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EDITED ORAL HISTORY TRANSCRIPT 2

JAMES L. GREEN
INTERVIEWED BY JENNIFER ROSS-NAZZAL
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The questions in this transcript were asked during an oral history session. Dr. Green has edited and revised the answers. As a result, this transcript does not exactly match the audio recording.

ROSS-NAZZAL: Today is June 7, 2017, this interview with Jim Green is being conducted at NASA Headquarters [Washington, DC] for the Headquarters Oral History Project. The interviewer is Jennifer Ross-Nazzal. Thanks again for taking time, I know your schedule's busy.

GREEN: My pleasure.

ROSS-NAZZAL: We certainly appreciate it. Last time we talked about your work with *The Martian* [movie], which was very interesting, very humorous.

GREEN: It was very fun.

ROSS-NAZZAL: I wanted to talk about your interest in social media, and talking with the public, because you seem to be very active in doing that type of outreach, why you think it's important, and some of the things that you've done.

GREEN: I didn't start out that way. In 2006, when I came to NASA Headquarters, it was all about, to me, service to the science community. By that time, I'd already written well over 100 scientific papers, peer-reviewed, and that is considered a good scientific record. I always knew that I would come to NASA Headquarters. Headquarters is viewed as the organization that does help support, directly, the planetary science community and the other Science Mission Directorate science disciplines. I had such a wonderful scientific career that I really wanted, and always felt motivated to give back to the community.

Then, of course, coming here to NASA Headquarters, I realized that that is only one small part of what we really do at NASA. I came in 2006, and started working right away on missions and budgets and administrating this and making decisions on that. Our budget was doing great, it kept going up every year. I must have been at least halfway effective, initially. We ended up with the change of [presidential] administration, the [Barack] Obama administration came in, and the priorities changed. Earth science was the most important priority, and then finishing JWST [James Webb Space Telescope], then astrophysics, and then heliophysics; planetary science ended up at the lowest priority. Not that it wasn't important, it's that every administration has to have a prioritization in how they move forward, because there's not an infinite amount of money and decisions are made on priority.

It was during that time period that I recognized, as our budget was projected to go downward—and significantly, in fact, in one fiscal year, we lost about $370 million, and that's a huge hit—that what I needed to do was to raise public awareness about the good things that we are doing. Really it dawned on me when I recognized a whole series of important planetary events, one right after the other was occurring while our budget was rapidly dropping. We had three launches in one particular year, which is very unusual for Planetary [Science Division], including a landing on Mars, and all kinds of science accomplishments coming up. So I recognized that this is a perfect opportunity to really give back to the public, not just the science community, but the public, because they're really one of our top stakeholders. They pay for everything we do through their taxes.

So it was very important to me, but I didn't know how to do that. I actually had no idea; I was clueless. How do we do raise public awareness of our science accomplishments? It turns out that I had an opportunity to bring into the organization a particular individual, Kristen [J.] Erickson, who had all kinds of background in the area of public engagement. She had helped support Shana [L.] Dale, she was involved in public communication, she was also involved in the Shuttle Program. She had a huge background, all over the place in NASA. In fact, she seemed to know every NASA employee in this building but me. She was in between jobs, and I had the opportunity to entice her to come and work for me in Planetary Science. In fact, what I did that day in particular was I put on my best suit, wrote up several nice viewgraphs, with all sorts of fantastic things that Planetary was doing and about to do, and then I did what I normally do, which is to get everybody excited about what you're doing.

I was able to bring her in the organization, and she knew right what to do. She put in place a plan that enabled us to bring a lot of people down to our launches. Typically a Shuttle will have 10,000, 20,000 people go to the launch, and to a landing—but a robotic spacecraft will have four or five hundred, maybe 800 at the most. Juno [mission to Jupiter] was the first mission past the last landing and decommissioning of the Shuttle [2011], so Kristen put in place a program that would bring 10,000 people down to the Juno launch, which is quite an outstanding step forward.

In fact, my deputy Jim [W. James] Adams promised [NASA Administrator] Charlie [Charles F.] Bolden that's what he would do. He was so proud, he came to my office, and said "We're going to bring 10,000 people to Juno."

I said, "Do you know what the heck you're talking about? How hard that is to do?" But Kristen knew how to do it, and she really pulled it off. In fact, we had 13,000 people for that particular launch. From then on, launch after launch, we'd have many thousands of people show up. In fact, GRAIL [Gravity Recovery and Interior Laboratory lunar science mission launch], which was early on in the school year, in September, we had 9,000 people show up. I didn't even think we could get 1,000, because it's not during the summer, it was launched during when school was in session.

The next big thing was Curiosity's [mars rover] landing on Mars. Curiosity's landing, to me, was quite a seminal event. It's a 1-ton rover, we've never landed anything as big as that, and we had a very unique approach to landing it. It had been delayed for two years due to technical problems. We really struggled to get it to Mars. And then of course the landing was an absolutely spectacular event. She [Erickson] put in place everything we needed to do, like events at the Centers, at a number of museums throughout the United States, even some activities internationally. You could go to Times Square in New York City, and you could be involved and see what's happening in the operations room at JPL [NASA Jet Propulsion Laboratory, Pasadena, California] on the jumbotron, and really participate in the whole activity as it was actually happening on Earth and on Mars, in Times Square! That's exactly what we did, she really pulled it off. So, from then on, I recognized that another part of my job, is to really let people know what we've been doing, and have them participate in it.

I'll tell you one particular story about that. Ed [Edward J.] Weiler, who was my supervisor at the time, the AA [Associate Administrator] of the Science Mission Directorate, had found out how extensive we were making this, and I was really making it very extensive well beyond what we really do. He said, "You're way overdoing this." He was coming from a perspective of the Hubble [Space Telescope] mirror problem, and he was really trying to protect me. "What if you crash?"

I said, "Ed, if Curiosity crashes, I know exactly what's going to happen. Somebody's going to get fired, and it's going to be me, and I'm good with that."

He looked shocked, and he said, "Yes, that's right." But he still wanted me to cut back a little bit. This was at a time when Ed was retiring. John [M.] Grunsfeld came in to be my boss and the Associate Administrator, so Kristen and I had, just a few weeks later, an opportunity to show John Grunsfeld our plans. It was during that meeting that a new philosophy was coming forth. John Grunsfeld was very much about giving back to the public. As a visible astronaut that does that on a regular basis, and he is so good at it.

So we had a 2-hour overview of all the outreach plans we were working on, and he turns to me as we walked out of the room, and he said, "You're at least six months behind." I was thinking at the time, if I had jumped on everything Ed said, and I'd cut back, we'd be nowhere. With all that said, I also realized that Ed had another point. I am optimistic by nature so I was mentally planning on a perfect landing. But in reality it was extremely risky and nowhere were we talking about the risk and letting the public know that, indeed, we could fail and it would crash.

JPL's response to our outreach plan was great; they had done a little movie about how Curiosity lands. It's quite a detailed, complicated landing scenario, and it has a little music in the background, so I showed it all the time. I was narrating it, "Okay, now we're hitting the atmosphere at 13,000 miles per hour," blah blah blah. I was really getting tired of narrating it, so I asked them, "Can you do something where I can just show it and show the risk?" They said yes, and they came back with something better, and it's called *7 Minutes of Terror* video. That was done really well. It showed what we wanted them to show, which is that what we do is risky, it's worth the risk, and we're doing everything humanly possible to be successful, but we may fail. Everybody's hopes and prayers and careers sometimes are on the line, and that's what the new video shows, and it does it so well. Look it up. It's on YouTube.

It's been from that perspective that I really have moved in the direction of giving back to the public whenever I can, letting them know what we're doing, and what we're finding out. I always say, Planetary Science is where it's at. It's got spectacular discoveries and events all the time. I enjoy coming to work early so I can sit and review what's happening, what's coming in from the Centers and science community, look at some of the news clips that are out, get caught up on some of the new discoveries that are happening. We're making scientific discoveries every day. It's unbelievable what happens in this field. It's really pretty spectacular.

ROSS-NAZZAL: Yes, you mentioned quite a few of them last time. Is there one in particular that stands out since you've been head of the division?

GREEN: There isn't just one, and the reason why is that every place that we go in the solar system is so very different. The solar system is really very complicated, and very different in the types of planets, the types of atmospheres, the temperature regimes, the mineralogy, just everything about it is a wonder. All that has to fit together into a grand plan, and that's really what we're moving towards understanding. Let me talk about a couple of the missions.

One of my top missions was Cassini. Cassini provided us a spectacular look at the Saturn system—the planet and its moons. We see a beautiful planet with huge storms and fabulous rings, and the rings are evolving, and moons that are pouring water out of huge cracks, that even form new rings around Saturn to Titan, a spectacular moon full of hydrocarbons and liquid on its surface, which is methane.

Juno, which is in orbit, looking at Jupiter and seeing that giant planet is so different than another giant planet, Saturn, and we don't understand the differences. We thought they were going to be pretty well identical, and they're not. They're very different. You just pick any place in the solar system, and I can give you discoveries that just floored me. We're continually doing that. That's what really makes it exciting.

Since I was at NASA Headquarters, one of the themes that has been developed that looked pretty wild at the time, and now looks like it really did happen in the past, was that there has been a movement of our planets into different orbits. In other words, where they were created is not where they currently are. They have been moved, and they have been moved due to gravitational interactions, primarily from Jupiter. That's just a phenomenal idea, but the computer modeling is now good enough to clearly indicate that seems to be the case, and we're finding evidence all over the solar system of when that probably did happen.

So rearranging our solar system is part of its evolution. We now take that and look at other solar systems around other stars and recognize how they have been rearranged by the same basic physics that's happened to them, in sometimes similar ways and sometimes even different ways. The solar system could have been very different if the rearrangement ended up with giant planets on highly elliptical orbits, scooping up all the terrestrial planets into another even bigger giant planet like it probably has done to some solar system we have observed. Fortunately for us, our inner terrestrial planets were left relatively alone, and Jupiter rearranged the outer part of our solar system instead. Everything about this field, you can just pick a subject and there's been just tremendous discoveries.

ROSS-NAZZAL: I wanted to ask you about certain key events, because we like to capture some of those histories. Can you talk about your memories of Curiosity's landing? I assume you were at JPL witnessing that event. I'm sure there are some good stories.

GREEN: Yes, I was, there are some great stories, and there are some personal ones too. We developed a contingency plan, and the contingency plan is, if there is a crash, if Curiosity crashed, how are we going to handle that? What are we going to say? How do we conduct our press conferences? What is the next series of procedures? A whole series of different things kick in. So for the Curiosity plan, it's called the "bad day plan," was like a half-inch thick. Once it was done, and we got it—I was supposed to read it on the plane on the way there—I thought, I'm not going to read it. I won't need it.

ROSS-NAZZAL: Fairly confident.

GREEN: I was, I was so confident, almost to the point of being cocky, I think. During the landing, I was really pretty calm. I just knew it was going to work. Part of that was really because Curiosity had some technical difficulties, and was not able to be ready for the launch that we had originally planned in 2009, so that gave us another 26 months to work out all the technical difficulties. That turned out to be the right thing to do.

JPL and all their sub-contractors really worked hard, to not only solve the technical difficulties, but to perform a lot of new tests. They tested the heck out of everything, and I was confident, at the end of that, that there wasn't anything humanly possible that we could do that we haven't already done. So if it crashed, maybe it's an act of God, but it wasn't going to be because we didn't do something, because we did everything we could think of. Because of that, I was just really confident. So yes, I was happy, and I was patting people on the back, and smiling, but I wasn't crying. I didn't need to do that, because now I was ready for the next stage. Let's go do the science.

I was also in this concept of giving back to the public and wanting more of our scientists to do the same thing. I remember one major meeting that we had. It was probably the Division of Planetary Science. There's like 1,000 scientists in the room, and I'm giving an overview of the Planetary Science Program, and I get to the upcoming Curiosity landing. I go into great detail about what's going on. I tell them about the Power Point material that's available for them to use, and I tell them I want them to read that, and I want them to be familiar with what Curiosity's going to do. This was important to me since the press in their cities go to many of these scientists to talk about planetary missions. Now, some of them are outer planets scientists or experts on comets or the Kuiper Belt. Some of them don't know a lot about Mars even, as an example. Not that they couldn't learn—they're planetary scientists—but I wanted them to grab that material, learn about it, and then become somewhat of a subject-matter expert in the areas where they live to do these interviews.

The local news station calls up the local planetary scientist and says "You just landed a 1-ton rover on Mars, what do you think of that, what's it going to do and where's it going to go?" I didn't want them to say, "Oh really? That's nice." I wanted them to say, "Yes, it's called Curiosity, and here's what it's got on it, and here's what it's going to do." I wanted them to get involved.

I had one of my top scientists in the field, who's not a Mars scientist, come up to the microphone and ask me the question, "Why is that so important? It's all about engineering. Why do we want to know and talk about the engineering part?"

And I go, "You're missing the point, it's spectacular engineering. It brings everybody together. You have a captive audience, now talk to them about the science, which is what you want to do." It was the perfect question, because all those out there that wanted to just talk science didn't realize the engineering is the hook that you use to get the public's attention, and now you tell them what it's going to do and what it means. There isn't any planetary scientist that couldn't relate what Curiosity's going to do to their field in some way.

ROSS-NAZZAL: Yes, it's pretty impressive. We were just out at JPL for a meeting, and we were out in the Mars yard looking around, and that was cool.

One of the other projects that I was thinking about was New Horizons [spacecraft, New Frontiers Program], and seeing the images from Pluto, for that first time. What are your recollections of that moment?

GREEN: Oh, absolutely. That, of course, was another seminal event in planetary history, the ability to fly by an object that's not been explored before up close. It was only in the 1990s that we recognized that it is an object that's not alone. It's not the singular thing we thought it was, which was a planet that exists in an orbit past Neptune. It's not that at all. It's an object that's the largest object of its kind, and it is really a volatile world. Volatiles are those things that go through changes based on temperature and pressure. So they're things like water, ammonia, nitrogen, and methane. Those are called volatiles.

There's a whole series of objects beyond Pluto, we call Kuiper belt objects. They began to be discovered in the 1990s. It was really the discovery of one of those, called Eros, which is believed to be bigger than Pluto, that caused the controversy about whether Pluto was a planet or not. By flying by Pluto and its moons, we really, for the very first time, had an opportunity to see what this whole population of objects was all about. That was tremendously exciting, and the surprise is that these are very different worlds than we are used to.

Earth's moon has a diameter that's greater than 3,400 kilometers. It's a big object. You look at it, it's hammered, craters everywhere. Those are all impact craters. You look at anything in and around us, and even those objects that exist around many of the giant planets—cratered all over the place. For Pluto, I expected to see much more of an object that looked like the moon than what we saw.

What we saw was a really unique world, much smaller than the moon that had huge regions of absolutely no craters. It had glaciers, not of water, that we're used to here, not our water ice glaciers that we have, but nitrogen glaciers. And the atmosphere that it has, even though it's tenuous, supports all kinds of weather. It snows red tholins, which are complex carbon molecules that are created from the disassociation of what's in the atmosphere, which is ammonia, methane, and carbon monoxide. Atmospheric compounds gets disassociated, rearranges itself, becomes complex carbon chains, gets heavy, drops to the ground, and they're red. So if you're standing on Pluto, it snows red tholins.

The moon doesn't snow, the moon doesn't have an atmosphere, and yet this object has got geology all over the place that's more similar to the Earth than it is to objects like the moon, and yet it's smaller than the moon. It's a volatile world, it's not a rocky world like we're used to, it's in a completely different regime. So by that flyby, I was just shocked, completely shocked.

I was floored, just by looking at the Pluto, and the fact that it has an object that looks like a heart, which is this big glacier, and it's mostly nitrogen. Its nitrogen ices. Some of my colleagues describe it like toothpaste, it sort of oozes all over the surface and eradicates some of these craters. It's not that it hasn't been impacted. Pluto has been impacted, but the atmosphere and the geology of the body really modifies the surface and eliminates a lot of the craters, and that's why it's an active world. We now know an enormous amount about Pluto, because the New Horizons data is now on the ground, it's taken a year to get here, and the science papers are just cranking out. We understand a little bit more about how the heart came about, which is also quite an interesting story.

We've also seen that Pluto has a bunch of moons. Several of them are small, but one of them, Charon, is huge. It's a little more than 1,200 kilometers about ½ the size of Pluto. That particular moon is so close to Pluto that they actually orbit a location that's outside the surface of Pluto, it's called the barycenter. Our moon and Earth orbit a place called the barycenter, except the barycenter is very close to the center of our planet, so it always looks like the moon goes around us, but in reality, we're actually moving back and forth a little bit because of the gravity of the moon.

For this particular set, it's like binary stars, where they sit and orbit each other, go around in their own little orbits based on their mass, and that's really fantastic. That has, over time, set up a situation where there's been an impact on Pluto that's carved out the crust, and material has actually migrated into it. It's called the cold trap, and that evacuated crust has less mass. The interaction between that and Charon has moved the crust such that the heart is exactly opposite of Charon, always. If you're standing on Pluto, you could look up and always see Charon on one hemisphere. If you were on the other hemisphere of Pluto, you'd never see Charon. They actually point to each other at the same place, all the time.

It's like we always see one surface of the moon, but the moon sees the whole Earth, all the way around. But for Pluto and Charon, it's just like the Earth would have one surface that always points to the moon. One day on Pluto, is a little more than six Earth-days, and that's what it takes Charon to move around Pluto, to move around the barycenter. So it's a really foreign system to us, in a way, it's not intuitive at all. That's really fascinating, very fascinating. So the scientists, I think all of them were very surprised. Even the New Horizons PI [principal investigator S.] Alan Stern was very surprised.

ROSS-NAZZAL: Were you out at JPL when those photos returned?

GREEN: At APL. It's an [Johns Hopkins University] Applied Physics Lab [Laboratory, Laurel, Maryland] mission. So we were just up the road at their Laurel Maryland facility.

ROSS-NAZZAL: What about Juno's insertion into Jupiter? Were you there when that was happening?

GREEN: Oh yes, I was at JPL.

ROSS-NAZZAL: What are your memories of that event? There are so many, I just picked a couple, just a handful. It might be a little tedious for you after a while.

GREEN: No, it's not. In Planetary Science, when we launch something, it has to last to where it gets to go, and get into orbit, or lands. There's always that anticipation after you launch it, of well, is it going to work? Because it's really not ready to be science until it gets where it needs to go. Juno was launched in 2011, and we got it into orbit last year, July 4, 2016, not quite a year ago. It was just another spectacular event. Every event has a certain set of parameters you look for. For Juno, it was all about the radio communications. It was all about looking at how they change as it gets into orbit, and when you communicate back and forth with it using radio waves, and the spacecraft makes a certain move, or it gets tugged by gravity, you get what's called a Doppler shift. So you're looking at how those signals change.

You're also looking at it going through its engine firing, and then reacquiring the Earth, and then sending its signal back, and then letting you know the spacecraft made it into orbit. There's always events that occur, and they all seem to be different. For instance, for Phoenix [Mars Lander, Mars Scout Program], which we landed on Mars, that was really neat, I was in the control center at JPL, but I wasn't in the main control area. I was sitting in the DSN area in the adjacent room, which is where the Deep Space Network signals first go. That to me was great, because I had a console that had a lot more information associated with it, and it's right where the signals were coming in and displaying it. For that particular mission, it has a whole series of things it does right after it lands.

One of the first things it does after it lands is to unfurls its solar panels. When it started its whole landing sequence, from the top of the atmosphere until it sits on the surface, which is about seven minutes, it's operating on the battery. So the charge on the battery is going down and down and down, because it's using resources. When the spacecraft gets to the ground and unfurls its solar panels, then the battery starts getting charged. While the battery's charging up, the spacecraft is looking for Earth. When it finds Earth, and it does a dump of the engineering data which include the battery voltages.

Serval of us were sitting there watching the data come in, and to me the critical thing was, if it's sitting on the surface and everything's working right with its solar panels extended, the battery would be fully charged. If the battery is fully charged, the solar panels were out and we're ready to go do science. Everybody in the main control room is waiting for the first picture, which is in the process of being taken. But I was waiting for the battery voltages, because I knew that as soon as the battery voltages were there, we were set. The picture was just secondary and come later.

So we're in this adjacent room, and there's four or five of us doing that. Even John Culberson, a [Texas] congressman, was there, sitting right next to me. I was showing John, "Hey we have to look at this number on the screen." It lands, the battery voltages come in, and it's already charged up to a hundred percent. John, and I and a couple guys go, "Yes, right!" And everybody in the control room is looking at us, like what happened? Then, 30 seconds later the first picture comes in, which we knew would be successful, because everything's ready, it's all deployed, and everything's going to work. If you don't have your solar panels out, that's it. That's the end of the mission.

It's those kind of things, and every mission's different. Each mission has different attributes about it that you watch to make sure it's going to work. And that's what makes it fun.

ROSS-NAZZAL: You have a very exciting job, that's for sure. Last time we talked about the Europa mission, and I wondered if you have any lessons learned for people following in your footsteps, or perhaps another position, about how to secure support for, and then funding for, a planetary mission, or even a human spaceflight mission.

GREEN: When I first came to Headquarters, and I was in this giving back to the community thought process, the couple of things that I wanted to do, one of them was to get the Europa mission going. It was something in the last Planetary Science Decadal [Survey], and also rated quite highly in the current Planetary Science Decadal that we have. I really thought, okay, I'm going to do this. Well, that was really pretty naïve, because it's incredibly hard to do.

The reason why it's hard to do, is it costs a lot of money, and the more something costs, the more visibility it has, not only with my boss, the Associate Administrator, but also the NASA Administrator, and also OMB [Office of Management and Budget], OSTP [Office of Science and Technology Policy], the [presidential] administration has to be involved in this, and then Congress has to approve the money. Everyone has to agree that this is what they want to do, and that this is the next priority.

That's very difficult, because we're in an environment where there's a lot of fantastic things going on, in all these other disciplines, in Earth science, heliophysics, and astrophysics. Therefore, you're asking for more money, where does that come from? Does it come from another group? Does somebody print the money? Is it new money somewhere? Find it under your mattress? Doesn't work that way. So, it took me 10 years to get that mission underway. We were working on it almost every year, some aspect of that, we were trying to push it and move it ahead. But everything lined up, and now it's on the books to be done, and we're going to fly it, it's going to happen.

ROSS-NAZZAL: What do you attribute that to? How did you finally get buy-in from OMB, OSTP, Congress, all these people? How did all the dominoes line up?

GREEN: Not very easily. There were times when it was easy for me to get my boss on board with that idea, but then I couldn't get the Administrator to support it. The Administrator has to say, "Oh yes, this is more important than a human exploration—" X-Y-Z thing, whatever it happens to be, or a James Webb Space Telescope. It has to be the most important thing for the Agency that year, if you're going to start something new.

So there were times it didn't even get out of this building, and there were times it did, for which the Administration would say, "Okay, well, planetary science is not Earth science. This mission doesn't help us with climate change, or create the data set necessary for us to make policy decisions, and that's more important." What you have to do, is you have to look for opportunities and be agile. During that time period, we took the opportunity to step back and re-look at the design. We have a certain approach. Our approach to planetary missions have been flyby, orbit, land, rove, return samples. That approach has worked really well for us.

The Voyagers have flown by, they've said, "Okay, these are the objects we want to go back to, so let's get into orbit." We get into orbit, we get high-resolution imaging, to the point that we now know where we want to land. Then you can put something safely down on the surface, and then you can get samples, or you can make key and critical measurements. That stepwise approach has always worked really well for planetary science.

In the Europa mission, the initial designs were all about getting a spacecraft in orbit around Europa, doing that second step. Along the way, Cassini [mission to Saturn] showed us that there's something easier we can do, that's just as good. And it goes like this: we were struggling with getting the spacecraft in orbit around Europa. It takes an enormous amount of energy to do that, because Jupiter is such a gravity-hog, and you really have to overcome some of the problems with bringing enough fuel, getting it the right speed, firing the right thrusters at the right time to change your orbit, to go into orbit around a moon like Europa in the intense Jovian radiation field.

What Cassini was doing was using Titan as a series of gravity-assists to change its orbit, and yet it was still orbiting Saturn. And every time it did that, not only did Titan do the service we wanted it to by changing the spacecraft's orbit and getting Cassini in a new and unique orbital plane, but we also got an opportunity to look at Titan really well. After more than 120 flybys of Titan, voilà, we have almost a complete map of it, as if Cassini was in orbit around Titan. And yet it's not, it's really in orbit around Saturn, and we just work it such that it has encounters with its moon, Titan.

The idea came about that maybe we should consider a new architecture for the Europa mission, and try that, and see if it can't work for Europa. We were even more motivated to do that because we knew that if we got anything in orbit around Europa, it's not going to last very long. The reason why is because the radiation belt is enormous at Jupiter, far greater than it is here on Earth, and we just don't have the electronics to last very long in that orbit. If we got into orbit around Europa, in 90 days the spacecraft would be dead.

Well, Phoenix sat near the polar cap of Mars, and its nominal mission was 90 days. It actually lasted close to 115 or so, before the snow in the polar region came down during the winter, covered it in snow and broke off the solar panels, and killed the mission. So I knew what it was like running a mission for 90 days. That team was exhausted, they were pushed to the limits in every way possible. They didn't get the things they wanted to get done, they had high aspirations. They did everything they could in that 90 days, and it just wasn't enough time. It just wasn't going to help them no matter how well they were organized.

The mission was spectacular, but everyone wanted to do more, and you can't do more if the mission's dead. So it struck me at that time, looking at that, and then seeing what Cassini's doing, a different architecture was needed. That's when JPL proposed this different architecture, that they're on to it, they've got it, this is a key thing that will enable us to construct a better mission that lasts longer, that enables us the time it takes to be able to do the data analysis and stay true to our idea of mapping the whole surface like it's an orbiter, and do multiple flybys.

So that redesign was a critical part of selling the mission. The fact that we didn't sell it early on enabled us to have the time to be able to think out of the box and try this alternate approach, which worked much better. It's funny how those things happen. You want your mission to proceed, you have an idea, an approach, and it never goes that way. All these big missions take a long and winding road. It's never what you initially thought you could do, it never works that way.

Part of that is because you're constantly challenged: can you do this better? How would you do it better? Can you reduce the cost, and yet still do the science? There's all kinds of pressure points, and you just have to take those in, do the best you can, move forward, and figure out that path, figure out the winding road to make it home.

ROSS-NAZZAL: Would you talk about your work with OMB and OSTP? Not necessarily in relation to Europa, but just in general, I imagine you spend a fair amount of time working with both agencies.

GREEN: Yes, we do. And we don't always see eye-to-eye, so they can be tough meetings, in the sense that we recognize that as part of the administration, we're all on the same team. So there are decisions made in any administration that I may not personally like at all, that I may absolutely hate, but I have to represent those positions. I have to say, this is our program, this is what we're doing with the money we get from the public, this is the support we're getting from the administration, and then really be a part of the administration.

If I don't do that, I would, and should be, fired to tell you the truth, and I completely understand that. It may not be exactly what I'd like, and in many times it wasn't, but that's the program I was given. I know all about it, I know how it got to where it was, and then sometimes, my philosophy is you live to fight another day. Is this really the fight you want? Or is there a way forward?

It turns out, there's always a way forward. You just have to come to peace with that and figure out what that is and go do it. That's what's critical, I think, about surviving in this particular job, which is very tough. It's the toughest job I've ever had, there's no questions about it, and that's because it deals with money. Anything that deals with money, public money, is something one has to be held accountable for. I'm accountable for everything that happens in my organization. Even though I may not directly be the person that screwed up mission X, Y, or Z, I should have known that it was moving in that direction and prevented it. One of my key roles is to execute the missions that we have, making sure that we have the right people on, that we're moving forward, that we're not going to miss our launch windows. If there's compromises that have to be made, we set up a process and a procedure to make those compromises, figure out a way forward, get it back on track, and make it successful. And we do that all the time.

The other thing that happens in this job is, like the Europa mission we just talked about, is, it's all about the future. The future of the Planetary Science Program, like any of these other disciplines, is on this 3rd floor in NASA Headquarters. If we don't work with the administration, if we don't work with Congress, if we don't get the money appropriated, if we don't plan for what we're going to do next, whether it's an announcement of opportunity for principle investigator missions, or we put together a plan for a strategic mission, it's not going to happen. It just doesn't happen without us. We are where the future of this program is.

Now, to me, from my perspective, what's a tremendous help is indeed the Planetary Decadal. This is where the National Academy [of Sciences] lays out a certain series of top questions that need to be answered with notional missions. I've read that document probably 10 times, and I'm referred to as a Decadal zealot, I follow it very religiously so to speak, and it has served me really well. It also keeps the program grounded. It keeps the program moving in the directions that we have agreed on, as part of the entire planetary community, are the best things that we can be doing with the money that we're being given by the public, because we're going to make the top discoveries, and we're going to do it in a way that doesn't waste the money.

So my position is all about the future, in addition to administrating the current set of missions that we have and making sure they're successful, and then acquiring the money to do so. I've got a fabulous staff to make all that happen. It's not just me, of course, it's really a team effort.

ROSS-NAZZAL: I imagine working with the Obama administration was challenging. As you pointed out, Earth science rose to the top, planetary science went to the bottom. Climate change was a big deal. Have things started to change now with the new administration coming in, where Earth science and climate change are no longer a priority?

GREEN: They're no longer the top priority. So planetary now is the top priority. These things go in cycles. We now have the healthiest budget we've ever had in Planetary's history, we've got a number of fantastic things going on, with our new Discovery [Program] missions that we've selected. Lucy and Psyche, one goes to the Jupiter Trojans [asteroids], and another one goes to a really spectacular [metal] asteroid, it's very unusual, that we want to look at called Psyche. We're building the Europa mission, the Europa clipper mission.

We're building the Mars 2020 mission, which is the start of sample-return. It's going to land on Mars, and it's going to core rock. It's going to look at how climate changed on Mars. Mars actually looked much like the Earth, it was an ocean world early on in its history. When life started on Earth, Mars looked like Earth. We don't know if life started on Mars, but it sure in the heck could have. It had an enormous amount of water, but something happened to it. Its climate changed very rapidly.

So what we learn in this process is, things that happen on the other planets can happen here on Earth. What's happened on Venus could happen on Earth, what's happened on Mars could happen on Earth. All these bodies evolve over time, and there are different stages of their evolution right now. We're finding out that Venus also looked like Earth for an even longer period of time, and may have had a significant amount of water up to a billion years ago, before the oceans eventually evaporated, and we had a runaway greenhouse effect.

Earth climate modeling was just completed by those people that do Venus climate modeling who discovered the runaway greenhouse effect on Venus which could potentially happen on Earth in the future. So, by studying our planets, we really may be looking at different aspects of the Earth's evolution, and we need to recognize how all those pieces fit in, and when that's really true, and when it's not true. If you ask a planetary scientist about climate change here on Earth, planetary scientists would very simply say, the climate has done nothing but change. It changes all the time, throughout the Earth's entire evolution. The question is not if it's going to change, it's how fast it's changing and what is it changing into? We have bookends like Venus and Mars to take a look at, to determine what those end states might be, what the next phase of Earth's evolution might be.

For Mars 2020, we're going to core rock. The rock record will tell us a lot about how the climate has changed on Mars. We'd love to be able to bring back samples that cover that era, when Mars was really wet, maybe had plant life, maybe microbial life, we don't know. It would be great to be able to bring back samples that cover that period of time, and then give us an indication of how fast it changed. We don't know now if it was 10 million years to go from a world that was a water world to the arid world that it is now, or if it was 100 million years. We really don't have a good idea, but we know it happened pretty fast, and 100 million years is pretty fast, even at that.

We're now getting indications on why it changed, and that involves the loss of the magnetic field of Mars, allowing the solar wind to impinge deeper into the ionosphere and into the upper atmosphere, and then strip away critical pieces of it. Once you lose that, it goes away on the solar wind, and goes out into the solar system, and it's not coming back. So right now, the outgassing of the planet has come to some equilibrium with the stripping of the atmosphere. We know that now, and that's also a recent find that's done by MAVEN [Mars Atmosphere and Volatile Evolution mission], which we got in orbit just a few years ago.

ROSS-NAZZAL: We haven't talked much about Congress, but I know you've testified in front of them.

GREEN: Yes, three or four times, actually.

ROSS-NAZZAL: Obviously John Culberson must be a close ally. Can you talk about testifying and preparing for that, working with congressional staffers, and some of those folks?

GREEN: When there's a hearing that's been set, and Congress wants to know more about a particular subject—it could be like what's the status of astrobiology, it could be about where we are on near-Earth objects, it could be about the general health of the Planetary Program—they make it a hearing. Then, a whole new process at NASA kicks in.

In general, I go over to Congress reasonably frequently and talk to staffers. We'll have a set of presentations where we'll give them an update on the program. They can ask us anything they want, anytime; we'll prepare the material they need. So you'll just have a few people around, a few staffers around. That happens quite frequently. It's not a hearing, but it's just a normal interaction. Sometimes it's done in the hearing rooms, which is kind of neat. Where all the congressmen or senators sit in their theater chairs, and you're at the witness table, and you're all sitting around in one of those rooms going through your charts. Those charts, we put together and get them approved, and we say the right things in the right way such that everybody's on the same page, and we're all very consistent.

But when there's a formal hearing, then a couple things happen. You have to write two documents. First there is a several-page document that responds to the topic of the hearing. "We want to know about the status of near-Earth objects." Fine, here's what we've been doing. You lay it all out, you lay the program out, you lay what you've done in the past, what you're doing right now, what you plan to do in the future, and why that's important. There's a large group of people in Legislative Affairs that help you with that long document. They help you say what you want to say, and say it right. English matters. That document is sent in for the record. Then you write a much shorter version, the second document, that's really a script that you read at the hearing. That document has to be under three minutes.

ROSS-NAZZAL: That's it?

GREEN: Oh yes, it's very important. This is the process, you read your statement at the hearing.

ROSS-NAZZAL: It sounds like theater, almost.

GREEN: Well, you will read your statement at the hearing, and it's a shorter version of your longer paper that you're submitted to Congress already, and it sort of sets the stage for the interview. You give it verbally in the hearing since you've also got an audiences there, like the public, sometimes reporters are there, and they haven't read your extensive material that you've submitted to Congress in writing. It does becomes public later, but not at the time of the hearing. This is why you have to be able to set the context by stating your position, so you then do an abstracted form of your larger paper.

Once you get those two documents done, and you do them as far ahead of time as you can, you're now ready for a really important internal process called the murder board. The murder board is a very essential part of the whole process. This is where you are set up with people from Legislative Affairs, and sometimes there are Planetary Science people, certainly people from OCOMM [Office of Communication] too, and others. Maybe even some people from the Administrator's office, it depends on how important the testimony is. And you go through a mock hearing process. You act like you're sitting there in Congress, and you read your statement, and they time you, "That was two and a half minutes, that's under three, good, and I got what you're going to say."

Then they ask you questions, and you respond. You have no idea what they're going to ask you. They could ask you anything. It doesn't necessarily have to relate exactly to the testimony that you just gave, because Congress can ask you anything in that forum, anytime. We see that all the time on the news. If there's something else going on, and they want to know about it, they ask. We call those dirty questions, and in the murder board everybody's got two or three dirty questions that they ask you, and they want to see how you respond. It's one of those things that you know you have to do.

You sit down on a murder board and you can't wait until it's over, but when you sit down, you have to have full attention, you have to know exactly what you want to say, you have to know exactly how you want to say it, and you have to know when to end what you're going to say. If you sit and elaborate, it may end up with more questions, and get deeper into a topic that may be the right topic, may not be the right topic. But you're opening yourself up, and that's not necessarily the purpose of the hearing. It could easily get off track. So you need to be focused, it has to be correct, no lying allowed, no guessing. You don't sit there and guess at the answer. Even if you're asked to speculate, I try never to do that. It depends on what they want you to speculate on, they might push you on a topic a little bit. Like, when are you going to find life on Mars?

ROSS-NAZZAL: Has that question come up quite a bit?

GREEN: Oh, it has. Some people like my answer, others don't. The murder board is, from that perspective, fun, but you can't wait until it's over. It's just one of those, "Oh my God, I have to get murder-boarded, it's just what I want to do." And then you have the testimony.

In all my hearings I was one of several on a panel. We were all witnesses. When you go into the hearing, you meet all kinds of people. You have to ignore what's happening on around you and be fully focused on the topic and with the questions asked. You have to be fully engaged with the rest of the panel too, because there's typically three or four people there and you may not know them all. They'll ask somebody from academia, or somebody from industry, or somebody from another NASA Center. There's an array of witnesses there. Everyone gives their testimonies, and then they're all asked a bunch of questions by the Congressmen and Congresswoman.

You need to be fully alert. Get a good night's sleep before you go. It's a very tough process. It doesn't bother me, I can do it. It's not one of my favorite things, but every one I've been in, I've been happy how each of my hearings have come out. I haven't regretted what I'd said, or I haven't thought about things I wished I'd said. I said what I needed to, and I was happy with the way that went. And an element of that is because you practiced it, you'd been through a murder board. They are critical for a successful testimony.

ROSS-NAZZAL: You mentioned working with Legislative Affairs and Communications. What's your relationship like with some of the other offices, say, Human Exploration [and Operations], and other offices that don't necessarily tie into Planetary Science. Do you work closely with those?

GREEN: We work really closely with Human Exploration, because Human Exploration is now planning for humans to leave low-Earth orbit and go out into the solar system. They can't do that without us planetary scientists. Human Exploration for NASA is not *Star Trek*, it's not "go where no human has gone before," because NASA has to know everything about where we're going, what we're going to encounter, how we're going to handle it, and therefore come completely prepared for all contingencies. It's all about lowering the risk to our astronauts.

Part of that is also because we are also planning to going to return to Earth. If you were not planning to return to Earth, maybe it would be different. The only way that this survey effort can be done is with planetary scientists. We're the scouts, we're those that know everything about Mars, not only because we want to know everything about Mars, or the moon, but because Human Exploration is going to need to have our expertise.

One of the things I started a few years ago was an interaction with Human Exploration on where we are going to land? I was doing this, actually, just around the time when *The Martian* was coming up. Before I got involved with *The Martian*, it really dawned on me that the array of satellites that we have at Mars today are capable to get high resolution imaging, and mineralogy, and knowledge about certain places on Mars, at such a fidelity, that it is good enough for NASA to land humans on Mars. We need that for our own missions, but Human Exploration needs that capability too.

What was happening, our top satellite, with high resolution imaging capabilities, is the Mars Reconnaissance Orbiter [MRO], which got into orbit in 2006. In your living room is a coffee table. If that coffee table sat on Mars, MRO could see it. It's a fabulous spacecraft.

The problem is, it's been in orbit for 11 years now, and it has observed about 3.5 percent of the Martian surface at that resolution. Only 3.5 percent! Why? Well, for several reasons. One, Mars is a really big place, and two, the satellite does a whole variety of other things, which includes obtaining information from the rovers and the landers on the surface and relaying that information and data back to Earth. Of course, Mars is far enough away, it's not like an Earth science satellite that can give us high-resolution high-rate data almost immediately. The further you are away from planet Earth, the lower the rate of data you can send back to Earth. So, our problem was clear to me, that if humans were indeed moving out and going to Mars, they're going to need high resolution imaging of their landing site, and I don't know where they're going to go.

So I got involved with Human Exploration, and it actually came about in a really unique way. I was asked to go to Comic-Con [International, entertainment and comic convention]. It was the very first time NASA's been at Comic-Con, and they were going to have a panel. It was going to be Buzz Aldrin, myself, Mike [Edward Michael] Fincke, who's an astronaut, and Bobak Ferdowsi, who is the well-known "Mohawk [haircut] guy" from Curiosity's landing, one of the really well-known [JPL] controllers that helped land Curiosity. So I went, had a wonderful time, the panel was spectacular, the place was packed, and Mike and I just hit it off. This was a really nice guy, Mike Fincke was just wonderful. I really enjoyed him. And he goes, "You have to come to JSC [Johnson Space Center, Houston, Texas] and give a talk with the astronaut corps."

I said, "Great, I'd love to."

He says, "I'll set you up with Stan [Stanley G.] Love, he's our seminar organizer," who's also another fabulous astronaut, "Come on down and give us a talk."

I said, "Great."

So a few weeks later, Stan Love gives me a call, or we communicated by email, I don't remember which, but Stan said, "We want you to come. You have to come on Monday morning, you can talk from 9:00 to 9:30, because we have astronaut corps all hands on deck from 8 to 9 on Monday morning, so they'll all be there. Please remember that these are really busy people, so from 9:00 to 9:30, maybe with 15 minutes of questions, maybe 9:45, don't feel bad if people get up and leave, because they have things to do."

I said, "Okay, sure." So, I wrote a talk, it was called "Learning to be a Martian: Science and Exploration on Mars." So I showed up. At 9:00 am I gave that talk, the place was packed. No one left, standing room only. It was great. I had a wonderful time. It was really a lot of interaction, a lot of talk. In fact, they had organized that afternoon that Stan and I would have a public event that would be broadcast to the rest of the JSC. They called it the "Mars half-hour" or something like that, where they record an interview and then broadcast it. You can actually get it on the net if you want to watch it. What was really funny about that public event was that Stan and I ended up disagreeing on where we will we will land on Mars. Stan stated that it didn't matter and any old flat place will work and I said NO WAY. We have to pick it very carefully since we will need to use the resources on Mars to support our astronauts.

It was actually about this time that the book *The Martian* was coming out. I had read the book, and this is how I'd actually gotten involved in it a year or two earlier. Right before this afternoon interview, I met with Ellen [L.] Ochoa, and she was the [JSC] Center Director, and she was an astronaut. We chitchatted for a while, and I finally said, "This is what I want. I want somebody in the astronaut corps to be detailed at NASA Headquarters and work with us on finding a human landing spot. And by the way, have you read *The Martian*?" She hadn't read *The Martian*. She didn't know anything about it. I said, "Okay, fine. Please do so."

"Oh, okay, I'll get around to it," or whatever she said, I don't remember. Well, she did read it, and months later she sent me an email saying "Jim, this is fantastic, I recommend this to every one of my employees."

ROSS-NAZZAL: I think there were book clubs at JSC.

GREEN: Oh, I bet. Well, I turned her on to that and she helped me get a JSC detailee. So, I got Rick [Richard] Davis detailed to me. I said, "Rick, here's the situation, MRO's only going to be available in the next several years because it is near the end of its lifetime, and we have to work with Human Exploration to find a landing site. So, work with them, get their requirements, and add our science requirements. Because astronauts, when they arrive on the moon and then onto Mars, they're going to do science. That's what we want them to do. So, let's figure out how to bring the requirements for humans on Mars, and a safe landing spot in an area where they can use the resources and we can do the science." He's still here working on that, and he's doing a fantastic job.

What happened next was a series of really important things. First, working with Human Exploration we defined a place on Mars called an exploration zone. This is an area that is about 200 kilometers in diameter on Mars where you land in one place, you live in another place, do science at a variety of locations, and you extract resources from different locations. Resources could be water from an underground aquifer or buried ices, it could be mining the dust that's there, that allows you to put it in 3D [dimensional] printers and create panels that are part of your habitat, or tapping heat that's coming from the interior of the planet, just like geothermal heat here on Earth. There are a whole series of things you can do.

There are areas also in that exploration zone where we want to do specific types of science. This is where the mineralogy is really fascinating that we want to look at, and this might be the place where there was the ancient shoreline of the old Mars ocean where life might have started, or crawled out of the ocean. There might be indications of that life at that shoreline in the rock record. So, once we defined what is in an exploration zone, we had a call to the science community and the engineering community to come together at a workshop on choosing sites. We're still talking about the 45 sites on Mars that came out of the workshop that satisfy both science and engineering requirements, and we're trying to whittle it down to a handful and then to one.

Now, unlike *The Martian*, we're going to whittle it down to one site, and we're going to go to that one site multiple times, for decades. It's not like we're going to go to one site, then another site and so on like what was in the movie. It doesn't work like that for NASA. We're going to pick one site, so we need to have all the data, and we have to go after the right site. We're now tasking MRO to get some small piece of high resolution data for each of those sites so that the scientists can get together and argue about what is the best sites, to prioritize them and then whittle it down. Then for maybe the top 20 sites, we'll get all the high resolution data that we can, in high resolution, and from that, whittle it down to maybe the top few sites. But somebody's going to have to pick the top site, and that will probably be well above me. Maybe even above the Administrator.

ROSS-NAZZAL: We've landed at different sites on the moon. Why are we only picking one site on Mars?

GREEN: Because of the infrastructure it takes on Mars and the limited lifetime of MRO. You want to lay down the habitats, you want to have power available. That infrastructure is far different than the moon. One has resources on Mars you don't have on the moon. But we do need to find the sites on the moon too. For the moon we have the Lunar Reconnaissance Orbiter.

ROSS-NAZZAL: It's kind of like a camping site.

[JLG NOTE: Since this interview, the Artemis program was created which clearly stated that Human Exploration sites on the moon would be use for long term stays. This changes the approach making it more like the Mars example.]

GREEN: Yes, and if you land on Mars, you're there for days to years. It's a different philosophy, but indeed, all that came together because we started that conversation, and that's going really well. I think in another several years, we'll actually get it down to just a handful of sites, and then MRO can actually be tasked to get the high-resolution imaging to blanket the site. That's essential for us to be able to land humans on the surface of Mars. We have to find, somewhere in that site, a safe landing spot. If you can't find a safe landing spot, then this isn't the area you're going to, and you'd better go to another area. So, all that has to be worked out. We have the process to do that now, and that's gone very well.

I would love to see, in the next couple of years, enough work done on that where we actually can say this is the landing site on Mars. It will take maybe a longer time, but the sooner we can get to that the better, and here's why: because we'll then spend probably a couple months acquiring all the data to create all the information on that landing site, and then we can make it available to the public, in a virtual reality form. You can put on the goggles, you can walk on Mars, this will be the site you're going to, really. You can put your habs [habitats] here, you can figure out where you're going to go to do science, you can create your paths to go there. You'll be able to recognize you can't go over the hill to get there, you have to go around it, because we'll also have all the altitude information.

I believe, our computer-literate kids that we have now are going to eat that up. And that's great, because those are the ones who are actually going to be on Mars doing it. So the sooner we can get them the information and the virtual experience of what it's like, the better. That will enable them, also, to participate in what that program is going to look like. It's not just going to be for the few, it's going to be for everybody.

ROSS-NAZZAL: That's the social media piece.

GREEN: That's the way I think about it now. Thank goodness.

ROSS-NAZZAL: We had talked previously about budget cuts, which you mentioned today, but there were some other challenges that I read about impacting SMD [Science Mission Directorate] in particular, that's the high cost of launch vehicles. I wondered if you could talk about that.

GREEN: Yes, that's the cost of doing business, and they are quite expensive. Planetary launch vehicles are not cheap if you're going to leave the Earth's orbit. I wish we could just use some of the smaller vehicles that are available to the other disciplines, but it just doesn't work out that way. It's 10 to 20 percent of the cost of a mission for the launch vehicle alone. Maybe in the future as other groups are getting more involved in it, more commercial vendors will be working on it. SpaceX right now, as an example, is perfecting a new rocket called Falcon 9 Heavy, and that's probably a vehicle worthy of some planetary missions that we can do. If Elon [Musk] keeps on track the way he is doing, it will be a very competitive cost, that will help drive down the overall cost of the launch vehicles, and we have to do that because right now they are just incredibly expensive.

ROSS-NAZZAL: I imagine that's a big challenge for you.

GREEN: It is. I'll give you an example. We could spend $200 million to launch a $500 million spacecraft.

ROSS-NAZZAL: $200 million?

GREEN: For the launch vehicle. Yes.

ROSS-NAZZAL: It's not quite launching the Space Shuttle, but it's up there.

GREEN: Just for the launch vehicle.

ROSS-NAZZAL: Do you have access to those vehicles, because I also understand there are other people who want these vehicles, the military.

GREEN: We have a contract vehicle at NASA that we use, that Human Exploration and Operations Mission Directorate actually manage the purchase of the launch vehicles that SMD uses. We have to use that contract, so there's a call for proposals for all those approved vendors that satisfy the NASA regulations that enable them to bid on planetary missions. Then the proposals come in and are evaluated, and the launch vehicle is decided on, and then we're told what the price is and we pay it.

ROSS-NAZZAL: That seems like the wrong way to do it—without competition.

GREEN: Well there is competition. Right now, we only fly American vehicles. It's not like it's open to every launch vehicle that's made by other nations. But that's part of doing business in Planetary Science at the moment.

ROSS-NAZZAL: That brings up a question that I was thinking about. Recently, [President Donald] Trump visited Europe, and there was a lot of discussion about him not bringing up Article 5 at NATO. Angela Merkel [Chancellor of Germany] made this comment that we can no longer count on the US. I know we have a lot of missions where we're joint partners with the Europeans. I'm wondering, has that filtered down to NASA? Is there some concern on the part of the Europeans about NASA's role and our partnership?

GREEN: That's a good question. We have a very long-term relationship with many space agencies. And we know, over time, that each of the space agencies are an element of a political environment, and our environments are very different. There are times when we make agreements to work together for which sometimes those agreements get broken. Sometimes they don't, and they actually go to fruition, and they are fabulous when that happens. But when they get broken, then a couple things can happen. One, say, from our perspective, that we renege on an agreement. We say, "Okay we're going to work together, we're going to do this," and now, "I'm not going to be able to do that for a variety of reasons, don't have the money, the administration doesn't want me to do it, or Congress doesn't want me to do it," and all those things have happened. "I'm going to renege on our international agreement. It's not going to happen the way we said it was going to happen."

That agency then can take the approach that, "You're just not reliable, we're just not going to work with you." Or, they can take the approach, "We recognize that you're doing the best effort you can in the political environment you're in, and that political environment, because our relationship has to extend over years, sometimes over administrations, changes. And so, we're going to accept that, and we're going to move forward, and we're going to create a different relationship. We’re going to create one that works. And if that breaks, we’ll find another way.” When we work with agencies like that, we are successful, because we’re both are committed to find a way to be successful, and that’s really important. To be able to help that along, we have frequent interactions with those agencies.

For instance, right now, we’re working on a mission with the Japanese. It’s their mission, it’s going to Phobos and Deimos, which are two moons of Mars, and it’s going to bring back a sample from Phobos. I’m all in. This is a fantastic mission. A lot of agencies in the past have wanted to do that in addition to us, and they have tried and failed their missions. The Russians have tried a couple of times and failed, as an example. ESA [European Space Agency] wants to do that, but JAXA [Japan Aerospace Exploration Agency] now is moving forward, and I think they’re going to pull this off, and we’re part of that mission.

I worked very hard to be a part of that mission. We’re going to provide them a gamma ray, a neutron spectrometer. We’re going to work with them on tracking, we’re going to work with them on navigation, and we’re going to be strong partners. That’s what it is right now, and we’re both working really hard in that framework. I’m going to do everything possible to make sure we meet our commitments, but there are things that are out of our control. Right now, everything’s looking great, and I want that to work, because I want them to work with us on the next set of missions. That’s what international partnership is all about.

There are several reasons to do this, not the least of which is the relationships it builds across our science community. Planetary scientists aren’t a dime a dozen. They’re very special. They’re highly trained. They’re multi-discipline. They have to know all kinds of things, everything from geology, to atmospheres, to chemical reactions, they’re very multi-faceted.

These are the ones that are tremendously successful in the field. Many schools have curriculum that bring in those elements that allow the training to occur to get them.

So we really, from a community, consider our international people as part of a community, in that manner, because they're doing fabulous science too. We like the intellectual stimulation of multicultural groups that are well-grounded in our science, that tackle tough problems, and want to work together with us, and we want to work with them. That's a critical element of why we want to work internationally, because the brainpower is there to be able to make great strides. It also allows me to execute things in the Planetary Science Decadal that the Decadal wanted me to do myself, meaning NASA, but we can do it internationally, get it done, and that saves us money. So there's a money angle to it too.

Now, typically, international relationships, international missions, if an agency wanted to do it and not connect with other groups, the cost of the mission is lower than the total cost of the mission with all the contributions. That may not sound intuitive, but each of the groups are paying only a small part of it, but there is overhead associated with it, and that overhead does cost some money. But it's a good deal for everybody, and it's really great relationships.

With ESA, in a similar manner, we're working with them on one of their missions, called JUICE [Jupiter Icy moons Explorer]. It's going to Ganymede, which is the largest moon in the solar system. It's a fabulous moon, it has its own magnetic field, and it has probably got a reasonable amount of water in an under-ice crust ocean. We don't know how much water, and how big the ocean is, and how deep the ocean is, but this mission will tease all that out. We have several instruments on JUICE that we're working on, and that will launch in 2022. The JAXA mission will launch in 2024.

So those are very important relationships for us, but we all know that our environments can change quite quickly, and it's because it's not like we can create the agreement and do it quickly. It takes a significant part of a decade to execute, and then that always goes over in administration, and that changes. Congress changes, everything.

ROSS-NAZZAL: What do you think has been your biggest challenge since taking this position?

GREEN: Probably the greatest challenge has been the Europa Clipper mission, the ability to really get it on the books and move it forwards, where all the stars line up, and everybody's on board with it. That's been very difficult, and it's taken quite a while to do. So that's something I've worked on the longest that's now coming to fruition. Another big challenge was Mars 2020. That actually happened easier, although that was quite challenging.

Mars 2020 came at a time when the planetary budget was going down, and down and down. This was the top Decadal strategic mission, with the Europa mission second. For Mars 2020 no one wanted to move that mission forward in the Obama administration, for several reasons, one of which, was that it was deemed to be way too expensive. That was a big problem, and OMB wasn't sure that if NASA did Mars 2020, what would happen in terms of bringing the samples back that the mission creates when it is on the surface of Mars. How many more missions would be needed to bring those samples back. Mars 2020 then, just seemed to be perhaps the camel's nose under the tent. If you get this mission, look at all the other stuff you have to buy, and you have to bring the samples back. If you're going to core rock, you're going to bring the samples back, that's what you're going to try to do.

That one was difficult, but it wasn't as difficult as the Europa mission. What helped sell Mars 2020 was Curiosity's landing was successful, and the fact that we can leverage a lot of the infrastructure that it created. Mars 2020, the rover that cores rock and puts them in cases for then eventual return, and then has a suite of instruments that really interrogates the area, and actually interrogates the core hole—even after you bore the hole in the rock, you can actually interrogate inside the rock and look at that stratigraphy of the rock inside the hole. The chassis for that is Curiosity's. How it lands is the same crazy sky crane system. It's the entry, descent, and landing system that we used. And we could go out and build that cheaper than designing anything new, plus we know it works. The overall price for that particular rover was far less than anything we could create new. We had spare material, we had all kinds of stuff that we could just bring together and execute this next rover mission. Consequently, that was an enabling element, whereas the Europa Clipper mission we have to build from scratch. No spare parts on that one.

ROSS-NAZZAL: What do you think has been your greatest contribution?

GREEN: Probably longevity. That sounds funny, but the average length of time for a division director in Planetary Science is 2.8 years, and I've been here 11 years. The reason why that's important is, it's taken me, as I mentioned, eight or nine years to get the Europa mission going. If I left after three years, somebody else would have to pick up where I left off, but that's nearly impossible to do. They'd have to pick up from the beginning, and it move forward. A lot of what I do is not anything you pick up a manual and read, "Oh okay, that's the next step." It doesn't go that way. It's not one of those jobs that is the same. It's always changing. It's an environment of change. Part of that is because how you implement missions, and the technologies around you, and what you bring in to facilitate those, and when do you do them. That's a moving target, so, you have to be able to quickly adapt.

You also have to be able to have some really good knowledge about the capabilities at your Centers. For me, I worked at Marshall Space Flight Center [Huntsville, Alabama] for five years, and Goddard Space Flight Center [Greenbelt, Maryland] for 20 years. I worked on Voyager, so I didn't work a lot with JPL, but I did work with JPL on a few things in the past. I had a fair amount of experience about the breadth of capability at our Centers, and that's very important. The experience base is critical. But indeed, I think having somebody in this position that's there for the long run, that goes through a variety of transitions, and then learns from that is critically important to be able to do the job.

I just talked about what we're learning from Cassini, we pulled into Europa. What we did on Curiosity, we leveraged a significant way, in order to do Mars 2020. Some of that doesn't necessarily happen so easily. You have to be able to work those issues. I was really lucky in my early career that one of my former teachers at the University of Iowa, who was working at NASA Headquarters, asked me to participate in an international set of quad-lateral meetings—it's a group called the IACG, it's the Inter-Agency Consultative Group, which is made up of four agencies, NASA, ESA, ISAS [Institute of Space and Astronautical Science, Japan], and the Russian space agency. Those four agencies got together and worked on a set of joint missions in the 80s, and into the 90s, and I was involved in those. That gave me an opportunity to work in an international framework and get to know the capabilities of the other space agencies.

When I hit the ground running as head of Planetary Science, I could just pick up the phone and call the Italian space agency and say, "What's going on with this instrument on Juno that we're trying to build?" And I could get some results because I knew the people and knew the activity. So that's very important. Somebody that takes these type of positions has to be towards the end of their career, had a broad range of experiences, particularly at different Centers and internationally, and is willing to think out of the box, as much as they can allow the people at the Centers to think out of the box, but also know when we have to make decisions and move ahead.

The worst thing is to be in the position I am in and not make decisions. Somebody asked me how many decisions I make a day, and it's probably 10. That sounds like a lot. The problem with the 10 decisions is some of them are really important, and the decision I make today can come back a couple years from now and haunt me, to where it could cost the division millions of dollars, or tens of millions of dollars, because we made the wrong decision. So, you have to be willing to make decisions, even the tough decisions.

I'm not the only decision maker. I advise, also, or recommend certain decisions that occur in Planetary to my boss, who's the Associate Administrator, who also is involved in making decisions that affect Planetary Science. I want that person to make the right decisions. It's very important to me that they make the right decisions, because I have to live with them too. I know I have to live with mine, but I often have to live with that person's too. At the Planetary Directory my bosses have been Mary [L.] Cleave, Alan Stern, Ed Weiler, John [M.] Grunsfeld, and now Thomas [H.] Zurbuchen.

ROSS-NAZZAL: That's the AAs?

GREEN: Five AAs. Yes.

ROSS-NAZZAL: That's quite a change. What do you think has been the toughest decision that you've had to make, and do you think it was the right call, or are you still waiting to find that out?

GREEN: Hindsight is always good. When I look over what's happened in Planetary Science, I don't regret anything, and in that, there has been some really incredibly tough decisions. Some decisions have been made now that we're going to be living out, and we'll see how they go, as you said, still left to be done. But what's critical is, are there decisions I could have made that were better decisions in the past, and I really can't point to anything. I think I've had a really good track record, which is partly why I think I'm still in the position. Seriously, it may sound funny, but I think that's true. The situation is that the things that we've done have really improved the position where we are, such as working with the Department of Energy and getting our plutonium straightened out.

When I first came here, we had a stockpile of plutonium that after a few missions it would all be used up, and we wouldn't be able to go to those dark places in the solar system and use plutonium. Why is plutonium important? Well, plutonium is a radioisotope that decays, and if you bring that material together, it's intrinsically hot, and in fact, it glows red, and you can't touch it, of course. It's just really hot, and you have to put it in an alloy, and then snug it up to another material called a thermal electric, which produces a voltage difference across the material that then you can charge a battery. So you can take heat, and you can make electricity out of it.

That's important because how we fly missions is we take the light from the sun on our solar panels, which generates electricity that runs experiments. But if you're very far away from the sun, or if you're in a location where the sun doesn't shine much, like crawling into a crater where it's always dark, as an example, and there are even those on Mercury, then, you need radioisotope power.

So we were going to run out of plutonium, and the challenge was, how can we get it restarted. It was being stockpiled in the weapons program, and in 1992, under the START II [Strategic Arms Reduction Treaty] agreement we stopped making it. We stopped making weapons, and therefore we stopped making the plutonium-238. It took a long time to get the administration on board with the idea, that we need to make this isotope without the weapons program. It took a long time to get Congress to buy off on it too, and it took me about six years to make that happen.

But, we're now making plutonium-238, and it's not quite in production, but in another year or two it will be in production, and therefore, anyone that steps into this job, there will no longer be a problem with going anywhere in the solar system you want to go. Without plutonium, more than half the places would be off the board, you couldn't go. So that was huge.

Early on, the decisions were, well, we really went at it. I wasn't taking no for an answer. We really had to figure out a way to do it. It's easy to say, "It's too hard to do, we can't do it anymore," and give up. But you can't do that. We have to end up being good stewards of the future planetary program. So getting plutonium restarted was critical for many things. Now Curiosity's got plutonium, Mars 2020 runs off plutonium. You couldn't do the Pluto mission without plutonium. Cassini uses plutonium. You can't go to the polar cap of Mars and drill down into the ice and look at an ice core, or any of that, without plutonium. You can't retrieve a sample from the back of Mercury, which is dark, and bring it back—because that's where you'd have to go, the front side's too hot, you'd have to go to the back of Mercury—without plutonium. By partnering with the Department of Energy we together make it happen.

That was one thing that we worked tirelessly on, we just had to go do it and make it happen, and then it worked out. You have to also take the attitude of never giving up on some things. I had that problem. I had a supervisor, when I was at Marshall Space Flight Center come into my office and say, "Don't you know when to give up?" I was trying to get something done, that had never been done at the Center before, and it was very simple, in my mind, but it had never been done. Because it hadn't been done, no one wanted to do it.

ROSS-NAZZAL: That's part of the NASA can-do attitude that we hear about, right?

GREEN: It is, but sometimes even the Centers don't have the can-do attitude. But indeed, you have to have the right attitude. If it's the right thing to do, you just have to keep at it, you don't give up.

After the Curiosity landing, which we made a really big deal out of, and it was perfect, and the rover is also working wonderfully well, that was just one of the highlights of my career, and it really exemplified the outreach, the possibility of outreach, because it was so huge. I didn't realize how huge that was until I went to Darmstadt for the landing of Philae, which was a little lander that was associated with the Rosetta spacecraft. That's the European Space Agency's Rosetta mission, going to Comet Churyumov–Gerasimenko. We were involved in that mission well before I came to NASA. There's like $150 million worth of instruments on

Rosetta, and we didn't have anything on the lander, but we did have a lot of experiments on the orbiter.

I went to Darmstadt, Germany, where the mission operation center is, I've been invited to come to landing event, and so I stopped at the front office get my badge and checked in. I'm supposed to go over to one of the buildings where everyone's congregating, and the press is coming in. It's a really big event, it reminded me immediately of what we did for Curiosity. So I'm walking from the office to the other building, I've just got my badge, and one of the project people came out, and came up to me, and said, "It's all your fault, you know." I'm thinking, "What?" I don't know whether I should be happy about that or sad about that. I had no idea what he was talking about. What did I do to deserve that statement?

Now, it wasn't too long before I found out, by talking to my people there, what ESA decided to do, in terms of opening up to the public the landing of Philae—which is this little lander on this comet—they felt they were forced to do because of what I did promoting the Curiosity rover landing. That's why it was my fault. It really stems from the fact that, as technical people, as scientific people, we get well focused on what we're doing, and the experience that we commonly have is we can easily get derailed if there are side-things going on.

In this environment when you're bringing the public along, it's not a little thing. It's in your face, and you have to deal with it, in addition to doing everything right with the mission and focus on its success. So it is a non-trivial thing to bring the public along. It is easier to say, we'll tell them later, and we'll make decisions along the way, not be diverted, not be derailed by reporters, or questions, or inquiries, or concerns, or all the stuff that happens along the way.

I get that, I understand that. That was their first Curiosity event, so to speak. Now, when they landed Rosetta on the comet, they did the same thing. That went much easier in the sense that they knew what they had to do. They knew how to isolate the project people that were making decisions from the public, and they knew who in that group could communicate with the public that wasn't directly involved in the decision making but was informed enough to then help relay the information, and therefore the excitement of the event. Now, to me, it was another just spectacular event. It was just wonderful. It was very historic, very much like the landing of Curiosity, even if it was "my fault."

ROSS-NAZZAL: I think this might be a good place for us to stop. Thank you so much.

[End of interview]