emphasis on education again, and on Earth science, and science in general. Talk about that for a moment and how you think that's going to affect NASA's science program here at Goddard.

VONDRAK: Scientists need projects, projects cost money. Therefore if you want to do science you need funding. I think the nation does realize that, and certainly Congress and our executives—president, vice president—every one of them I think has appreciated science in different ways. I think our current administration recognizes the value of science, so I'm confident that NASA will keep doing science.

The type of science will depend on what NASA's destination is, what the vision is for where NASA should be. If we're going to stay in Earth orbit, it'll be a lot of physiology and life science. If we go somewhere else, it'll be different than that.

One of the things I'm proudest of here is something I really don't work in, and that's astrobiology. When I was on the NASA advisory committees and came here to Goddard as the Chief of the Lab for Extraterrestrial Physics, it was clear to me that astrobiology was an embryonic activity at NASA that would be important in the future. So I came to Goddard and I said, "Can we do astrobiology here?" We had a vigorous astrochemistry group that was all inorganic chemistry and they said, "We don't have any biologists." The Center didn't want to get into lifeforms, if you like. They were nervous about that. I could understand that.

So I said, "Well, how about organic chemistry?" The groups here responded to that. We recruited hard. We got some exceptionally talented biochemists who were doing astrobiology, recruited some of them from NASA Ames, and we set up an astrobiology group here.

Paul [R.] Mahaffy, who is our Division Director now—he and the group he was in had focused on atmospheric measurements. Paul was wise enough to say, "We've got to do landed experiments and do things where we're actually working with chemical reactivity and analyzing the solid surfaces." That led to that group really being successful in that area, so we've got one of the foremost astrobiology teams in the country.

That's an evolution of science. Under full cost accounting, remember I told you one of the challenges was to get scientists to do work that could be funded. I said science evolves. You don't want to go into an area that you're completely ignorant of, but if you could take your laboratory work in astrochemistry and evolve it into one that's doing astrobiology, you're going to be more successful than you would be working in an area that is not as important to NASA.

Meeting the challenge of evolving the research is one of the most difficult things for scientists to do, because they've been successful in what they know how to do. They want to keep doing that because they know how to do it, and there's still questions that interest them. But to move into a different area is important. You do that by evolution, not by just killing what you're doing and starting over with something fresh.

JOHNSON: You retired in 2013 technically, but you're still working.

VONDRAK: Yes. What happened was three years ago I saw my 70th birthday coming and I said, “I’ve got to slow down. I’m getting old, I don’t have as much stamina as I used to. I can’t work 80 hours a week, I can only work 40.” I said, “I’ve got to slow down.”

Plus, you’ve got to give the younger people a chance. I don’t need to be Project Scientist forever. When I was about 68 I had a very capable Deputy Project Scientist on LRO, John [W.] Keller. I said, “John, why don’t we do this? You become Project Scientist, I’ll be your Deputy. I’ll still hang around. I’ll help you, I’ll coach you. I’ll do some of your work for you, but you should lead the way.” It was similar to what I did with the division directorship.

Then when I hit 70 I said to management, “I don’t really want to keep working. I want to retire.” The answer was, “Well, can’t you do something useful?” There was a program I could take where I could transition into retirement by working half-time. I signed up for that, and would only get paid for 20 hours a week. So I cut back.

That was a three-year program, so I did that for three years. Then last summer when I hit 73, I retired completely, but I’m an emeritus scientist. What an emeritus is, it means you’re a voluntary civil servant. The division provides me with an office and a computer and a badge, and I get to come to work whenever I want. I work on research papers and I help advise, coach, mentor, whatever.

JOHNSON: The best of both worlds. You get to retire and still do work.

VONDRAK: And my wife loves it. When I was working half-time, I’d go to work every morning and say, “I’ll come home right after lunch.” Then naturally my wife would call me and tell me I’m late for dinner. I worked it out so I come to work only on Tuesday, Wednesday, and

Thursday, unless there's a strong reason to come in on a Monday or Friday. So I'm here three days a week. I have four-day weekends, and I'm very happy.

I think I'm still useful. It's fun, I get to work on fun things. I've always been a fan of the Arctic explorers, the polar explorers, and so I'm really happy that in my career I've gotten to all of the high latitude places in the Arctic. I've been to the geographic South Pole doing research.

I made a trip to the north magnetic pole for part of an educational video we made on the Earth's magnetic field. I said to the producer, "What we should do to explain the magnetic field is measure the magnetic field here in Washington, and you discover it's tilted by about 45 degrees. Then go further north, and then go to the magnetic pole where it's pointed straight down." We did that, and that was a great field trip. Nice educational video. People tell me they like it.

That got me reading more carefully on all the searches for the north magnetic pole. It turns out Roald [E. G.] Amundsen, who went to the South Pole—his first trip was the Northwest Passage. He looked for the north magnetic pole and he couldn't find it because it seemed to be moving. It turns out the north magnetic pole right now is almost at the geographic North Pole and is headed towards Siberia.

I started reading into why that is, and talking to the magnetics experts here, and then also reading Amundsen's diary. I've just finished an academic research paper for an academic Society for the History of Discoveries. The title is "Roald Amundsen's Difficult Search for the Elusive North Magnetic Pole," and explaining why he had such a difficult time. That's just a fun project. It's a history project, but it involves understanding why the Earth's magnetic field is changing. The historians and biographers who have written about Amundsen have said, "For obscure reasons he wasn't able to find it." Now I think I've written a paper that sheds more light and explains, and solves that historical puzzle. Something he never appreciated, and most historians didn't realize, that the pole is in motion, both every day and on an annual basis.

JOHNSON: It goes back to what you said. When you were a child, those first books that you read were with explorers, and got you interested in science and math.

VONDRAK: Right. Science fiction, history books. Now you have a career where you live it rather than reading about it.

JOHNSON: That's exciting, that is very exciting. I was going to ask you, just to close, if you look back over your career, is there anything you'd consider as your biggest challenge with your career with NASA?

VONDRAK: The biggest challenges, aside from the research, is working with people. Science management involves people. Scientists are people. They're human, they have problems.

Then also the other challenge is selling projects, funding. I've been associated with many projects that were beautiful ideas, proposals that we worked very hard on, that weren't funded. Now when NASA has a call for missions they'll typically get 35 very complicated, well-thought-out, mature, very compelling proposals, and they'll fund one or two.

On a research grant, the success ratio is about 10 percent. Maybe 20 percent if the program is well-funded. Most scientists here have to write five proposals a year and hope one gets funded. There's an abundance of good things that can be done. You have to find the right way to get them funded.

I guess the individual science that I'm most happy with is the work I did on understanding the polar upper atmosphere, the aurora, the electrical connections in the aurora to the Earth's magnetosphere. That was, I think, very satisfying. I used innovative techniques, found ways to make the measurements I needed. With Apollo, I think it was making the connection between Apollo exhaust and the way the Moon loses its atmosphere. I think that was important.

Then after Lunar Prospector discovered water on the Moon, or indications of water, they thought it was due to comets. I recruited a really fine postdoc to come here and she and I developed a model for how the solar wind interacts with the Moon. We could actually calculate how much water originates from solar wind hydrogen interacting with the lunar oxygen in the subsurface, and then migrating to the poles, and could show that the solar wind is actually a substantial source of water in the permanently shadowed regions at the poles. I think that was a very significant contribution, and still used as a standard model.

In your career if you can do three or four things like that that say, "That's really been fun and that's been important," that's what I enjoy and what I feel proud of.

JOHNSON: Was there any project or any work that you did, anything in particular that we haven't talked about that maybe you wanted to mention before we go, or anything you wanted to add?

VONDRAK: You mentioned technology, and I think one of the aspects of NASA that I find a bit frustrating is that in its youth NASA was a very innovative agency and could take on new work, develop new approaches. Now it's gotten very conservative, it doesn't want to do anything unless there's almost no risk.

If you're doing technology or if you're trying to push the frontier, you have to accept failure. When humans are involved, you don't want to lose life or harm anyone. But for robotic systems, or even systems that don't directly affect humans, you should be able to try something new that may not work. Now when you write a proposal you've got to almost guarantee success.

For example, I've been working on concepts for using tethers in space. People don't realize in the Gemini Program, one of the Gemini crew rendezvoused with the upper stage, they hooked a line to it. They separated out by several hundred feet and they spun around to get artificial gravity. That was the last time NASA got excited about a tether mission. People tried that on Shuttle, using an electrodynamic tether, but that, due to workmanship issues, failed. The first one was a failure. The reflight was successful, but NASA just did not want to do it again. You can make measurements around the Moon using tethers that would enable low-altitude measurements that aren't possible because of the irregular gravity field.

You have a terrible time persuading engineers at Goddard and anyone to say that yes, we're willing to take that risk and try it. They say, "Something like that, it's not in our toolbox. We don't want to try it." NASA needs a way to have some fraction of its activity, part of its portfolio, doing things that are truly innovative.

When SpaceX [Space Exploration Technologies Corp.] does innovative launches, I applaud. I feel really good about it. I say, "NASA could have been doing this 20 years ago." But no one at NASA engineering or NASA management I think would have been willing to take the risk. SpaceX failed many times before they were able to bring their boosters back to the Cape [Canaveral, Florida] or to their barge. They're now using it as part of their toolbox.

JOHNSON: It's almost like the commercial companies accept that risk, whereas NASA has become so risk-averse because of accidents. If NASA fails, then it's political. It's all these things that happen.

VONDRAK: That's right, you're exactly right. That's why NASA management doesn't want to do that, because they say, "Even if a little rocket fails it'll make the front page of the [*Washington*] *Post* [newspaper]." You don't want to have NASA on the front page of the *Post* associated with something that didn't work.

SpaceX, their motivation is to make money, or to push the frontier. So they're willing to accept that because they want to distinguish themselves from their competitors. NASA doesn't have that as part of our culture, and I would like to see NASA have some element of it. If you're putting people on the [International] Space Station they've got to stay alive, you're not going to take risk. But if it's a robotic spacecraft or something else, you've got to be pushing the envelope.

JOHNSON: If there's anything else—or you have your list there, just make sure we haven't left anything off.

VONDRAK: Last night I looked at those questions and I said, "How do I make sure I don't overlook something?"

The only other comment perhaps is that you have to, in your career, be willing to try new things and not have them all succeed. Not only do not all your proposals succeed, but I've been associated with missions where we worked very, very hard to get something done, and then the spacecraft died or the rocket blew up. That's very disappointing, but you have to be able to be resilient and keep trying and not get totally discouraged.

There's been another thing that pushed the envelope—solar power satellites. In the early '70s when the U.S. had to face an energy shortage for the first time, I worked hard on developing concepts for solar power satellites. I was on a Department of Energy panel for looking at upper atmospheric effects of solar power satellites. I think they should be part of our tool kit for solving our energy needs.

I'm still appalled that NASA doesn't have a technology office, or some office working on concepts for getting power from space and beaming it back to Earth. We should be doing that, NASA is the right agency to be doing that. There's no significant activity in that area.

That's something that maybe our children or grandchildren will shake their head and say, "Why did NASA lose their interest in doing it, which they had in the '70s?" We had a solar power satellite activity at NASA, and it's just gone. It should be in our toolbox. If we want to be resilient as a society we have to have more ways of accomplishing our needs.

JOHNSON: That's very true.

VONDRAK: Thank you very much.

JOHNSON: Thank you for taking your time to talk to us for the project, we appreciate it.

[End of interview]