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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 April 11, 2017. This interview with Dr. Jim Green is being conducted at NASA Headquarters for the Headquarters Oral History Project. The interviewer is Jennifer Ross-Nazzal, assisted by Sandra Johnson. Thanks again for taking some time out of your afternoon to meet with us.

GREEN: My pleasure.

ROSS-NAZZAL: We really appreciate it. I wanted to ask you about becoming head of the Planetary Science Division in 2006. What led to that opportunity?

GREEN: I had an absolutely spectacular science career. I was a student at the University of Iowa [Iowa City]. I got my undergraduate, my master's, and PhD there. [James A.] Van Allen was there. It was a fabulous time for the space program. I was involved in major missions and experiments.

When I got my degree, I then left and went to [NASA] Marshall Space Flight Center [Huntsville, Alabama] in 1980. I had a wonderful career at Marshall Space Flight Center from '80 to '85. I continued on with my science and worked on several different missions while I was there, more than I did at the University of Iowa.

I was also a diver in the neutral buoyancy tank [Neutral Buoyancy Simulator] and pushed around engineers and astronauts in the water while they were learning how to work in space, using water as a medium for feeling weightless. That gave me an enormous appreciation for NASA's human exploration activities.

In '85 I left and went to [NASA] Goddard Space Flight Center [Greenbelt, Maryland] and continued my scientific career, but also started in management by becoming the head of the National Space Science Data Center or the NSSDC. By '92 I was the head of the division Space Science Data Operations Office, which had three branches including the NSSDC. We were getting to analyze and manage a variety of data across many NASA missions because we had a significant amount of funding. I then continued on at Goddard until 2006. I'd been at Goddard Space Flight Center (GSFC) more than 20 years and had a fabulous scientific career.

From a scientific perspective, scientists feel that a really good scientific career is measured by several things, one of which is the number of peer-reviewed scientific papers you write, in addition to their citation, in addition to how important they are, and how well known you are in your field both nationally and internationally. By 2006 I had about 110 or so scientific papers. One hundred scientific peer reviewed papers is considered a good scientific career.

I feel that I was very lucky. I was involved in so many fantastic scientific missions and discoveries that it was probably in the late '80s I developed the idea that one day I wanted to give back to the scientific community through some sort of service. For a space scientist, I think that the best service one can do is actually come to NASA Headquarters and work in the science program helping the science community be successful.

Plus, I knew a number of people that were at NASA Headquarters. One of which was Dr. Stan [Stanley D.] Shawhan, who was the head of the Magnetospheric Physics Branch at NASA Headquarters for a number of years. He got me involved in a whole bunch of international activities, starting in ’86 all the way into the ’90s. It was during that time period that I really created great personal connections with a whole variety of international scientists and administrators from different space agencies, with really tremendous exposure. That turns out to be really important, as head of Planetary Science.

In 2006 the head of the Planetary Division left NASA, the deputy position was also vacant, and the Science Mission Directorate [SMD] were desperate for someone to come in right away. The Associate Administrator of the Science Mission Directorate was Dr. Mary [L.] Cleave with Dr. Colleen [N.] Hartman as her deputy. They decided that a detailee from Goddard Space Flight Center could come and work at NASA Headquarters as Acting Director of Planetary Science until they could actually advertise and get somebody to come in and take the job.

Colleen called Dr. Ed [Edward J.] Weiler, who was the GSFC Center Director at the time, and I’d worked with Ed off and on for quite a while. Ed and I were good friends and working colleagues at that point. Colleen read Ed a list of people that she would like to see come on detail. At the end of that list Ed said, “Call Jim Green, who was on the list. Tell him to get down to NASA Headquarters and help out.”

I know this because she called to tell me that Ed had suggested me, and that she wanted me to think about it for a week at the most. I said, “I don’t need to think about it. Ed just told me what to do.” I was already thinking about coming to NASA Headquarters and helping out anyway, so this was a perfect opportunity to do that. I said, “I need a few days to create a transition plan so that my supervisor [Dr. Laurie Leshin] could approve me coming down to Headquarters and work."

I came to NASA Headquarters after about a week in August 2006 and started into the position. I immediately enjoyed it, so I applied for the position and got it officially.

ROSS-NAZZAL: What were some of your goals as you took over the office?

GREEN: Actually at that time, because I was a detailee coming down, I mentally thought "There's two things I've got to do." One is to fix some of the research activities that had funding significantly cut back. If you see this budget [demonstrates], in 2005 the budget for planetary science was $1.4 billion, and in 2006 when I came they had cut it back to $1.1 billion. So they'd cut it nearly $300 million. This is just an enormous cut. The first thing I wanted to do was figure out a way to put some of that money back into the research part of the program, because that funds our scientists at universities, industry, and the NASA Centers.

The second thing I wanted to do was start a mission to Europa. In my early scientific career I worked on the Voyager 1 and 2 [Program] data, and I did a lot at Jupiter. Europa is one of those moons of Jupiter which is so spectacular that we just have to go back. Everything we find out about that moon is so unbelievable. It's a huge body, about the size of our own moon. It has an icy shell, and underneath that shell is an enormous ocean, so we call that a water world. In fact it has twice the amount of water this Earth has on its surface.

It's been that way for probably four-and-a-half or so billion years. That means we believe it has all the right conditions like water and organics material so that it may harbor life.

It turns out that Thursday of this week we have a major press conference where we're going to talk about that a little bit.

ROSS-NAZZAL: We'll have to tune in.

GREEN: You'll have to tune in.

JOHNSON: Unless you want to give us a heads-up.

ROSS-NAZZAL: You could you give us some detail.

GREEN: Okay, we'll put it on record since this will be beyond the press release anyway.

One of the things that we've been discovering is that this particular moon of Jupiter, Europa, which gets squeezed by Jupiter's tidal forces—that heat is dissipated by melting the ice, and therefore creates the ocean under its icy crust. But the surface also gets stressed, and in fact cracks form. Coming out of the cracks we're now are observing huge amounts of water that are pouring out, splashing down on the surface of the moon. We're seeing that with the Hubble Space Telescope.

This is really exciting, because one of the missions that I've been able to get started—and it took me 10 years to do it in this job—is a mission to Europa. It's called the Europa Clipper. We're building that and it'll launch in 2021 or so, and it will fly through these plumes, and it will be looking for signatures of life and how habitable that moon might be.

Clipper will also be performing high resolution imaging of the moon, looking for a place where we could actually land and then taste the water. Hopefully we'd land underneath a plume, and the plume material would fall down on the lander and that fresh material might have life that has come up from that under ice crust ocean.

It's starting a series of things that we want to do on the outer solar system that I had really hoped to start when I came in 2006, 11 years ago.

ROSS-NAZZAL: Took a while, I guess.

GREEN: Yes. What it tells you is these things are really hard to do. I devoted a significant amount of my effort and time to try to make that mission happen, and along the way many other missions that I've been involved in. It also tells you how naive I was to think I could get the Europa mission going quickly.

As a Division Director in Planetary Science, I've been here 11 years. I'm the longest Director NASA has ever had in Planetary Science, where the average is about 2.8 years.

ROSS-NAZZAL: Why is that?

GREEN: That's because this is not an easy job. It chews you up and spits you out. I went through some very rough times but I didn't quite. The budget is an example of what I mean by being chewed up and spit out.

I am the top advocate for planetary science in the federal government. That's an enormous responsibility. The entire planetary science community depends on me and my team making progress in keeping our budget up, allowing us to be able to fund activities that are not only pure research but also planetary missions. Doing the right thing to make tremendous discoveries that allow us to keep the program going.

Some scientists don't really understand the role that NASA Headquarters plays. But here at NASA Headquarters, the future, the entire future of our science disciplines in planetary, heliophysics, astrophysics, Earth science—this is true for all of them—is done right here on this floor, in this building.

Not only do we obtain the funding from Congress to be able to administer the program that we set up each year, but we're constantly planning the future. In this one particular figure [demonstrates], just to give you an example of that—here we are in 2017, which is right there, and all these missions here are our future, so they haven't been launched yet. One, two, three, four, five, six, seven, eight, nine, ten, eleven missions.

That set of missions are all new, and that's our future. If you can't pull that off and you can't create the opportunities, then there's fewer of these or none of these. In fact some disciplines work really hard that after a couple years they have one mission, and yet we've been tremendously successful with so many missions. We do that in a whole variety of ways. Several of these missions are international missions. We've got one, two, three, four space agency partners in that set. Nearly half of our future missions, that we haven't launched yet, are partner missions.

That means the international community of planetary scientists that we connect to, in different space agencies, are really critical to our success. Fortunately, I know these people for decades now, because I worked with them even in the 1980s. Getting our missions on the books and moving it ahead, being able to manage the budget situation that we have over time, and keeping the community healthy, and with that also keeping them informed of the problems that we have along the way is how I manage to stay in my position.

For instance, in FY12 [fiscal year 2012], as our U.S. economy was tanking in general and the priority of doing planetary science in the federal government was going down, it was more important to do other types of things like Earth science or JWST [James Webb Space Telescope]. Planetary science lost well over $200 million in one fiscal year, which is an enormous amount of money in our budget. So, you've got to be able to pick yourself up and move on and build it back.

It's those things that happen along the way, the successes and the failures, that if you're constantly beaten down—that makes this a tough environment—and you don't make progress, then the best thing you can do for the community is leave, and bring somebody else in who can succeed. Fortunately I've been really quite successful, and I feel really good about that success.

ROSS-NAZZAL: You mentioned that you have a staff of people who work for you. Would you tell us about the office and how it's evolved over the years since you took over in 2006?

GREEN: It's turned over quite a bit. Probably at least half of the people that we have today weren't here in 2006 when I started. But I have a tremendously dedicated group of people that really get it, that really understand what we're trying to do, and are tremendously talented to be able to pull off such a spectacular program. Our success in planetary science can't possibly be done by one individual, by me. It has to be done by our team. They're involved in all aspects of planetary science, and they feel that ownership too.

Here's why it's so important. In the federal government, if you look at everything that the administration funds, NASA's planetary science is the only location in the federal budget where we actually do planetary science. In Earth science we're not USGS [U.S. Geological Survey], or NOAA, we're not several other agencies that work in that particular area.

The Earth as a planet is incredibly important, but the point I'm trying to make is the whole community depends on us, on NASA. They can't go anywhere else for funding. The only other place they could go is leave the United States and go to the European Space Agency [ESA] and work within that framework, or the Japanese Space Agency or some other place.

That's why it's critical that we retain our scientific workforce. In fact when this happened, when our big decrease in our funding happened beginning in FY12, the team—with me as the lead—was able to put together a program that literally kept most of our community together, knowing that it would only be a matter of time when we'd restore our funding to its former value. It's taken us several years to get the funding back up, but we're well beyond where we were in '12.

In fact our budget prospect for FY18 looks like it's going to be $1.9 billion, which is right up here [demonstrates], almost off the chart.

ROSS-NAZZAL: That's great.

GREEN: We need that money if we're going to execute those missions that I mentioned.

ROSS-NAZZAL: You mentioned that you are the advocate for planetary science. NASA has so many competing missions. You've got aviation research, you've got human spaceflight. How do you work to ensure that you get a piece of the pie that's going to work for all the missions that you have in place?

GREEN: We're really lucky in the science areas—and planetary is one of the four major science areas that NASA supports. Earth Science; Heliophysics, the study of the sun and solar wind; Astrophysics, the study of things beyond our solar system; and Planetary Science are the four major disciplines.

Each of our disciplines works with the National Academy [of Sciences] (NAS) to develop a 10-year strategy, and these are called decadal surveys. The origin of the NAS decadal process actually started in the 1960s when Astrophysics did its first decadal survey, and we're right now, in the second planetary decadal survey.

What that's all about really is getting the NAS to bring in the best scientific minds in the nation; discuss, debate, prioritize, and determine what are the top science questions that we ought to go after? Then from that broadly create a series of missions or mission concepts that could answer those questions. The reason why they have to do that is you have to determine whether you can actually afford to answer some of those questions. There's an element of being cognizant of the budgetary constraints that always come with any program being funded by the federal government.

What we're doing then is following the planetary decadal. The decadal lists the questions and the concepts and the things that we want to go after, and I have enormous freedom with my team to be able to craft approaches to go answer those questions through our missions and research that we fund. Some of those could be answered by partnering with certain international space agencies who have missions that are going to certain locations that will be taking data, and actually that data can answer some of those questions. Then that's something I don't have to go do myself, I can partner with them and we can do it together.

On the flip side, we have a lot of those agencies that work with us. NASA is really quite well-known worldwide, I don't need to tell you that. But there's a lot of space agencies that want to work with us. It's also relatively easy for us to encourage and obtain agreements that allow those nations to have experiments on our missions. We have a number of those that have quite a bit of international involvement.

That relationship is incredibly important for us to be able to execute our program. The more we partner, the more we can do. Sometimes when our budget is low we can still get a lot done, because we can leverage those other nations that are involved in planetary science.

ROSS-NAZZAL: When you're using that decadal planning guide, have there ever been any missions that were proposed that you say, "This is too much, we need to descope it"?

GREEN: There are. One of the top decadal missions was the beginning of sample return on Mars [Mars Sample Return mission]. The way the decadal laid that out was completely unexecutable. If I had to do what the decadal told me just exactly that way, we'd still be struggling. Yet right now that mission will launch in 2020l the mission is the Mars Perseverance Rover. We developed a better approach, we found a way forward.

That approach actually leverages everything that we've learned from a rover called Curiosity that's sitting and working on Mars now, even though the decadal was developed before we even launched Curiosity. It's one of those things that you learn a lot over time, and you want to be able to take what you learn and pour it right back into the program and make it better.

Also, another mission that's in the decadal is a Europa mission. The Europa mission was the top mission in the previous decadal. As I mentioned, when I came down to NASA Headquarters in 2006—and during that time period was the first planetary decadal—the Europa mission was the top mission. I would constantly argue, within my ability as director of planetary, to be able to move forward with a mission like that. I could always point to the planetary decadal saying this is one of the top missions we should be doing, but I never was able to get it together to the point of having it approved until recently.

It's very hard to get brand-new, very large expensive missions together. What it does is it requires my boss, the head of the Science Mission Directorate, to say, "Yes, we want to go do that above all else in SMD." Then I have to convince the [NASA] Administrator and all his staff that this is the mission we want to do and get everybody behind it.

Then from a NASA position, we have to convince the [presidential] administration. The administration has two major organizations, which is the president's science office, OSTP [Office of Science and Technology Policy], and the Budget Office, OMB [Office of Management and Budget]. There's two whole organizations you've got to convince.

Once you do that, then you got to convince Congress, which has got two groups. It's got a House and a Senate. From that, if you get all those groups together and all those to agree that this is the next major mission, you then actually could get it started. But it only takes one of those groups to stop it.

ROSS-NAZZAL: Can you give some examples from your experience with the Europa mission, and how you were able to successfully finally see that come to fruition?

GREEN: Every year since 2006 I would propose to upper management, "It's now time, let's move forward with a major Europa mission—" we called it a flagship. It's a large strategic mission.

I'd sometimes get further than other years, but I never quite would make it. What happened—and this started in 2011 and 2012. Right at the time when our budget was going down, at a time you would think that you'll never be able to move forward with anything, a major discovery was made at Europa with older data, and with Hubble data.

That was some indication that there may be active plumes. What we're going to announce this week is that it's pretty definite that we now have found permanent plumes that occur, that the cracks do open, and just walls of water come squirting out. We now know that's got to be happening on Europa.

But there was an inkling of a new discovery. Couple that with one of the major agency initiatives, which was the Space Launch System, the SLS [rocket], and being able to have the opportunity to use the SLS to go to the outer solar system. We had done a study that enabled us to take a look at how fast we can go to Europa using a variety of rockets. If we used a conventional rocket, what we call an Evolved Expendable Launch Vehicle, EELV, we have to do gravity assists on the inner part of our solar system. We've got to fly by Venus, and then we've got to fly by the Earth, then maybe we have to fly by Venus again. We've got to get enough energy to fly out to the outer solar system.

That typically takes us about eight years. Once we launch the mission, eight years later it's at its target. With the SLS, we can go from the Earth straight to Europa in two-and-a-half years. To us that's a complete game changer. That takes the outer solar system and blows it open for us to be able to go not once, but a couple times in a decade. Prior to that we would go once every other decade. You can see it's just radically different.

We don't know much about a lot of things in our solar system, particularly our outer solar system, and consequently, having the ability to get out there is critical. The agency was moving ahead with the SLS, and the fact that Europa science in addition to human exploration was planning to use it, or could use it, really got the attention of the NASA Administrator. Finally the decision was made that [Administrator] Charlie [F.] Bolden [Jr.] at the time would approve this and we'd move forward. One of my jobs was to give the presentation to the Administrator. To me it was a seminal talk, one of my best talks ever, because it led to Charlie's support of the Europa mission with an SLS as a possible rocket to go forward.

That made all the difference, because then all we had to do was convince OMB and OSTP. We already had a number of people in Congress that were already ready to do it. John [A.] Culberson was all over it already. That's because the more we find out about this body, the more we're excited about it. It has all the right conditions, we believe, for it to be able to harbor life.

Just as a small digression, I think finding life beyond Earth is really a tremendous driver for us as scientists, but many people in this nation want to do that. It's a tremendous goal of ours to be able to determine, "Are we alone or not?" You can already see the popularity that Exoplanets—finding planets around other stars and whether they could be like Earth, or just Earth size, but maybe like Venus. You can't live on Venus, but you can live on Earth.

There's a huge drive to be able to do that, so we have enormous public support in moving forward with this. Plus it's a spectacular question to answer. Over the last several years I've told everyone in planetary science at my town hall meetings that I plan to be the Director of

Planetary Science when we find life beyond Earth. Because we'll find it first in the solar system, and if we can find it in the solar system it's everywhere in our galaxy. It's then only a matter of time to find intelligent life elsewhere.

Europa is quite important to us because we never thought a body like that could exist in the outer part of a solar system, so far away from a sun that enabled it to have an environment where life might exist. It's revolutionary in the idea that the energy that it needs is really the tidal forces it gets from Jupiter.

Let me give you an example. We feel tidal forces between the moon because as the moon moves over the Earth, and we see the effect of its gravitational pull, even the water will move upwards towards it. And as the moon moves away, it moves down. That produces the tides, that's very well known.

The same thing happens with this moon. This particular moon is orbiting a Jupiter that if it was a fishbowl, you could put 1,000 Earths in this fishbowl. It's huge, it's unbelievably huge. Although it's mostly a gas giant, it's not like a terrestrial planet in that volume, it's still more than 300 times as massive as the Earth.

When you have a body like Europa, which is the size of the moon that goes around Jupiter, it goes around Jupiter in an elliptical orbit. Sometimes it's far away, and then on the other side of its orbit it's close to the planet. When it's close to the planet, the planet squeezes it. As it moves around and gets further away, then that grip lessens.

If you just look at the moon, all it does is go like that every three-and-a-half days (85 hours). That energy has got to go somewhere, and it melts the ice and creates a liquid ocean. It's still so cold that it maintains an ice shell. The tidal forces, every three-and-a-half days that icy surface moves 30 meters up and down. That's about the height of this building, every three-and-a-half days. If you were sitting on the surface you would be going up and down like that [demonstrates] every couple days.

That heat has got to go somewhere, it gets pumped into the ocean, and now we believe that ocean is full of hydrothermal vents on the ocean floor. It's water, so that means it exists in a certain temperature range below freezing. There's indications that the bottom of the ocean is a rocky surface. The analogy of hydrothermal vents is really very good. Hydrothermal vents in our ocean were discovered in 1977. It wasn't that long ago; we didn't know they existed prior to that.

When you go to a hydrothermal vent on Earth—and it's believed there's tens of thousands of them and we've only visited 300 of them. Some of them is where the water is alkaline, and some of them is where the water is very acidic. It's a huge amount of hot water and rock coming out in fissures in the ocean, and they're all teeming with life, just teeming with life. You don't need the sunlight, and you don't need the fact that you're where we are in the solar system. If you have that kind of environment, even if it existed out at Jupiter, we believe it's a habitable environment and life may actually be there.

The other thing about it that's really great is it's what we would call a second genesis. There's a theory of what's called "panspermia." If life started on a particular body in our solar system and it was bombarded, and life left that body on an asteroid—or a piece of the body at impact—it could actually live and survive on that body until it falls on another body. Life can move through impacts from one body to another.

In other words, we could actually be Martians. Life may have started on Mars first, through impacts imported inward, deposited here on the Earth, and the conditions are right for life then to pick up and start again. Then we'd be related to life on Mars.

Europa and Jupiter, which is five times the distance from Earth to the sun—it's called five astronomical units, where we're at one astronomical unit—is so far away that we can't get any rocks of impact up the solar system to Jupiter from Earth. If life started on that moon, Europa, it had to start completely independent of life here on Earth, and that's what we mean by a second genesis. Life had to occur in a way that was completely unrelated to how it occurred here. Life may start and be exactly the same for any genesis, but that's the current thinking of it.

When you talk about life, we view life as having three major attributes. The first thing is it's got to metabolize. That means it ingests material along with a liquid. The liquid is used to dissolve the material, extract nutrients, and then the liquid is used to extract the waste. That's part of the metabolism process. Second thing is it has to reproduce. Cells divide, become other cells. Then the third thing is it has to evolve. Over time the object changes into different things to accommodate the changing environment that it's in. That's the definition of life, those three attributes.

For us, the heart of our finding life in our program is really all about following the water, going to places where we believe there's a fair amount of water. What we traditionally think about planetary science is that water must exist only in the inner part of the solar system. That was an idea that we had for decades, and it turns out it's wrong. We now know that it's wrong.

Here's how to think about it. If you started at Pluto with an ice cube and you moved it towards the sun, it would remain an ice cube until you got to a certain location where the heat from the sun would be enough to start melting the ice cube. You could melt it, and that location is called the snow line. Anything interior to that location in and around the sun is where water can exist in liquid form, given the right conditions, given a planet that can maintain a pressure that can keep it water. That location, the snow line, is a little farther than Mars. It's actually what we call the asteroid belt. Anything beyond the asteroid belt, water has got to be frozen. That was the idea.

So the outer part of our solar system wasn't important, until we found Europa. And then we found Enceladus, and then we found Titan, and Titan has got liquid on its surface. The only other body in the solar system that has liquid on its surface. It has huge bodies of liquid that are larger than our Black Sea, and Titan is a moon of Saturn.

The thing is that liquid on Titan is not water, it's liquid methane, but it is liquid, and Titan has all the other elements that it needs. It's got all the hydrocarbons you can possibly imagine. So if there's a place where life exists that's completely different than ours, it's on Titan. That's the kind of stuff we have in our solar system that we can go explore and look at. That's what makes the planetary science field really exciting.

ROSS-NAZZAL: There's so many fields in planetary science. I'm curious if you could talk about your relationship with all of these academics and all of their professional societies. How do you keep up with all of the research that's going on, being head of the division, and being an advocate, working the budget, all these sort of things? That seems like a tremendous amount of work for one individual.

GREEN: Yes, but it's the fun part. I work about 12 hours a day. I have my whole scientific career. When I come in, which is about 6:00 a.m., before my day of meetings really begins, which is on the order of 8:00 a.m., those two hours I spend reviewing what's happening in the fields. That's in the field of astrobiology, planetary geology, planetary science in terms of Mars or Venus or anything in our solar system. What we have today via social media is so spectacular that it's easy to find your way through these new discoveries. I have access to pretty much all the major journals. There'll be monthly editions of things that come out. It's easy to run through them, look at this, look at that, and see the enormous progress in the field being made.

Some of those are being picked up by the news service, so you can see what the public is interested in. Sometimes when I find something in that venue I'll go right back to the journal where it came from and then understand the basics of what's going on. Spending a couple hours every day reviewing our field and what's happening is really exciting. Indeed, it gives me a tremendous perspective of what's going on, but also an understanding of how it's connected.

The press conference we're having Thursday is a connected set of science that was coming out, that we would normally have written a press briefing for, and that would have been the end. But the fact that there are several things that we see at Saturn and that we see at Jupiter and they're related is what we're doing. We're talking about a number of exciting discoveries that tell us something very important when we bring them together and we think about them together.

The hydrothermal vents—we see evidence for on Enceladus. We don't see them on Europa because we haven't been back to Europa, but the fact that we're seeing all the same attributes on Enceladus that we see on Europa must mean that Europa has hydrothermal vents too. We're pretty sure now that Enceladus, which is a smaller moon which has a lot of water and an ice shell that orbits Saturn—we're very excited about that body—at the bottom of its ocean we have hydrothermal vents. Enceladus could very well be teeming with life, too. What we have to do now is put together the right missions and go find it.

ROSS-NAZZAL: There have been so many interesting scientific discoveries since you've been in this position.

GREEN: There really have been many spectacular discoveries announced.

ROSS-NAZZAL: I wondered if you might share some of those. I was thinking of water on Mars, for instance.

GREEN: These are the missions I've been involved with. I can look right down here [points to list], and I can just see the huge discoveries that have been made as we go through that.

Cassini-Huygens was really two missions: Cassini that's orbiting Saturn, and the Huygens probe, which is an ESA probe that went to Titan. This is where ESA worked with us, and we gave them a ride. We're part of Huygens. The probe landed a set of experiments in a big capsule-looking spacecraft that landed on Titan and measured its atmospheric density, its temperature, did all sorts of imaging. That's why we know a lot about Titan, it is from the Huygens probe.

Then Cassini also contributes to our knowledge since it had an atmosphere-penetrating radar, because Titan has got a tremendous atmosphere. It's mostly nitrogen; it's most like our own atmosphere. Doesn't have the oxygen, but certainly has got a lot of nitrogen. Titan is where we find the methane lakes and seas. Those are fabulous discoveries. Then of course Cassini's also observes the planet Saturn. Saturn is like Jupiter. It's a huge gas giant, and its structure is being observed by many instruments on Cassini. It sees huge storms, lightning, all kinds of things that we're familiar with on our Earth on these huge gas giants.

You can just go right down the list. There's Mars Odyssey. Mars Odyssey has been at Mars since about 2002 and is still working great. One of the best things it ever found was an indication of a subsurface layer of water based on remote sensing from its neutron detector and that gave us a reason to get down to the surface. Curiosity [rover] is on the surface, and it observes all kinds of evidence of water. Spirit and Opportunity [rovers] have also been down on the surface, and they see all kinds of signs of water. In fact there's minerals that can only be created in the presence of water, like hematite.

So we now know, based on many of those missions at Mars, that Mars had an enormous amount of water in its past. In fact, the estimate is about 30 percent of its northern hemisphere was an ocean, and in some places it was more than a mile deep. It had that ocean for maybe more than 100 million years, maybe as much as 500 million years. During that time period, that's an environment where life could have started. That happened at the same time life was starting here on Earth, exactly the same time.

What happened to Mars is it lost its magnetic field. Then the solar wind just started stripping its atmosphere, causing the oceans to evaporate, and Mars then moving into more of a dry, arid planet that it is today. But Mars has an enormous amount of water still trapped in its polar cap and underneath the surface. We're finding that out from our orbiters and from our landers and rovers that are moving around.

Curiosity is sitting in an area which was full of water over tens of millions of years, maybe longer. It's sitting in an area where there's sediments that filtered through the water and lay down on the surface. As Curiosity has bored down and grabbed that material and brought it in and tasted it and then found out the composition, we can tell that the water was actually not salty at all. You could drink it. If you were there 3.5 billion years ago, you could drink that water. It wouldn't have been a problem.

Dawn is another mission. It's an asteroid mission, and it has gone into the asteroid belt, visited Vesta. Vesta is the second-largest asteroid. Vesta has a core made up of nickel and iron, and then a mantle, crusty area. That is a seed of a planet. That actually is the beginning of making a planet.

We now realize that these bodies that we call the asteroid belt, that exist between Mars and Jupiter, are objects that are trying to become a planet. I was always told when I was in grade school that the asteroid belt was two planets that collided resulting in a bunch of rubble. That turns out not to be true.

What happens is these bodies are trying to accrete. They collide, break apart, then the gravity pulls the pieces all together, and then they re-form one larger body. That's called accretion. Accretion is a violent process it turns out. The more things you accrete, the bigger you get, and you become a planet from that.

What happens is, because Jupiter's mass is so great, that when these asteroids collide and then they try to come together, they can't, because Jupiter pulls them apart, and they don't come back together to create a larger body. It's because Jupiter's gravity has kept them apart that you don't have a planet, and in addition Mars is a runt because of it. Mars is not as big as the Earth, but probably would have been if Jupiter hadn't pulled the mass out of that area. The dynamics of our solar system we're starting to learn by examining these small objects.

Then missions like NEOWISE [Near-Earth Object Wide-field Infrared Survey Explorer] is an infrared mission, and it's looking for near-Earth objects. What happens in our asteroid belt is there's a variety of interactions that occur for which asteroids will move out of the asteroid belt and move inward. When they move inward and start orbiting the sun many will cross our orbit, they can be dangerous. We could actually have an impact. We now know that the dinosaurs—which didn't have a space program—there was an impact of about a six-kilometer asteroid which created such an environment that the dinosaurs couldn't survive it. About 85 percent of the life that was on Earth at that time was eradicated. That's from a simple impact, a simple impact of a six-kilometer object with the Earth.

What is NEOWISE doing? It's finding all the asteroids it can find. It has many more to discover. But that, plus our ground-based observing program, we have found about 15,000 near-Earth objects, those that cross our orbit and could impact us. Out of that list there's about 1,500 that we call "potentially hazardous." That means in the next several hundred years, maybe several tens of thousands of years, they may impact the Earth, because their orbits are such that they cross ours or they're significantly close that we may have problems in the future by attracting them. Here's what we know. Right now 100 tons of material falls from space onto this planet every day.

ROSS-NAZZAL: That's a lot.

GREEN: It's a lot of material. There are some small objects, but it's typically dust material. As we move around, the dust that's left over from comets, we sweep it up. It's a dirty area. We don't live in a really good part of the solar system, it turns out. I hate to tell you, but we now know that. We didn't know that a couple decades ago. We didn't know any of that.

Out of these near-Earth objects that we're looking at, there's about 900 that are planet killers. Those are all big enough to destroy most of the life on this Earth. We now know it's not a matter of if, it's only a matter of when one of those will come by and hit us. We've been monitoring them and observing them, and there's quite a few more to find. We statistically believe we've got all the really big ones, or most nearly all the big ones, that we're looking for. But there's still some that are so big, like 100 to 200 meters in size, that if it hit Washington, DC it would take everything out to the edge of the [Capital] Beltway [Interstate-495]. It'd all be gone. That's only an object that's a couple hundred meters in size. That's no big deal; there are plenty of them out there. There's tens of thousands of them out there.

ROSS-NAZZAL: Somebody's going to take this oral history and create a movie script or something based on this. They already have *Armageddon* [1998 film].

GREEN: They did, it was called *Deep Impact* [1998].

ROSS-NAZZAL: *Deep Impact*, yes.

GREEN: As we started early on in our program, within the last 20 years finding this out, then Hollywood kicks in, and does a movie of these things.

JOHNSON: Scares everyone to death.

GREEN: Yep, scares everyone to death. We're not done finding all the objects we need to find. That's the first thing you need to know. But we already think we're in pretty good shape for at least the next several hundred years, in terms of a planet killer. Which is good.

But there are some out there that are probably going to hit the Earth, maybe in another 100 or 200 years. Earth is a big place. Maybe it'll hit the ocean. If it hits an ocean there'll be a tsunami, depends on where it comes down. That could be bad or could be benign.

The one that came in over Russia at Chelyabinsk [February 2013], where 1,000 people were injured because they went to the window and there was a sky burst with a shock wave breaking windows for ten of miles all around. As these things come in, the atmosphere really heats them up and they actually explode before they hit the ground. That thing was only 17 meters in diameter. That actually was really an itty-bitty one. A 17-meter asteroid is very hard to find orbiting the sun. We need a couple hundred meters in size before we can find them more easily. NEOWISE is looking for them, and we have a whole bunch of ground-based telescopes to do that too.

I go up this list, and this one right here, OSIRIS-Rex [Origins Spectral Interpretation Resource Identification and Security-Regolith Explorer] that we launched last year. It's on its way to an asteroid, a near-Earth asteroid, and that asteroid is called [101955] Bennu. Bennu is 500 meters in size.

That particular asteroid is also a potentially hazardous asteroid. In 2135 it comes between the Earth and the moon, and it may get a gravitational kick if it comes to just the right place that will put it on a trajectory that the next time around it will come and hit the Earth. A 500-meter asteroid, that size, would take out the state of Missouri. That'd be a really bad day.

We're going to be orbiting that asteroid starting in August of next year. We're going to be orbiting it for more than two years, we're going to go down and get a sample, and we're going to bring that sample back. We'll know everything that we need to know about that asteroid to figure out a way to deflect it or to change its motion such that it doesn't become potentially hazardous in the future, if we have to.

The reason why we want to bring a sample back is it's a very primitive body. It's a really early primitive body that came together at the time that the Earth started to come together. It's full of carbon, and it's full of all sorts of material. We believe it's full of amino acids, we believe it's full of water. It's got all the right juicy stuff. Early on in the Earth's history, many of them like that that hit the surface of the Earth, after the Earth was created, probably brought enough material for life to get started. You have to have the right material for life to start. We believe asteroids have been doing that early on in the history. Not only did they create the rest of the planet, they also bring the materials necessary to start a habitable environment where life might be able to start. That's the theory.

OSIRIS-REx will help us with understanding potentially hazardous asteroids, and how we can manage to survive the bombardment that will happen in the history of this planet, for humans to be able to live here safely. But it'll also gives us some hints on what early Earth looked like and what material we started with on the surface of the Earth.

We don't know everything about that early Earth surface environment. You would think "Well, what do you mean? You can go out and find rocks and look at them, and weren't they here on the surface of the Earth since the beginning?" The answer to that is no. The reason why is plate tectonics, the biosphere, and weathering has changed the entire surface of the Earth.

For instance, we believe the Earth is 4.5 billion years old. The moon is that old. We know that by bringing rocks back from the moon. We can date those. The age of the moon is the age of the Earth. They were created just about the same time. The oldest rocks we can find on this Earth are about 3.6 or 3.7 billion years old, not 4.5 billion. Those are all brand-new rocks. That means the rock that started creating the Earth has melted and accreted with other material. Then when it solidified, it's a different rock. When it melted, the heavier elements left it and went to the center of the Earth, because that's what gravity does. It's only over time, where geological processes take the material that comes to this planet and creates the environment that we currently have, and all that is turned over.

It's just like the surface of Europa. If you go to Europa, you can hardly find any craters on it. Why? It doesn't mean it hasn't been hit. You can look at our moon, and you can see the things that have hit the moon. The moon has original material on it; that's the surface of the moon. Europa has been hit all kinds of times, except its surface has also turned over. We believe ice plates at Europa have gone under its ice crust. There's been subduction just like our rocky plates have done, but on Europa new ice forms. Where there's craters, those are eradicated also by material that falls in from these plumes and cover them up or from subduction.

Going and finding the original material that was on the surface of the Earth when life started on Earth, we can't do that here on this planet. We might be able to do it on Mars though, because Mars had an environment that was like Earth, and water at a time when life started here on Earth. So there's a lot of things about going to Mars to look for life that relate to us, because it tells us about that very early environment. Mars did not have plate tectonics.

There's just been an incredible array of missions and discoveries over time, and of course probably one of the most historic missions on my watch was New Horizons and the [2015] flyby of Pluto. Why is that important? We hear a lot about well, Pluto is no longer a planet. What does that mean? From a NASA perspective, I don't care if it's a planet or not. It's an object well worth visiting, that's for sure. Just to give you a little idea as to what's been happening, Pluto was discovered by Clyde [W.] Tombaugh in 1930 as another planet, an object beyond

Neptune. That's the way it stayed until about 1992 when another object beyond Pluto was found.

That fit a theory by Gerard [P.] Kuiper in the '50s that said there should be a whole bunch of objects beyond Pluto that are left over from the creation of the solar system. Little bits and pieces that are way out there. Much like the asteroid belt that created the terrestrial planets, there must be bits and pieces of things that started the giant planets left out there. That was called the Kuiper Belt.

From 1992 on, we started finding objects out in the Kuiper Belt like crazy. Right now there's about 2,000 objects that are Pluto-like objects beyond Pluto. A brand-new region of the solar system. In our lifetime, we've discovered another part of our solar system. That's really the outer part of our solar system, the Kuiper Belt. One of the objects, called Eris, was believed to be bigger than Pluto. The debate was, "Well, if Pluto is a planet, are we going to call this other object a planet or not?" And they didn't want to do that; that was the astronomers in the IAU [International Astronomical Union] which manage the naming conventions. But right now, when we flew by Pluto what we discovered was an object we had no idea would look the way it does.

Now that object, created at the beginning of our solar system from material that's in the outer part of our solar system, has been bombarded and accreted and created. It should look like the moon, should be hammered with craters all over the place. Pluto is about the size of the United States.

What does it have on it? It has glaciers; it has an atmosphere. The atmosphere is mostly nitrogen. These glaciers are nitrogen glaciers, so it's almost like toothpaste that moves around on the surface and eradicates the craters. It literally modifies the surface of the body. It's unbelievable. I never imagined anything like that. It tells us that these Kuiper Belt objects are really important to understand how the solar system came together to be created, and we need to know more about them. Our Pluto flyby was the very first thing to do.

In planetary science, in our whole history, which is only about 53 years long, maybe 54, what we do is we fly by, and that's a survey mission. If what we flew by is worthy of study, then the next mission will be an orbiter. If we really like what we see, then we want to get down to the surface. We land, rove, and return samples. Methodically we work—flyby, orbit, land, rove, return samples. We've done that with the moon, and we're well on our way of doing that with Mars. There'll be other objects in the future we'll do the same process with. But Pluto we've never been to. This is the first time we've been to it, and we just flew by it. It's really quite an exciting time.

There's another set of things that we've discovered. There may be another planet the size of Neptune that also is well beyond Pluto. That comes from understanding some of the early dynamics of our solar system.

We now have computers; we can do computer modeling. In the last 10 years, it's quite clear from our computer modeling that in a computer we can create a solar system. The planets can accrete. We can get the terrestrial planets; we can get the giant planets. That's a solar system. When we start out with creating our star [the sun] and do this in a computer, and we want the planets to form where they are, we can't get them to do that. The outer planets in particular—Saturn, Uranus, Neptune—are too far out. We can't get them accreted before the Earth forms, for example. None of that happens in the way we thought it should happen.

We can create these giant planets if they all started their life closer to the sun. If we bring them inward, we actually can create them. So if we bring in Neptune, Uranus, and Saturn to where Saturn is today we can create all the planets. Once they are formed, then gravitational interactions between Jupiter and all these giant bodies are such that Jupiter throws them out. This was a very big surprise. Jupiter is so big, it actually rearranged our early solar system to what it is today. So we believe the solar system started out pretty small, and that gravitational interactions with Jupiter threw all the larger planets out away from the sun. It literally moved huge planets and put them in different orbits. That's a concept that is still hard to understand, but that's what the computer modeling tells us.

When we look at exoplanets, we now realize it's the only way some of those solar system can form too. The first type of exoplanets we saw were huge Jupiters on highly elliptical orbits around stars, huge Jupiters. And yet we know when stars are created you also have a cloud of material that starts to collapse to form the planets. As things collapse it actually starts to spin, and so a disk forms next, and in that disk then you start accumulating enough material through accretion planets are created.

All those orbits are nearly circular. They're not like many of these exoplanet orbits [demonstrates elliptical]. They should be nearly circular. But you can create two huge planets that end up gravitationally interacting. One gets thrown out, and one gets thrown in, and one can get into a highly elliptical orbit. Then the tidal forces from that sun on that planet creates a circular orbit over time to get a huge Jupiter close to its star ever though it was not created at that position. So the first set of exoplanets we started to see were all huge big Jupiters, many on elliptical orbits, but some on very close circular orbits. It's only through gravitational interactions you can evolve those two type of orbits. That gave us the idea also that that must have happened in our own solar system.

When we do the rearrangement of our solar system, the best way it works is that there's a planet that's no longer there that gets thrown out. So for our solar system, there might be another planet, and it might be way out there. That's what many astronomers are looking for right now. They might find, in the next couple years, a brand-new planet the size of Neptune very far from Pluto's orbit.

ROSS-NAZZAL: You've mentioned that planetary science is undergoing a scientific revolution. Is this part of that revolution?

GREEN: This is part of the revolution, yes. When I was in grade school, about everything I learned about the solar system is wrong. Pluto, well it's only one of a whole number of other objects called Kuiper Belt objects. The asteroid belt is a planet trying to come together, and planets in the position they are now were not in the position when they formed. They're moved there. Those sets of ideas occurred in the last 10 to 15 years. It's just been absolutely revolutionary. We have a lot more to learn. We have a lot more to learn about our environment.

Now we know also that not only is this fun and exciting, but it's absolutely essential. If we don't find all the near-Earth objects, we don't know how long this civilization is going to survive. We worry about climate change, but that's not the only thing we need to be worried about, because planetary catastrophes can happen, and we now know that. We see that when we look at Venus.

Venus, we actually do a lot of modeling about Venus. Venus is an Earth-size planet. It's closer to the sun than we are, but not a lot, and yet it's hot enough to melt lead on its surface. There's no water on the surface of Venus. The atmospheric pressure is 90 times our atmospheric surface pressure. Just to give you an idea what that's like, that's like going about 1,000 meters in our ocean. That's crushing depths and for Venus that's just an unbelievable pressure, and it's all atmospheric pressure based on gases that are there. Venus has what we call runaway greenhouse effect.

So concepts about climate change, and in particular how enhancing our carbon dioxide enhances our temperature, is because we know that that's the environment that Venus has today although that is not what Venus started out with. The best climate modelers that actually have been talking about climate change and the amount of carbon dioxide that we are producing on Earth and how it is changing our temperature structure—they were all originally planetary scientists working on Venus. That's where that whole idea came from. Jim [James E.] Hansen made most of his scientific career by Venus modeling.

What happened on Venus can happen on Earth. What's happened on Mars can happen on Earth. By understanding our planets—we're so lucky to have the terrestrial planets that we have, that we actually can look at and model and understand the physics, because it's all about what this planet will evolve into over time.

We live in an instant in time. Every individual's life is really just an instant in the overall billions of years' history of this planet. Right now we're enjoying being in the right place at the right time with the right amount of water. We are the first species that actually has the ability mentally and physically to be able to leave this planet and go elsewhere in the solar system.

Without engineering our own climate, this planet will eventually look like Venus. You can't stop it unless you engineer it differently, unless you do climate engineering. Why is that? Because the temperature of the sun is going to continue to increase. That increases over time, and that's going to heat up this planet, which is then going to melt the ice, which is then going to liberate the trapped methane, and methane is an even worse greenhouse gas than CO_2 [carbon dioxide]. That'll evaporate the oceans, and water vapor is a worse greenhouse gas than CO_2. All that is going to happen to this planet.

We know that by looking at Venus. When we end up looking like Venus, we'd better be on Mars, or this species won't survive. We already know that, based on the science that we've been doing. Planetary science is actually one of those sciences that's really important for the survival of this human race. No question about it. Many people don't understand that.

ROSS-NAZZAL: That's a great elevator pitch.

GREEN: It's true. The difference is planetary science evolves over time, and we're talking about a long range plan for the species. So it's not your kids or your grandkids or their grandkids. It's really the survival of the human race and what that involves. Knowing the environment that this planet is in and how it'll evolve over time is really in the domain of our planetary science field.

ROSS-NAZZAL: You mentioned going to some asteroids. I was curious—our new President [Donald J. Trump] has decided to cancel the Asteroid Redirect Mission [ARM]. Were you working on plans for that mission?

GREEN: No. Actually, that's not my mission. That's human exploration's mission. They were developing a variety of technologies to test, and that's a way to test them. The fact that it's canceled, we'll test them a different way.

One of the things that's being tested is the development of significant ion engines. The ion engines are the ability to take and move a spacecraft great distances over time—getting it in orbit, breaking orbit, and moving the spacecraft to different orbits or even different objects. I'll give you an example. *Star Trek* [science fiction TV show], you have warp drive. The ion engines are not warp drive, they're the impulse drive on Star Trek. We are right now where *Star Trek* is. Let's use our impulse drive. That's the ion engines we're developing. We're just at that stage. We haven't invented warp drive yet. Maybe somebody in the agency is working on it, but I'm not working on it.

We have tested ion engines. The Dawn spacecraft uses ion engines. We launched that in 2007; that was actually one of my first launches when I came to NASA Headquarters. Dawn has already gone to Vesta, gotten into orbit, broken that orbit, and went to another asteroid, the largest asteroid, called Ceres. It's orbiting Ceres right now, and it may have enough fuel to leave Ceres orbit and go to another object. It's that capability, and that's just the small one. ARM was building a much larger spacecraft to carry cargo back and forth to Mars along with crew. Did you see *The Martian* [2015 science fiction film]?

ROSS-NAZZAL: Yes.

GREEN: It's the ion engines that propel *Hermes* [orbital spacecraft in film]. The concept is as *Hermes* was coming in, it fired its engines and did an Earth swingby and went back out, rather than just come in and fall into the atmosphere. That's the scale of the ion engines we're talking about.

Since ARM can't test those, I'm looking at ways where we could use that in planetary science and test them. Even though ARM was canceled, there are a number of technologies that NASA is developing, that we'll just test a different way. That's one thing about NASA, it's very flexible.

ROSS-NAZZAL: You mentioned those ion engines. One of the things that your division used quite a bit for its planetary missions was plutonium to fuel those missions. For a while we were running low, and I understand that you helped create policy and draft that. Can you talk about that effort?

GREEN: Yes, I fixed that. Took me years to do that, by the way.

ROSS-NAZZAL: I imagine that was a very large effort, working with DOE [Department of Energy].

GREEN: The advantages of staying in this position for a long period of time is the timescale to get things done that are of significance to help the community are not short term, they're long term. Plutonium is one of those top things. Plutonium-238 is an atom that has 238 protons in it, and that's why we call it plutonium-[238]. Then if we get a bunch of it together, let's say we get 100 plutonium atoms, in 88 years we'd have only 50. That's called the half-life.

What happens is you look at the nucleus that has 238 protons and watch it, all of a sudden it explodes. It goes from completely stationary to two huge pieces that are moving. That's radioactivity. The ability of an atom not to maintain its structure but to change its structure and generate energy is called radioactivity. Anything radioactive does that, just explodes bam-bam-bam, automatically.

What we do is we develop systems that depend on the decay. That's what it's called, decay. It's not called an explosion, it's called a decay. It changes it from plutonium to something else, neptunium and a helium particle, or other elements that come from that. We get a whole bunch of that material together, then we can calculate how many of those atoms will explode over time. The motion of the decayed products generates energy, and we just wrap it in material that then can take that energy, which would produce heat, because as these particles explode in a metal casing and produce heat, the casing get very hot. Then we take that heat and we charge a battery with it, it's called the thermoelectric effect. You can actually generate a voltage difference on a particular type of material if you can heat it, which then can charge a battery.

Nuclear power to us means gathering this plutonium-238, putting it in machines. We pull it together in little marshmallow-looking objects, and then we encase it in quite an important material, an alloy that'll hold it all together. Once encased, it glows red-hot and then we put it in a larger case, and then we wrap it around. That heat generates power, charges a battery, then we run all our experiments off the battery.

It's like this thing right here [smartphone], runs all day off the battery. Except you charge the battery up at night, right? For us, we don't have to charge it up. All the applications and all the experiments run off the battery all the time. All you have to do is charge the battery. That's all we do. We've been doing this for 40 years. It's just not packaged the same way, but the concept is the same. So we charge a battery, run our experiments.

What was happening is plutonium-238 was a by-product of making bomb material. In the ’50s, ’60s, and ’70s, and a little bit into the ’80s, when the United States was creating material for bombs, one of the products was plutonium-238. So that was extracted. You can’t make a bomb out of plutonium-238, it’s not energetic enough. It’s dangerous, but it’s one of the most easily manageable radioisotopes you can use. It’s relatively safe, if I can say that, to humans, if you manage it right.

You can’t use it to make a bomb, but you can use it to make a long-lived system that can then power spacecraft. That’s great, because places we go where there’s no sun, you’ve got to take your battery with you, and it’s got to be charged all the time.

What’s happened over time is we’ve had so many missions that have used plutonium-238, our stockpile of it was going down and down and down. The SALT [Strategic Arms Limitation Talks] II agreement said, “No one’s making bomb material anymore.” The SALT II agreement said, “Stop making bomb material.” All of a sudden we could not make any more plutonium-238 because that was a by-product of the bomb-making material.

I had to convince the administration. I had to convince my boss—just like starting a mission—and OMB and OSTP and Congress, that there’s a way to make plutonium-238 that’s not the bomb process, but it’s a different process if you allow us to do that. We’ll work with the Department of Energy to implement that. They’re the ones that actually do it; Department of Energy has to do it. They’re the ones that manage our supply of plutonium.

The Department of Energy found a safe way to make the plutonium. We’ve been great partners with them to make new plutonium. The process starts with neptunium. You put it in a reactor, and you irradiate it with neutrons. You can actually create plutonium, and then you extract the plutonium. Once Congress approved it, we’re starting to make plutonium.

Now, although our stockpile of it is going down, it'll start going back up. We finally got Congress to pass a law that allows us to do it. It's not in violation of any treaty. We provide funding to the Department of Energy to manage it and make it for us and stockpile it. That means for decades to come we are good stewards of the planetary program because we'll be able to launch anything in the outer solar system that uses plutonium. Like New Horizons, when it flew by Pluto, it's so far away. You know how far away Pluto is in terms of speed of light?

The moon is so far away that it's two-and-a-half seconds to go from the Earth, bounce a light wave off, and come back. Two-and-a-half seconds, bing, it's back. Pluto is four-and-a-half hours away, or nine hours' two-way travel time. It's that far away. The sun looks like a star at night if you were on Pluto. You walk out at daytime on Pluto, and there's a little bright star and say, "Okay, that's our sun." There's hardly any heat from that star getting to you. There's no way you can use any sunlight. That's what plutonium provides us, the opportunity to take our own power and go.

Although we talk about it as being something we would use to the outer part of our solar system, we actually use it on Mars, because we operate the rover 24 hours a day. It can process stuff at night for instance. Curiosity can move around. It can do all kinds of stuff based on the power that it has, and it doesn't need to be during the daylight hours only. It could be in a blinding dust storm, and we could operate it. Doesn't matter.

Another thing it can do, it can go to the polar cap, like going to Alaska. It's dark most of the time. Particularly during the winter, it's dark all the time. Sun comes up at 2:00 in the morning, goes down at 4:00. If you've ever been to Alaska, that's what happens at a certain time of year. There you also need to take your power.

There's all kinds of missions that we do that can use radioisotope power. You don't have to go to the outer part of the solar system. If we were to get a sample from the planet Mercury, which is so close to the sun it's 700 degrees on its surface, we would use radioisotope power. The reason why is we wouldn't go to the day side to get a sample. We'd go to the night side to get the sample, where it's cool and we actually could land and pick out our sample and then bring it back. That means we'd go to an area where for a long period of time, the sun is not shining and you need plutonium to do that.

So plutonium is really a critical part of our program that we got to have to be able to make planetary science work. It's unique. Earth science doesn't need it, heliophysics doesn't need it, astrophysics doesn't need it. We do.

ROSS-NAZZAL: Were you coming up with new possibilities in case this didn't happen, in case the Senate or Congress said, "We don't want to reestablish that line"?

GREEN: That's a good question. In reality, the options are so few that this was really our only real option. We really had no choice. So year after year after year, from 2006 on, I'd keep working on it. It was around 2011, 2012 that we actually got the approval to keep moving forward and got our congressional okay. Then we had to get the money appropriated. Even though my budget goes down another $50 million I had to give that to Department of Energy to start the process of plutonium.

ROSS-NAZZAL: What impact does that have on your strategic missions or Discovery [Program] missions or some of the other missions you're working on, New Frontiers?

GREEN: We decided to keep our research program going and take all the money out of our future missions. Things that we were going to start, we stopped. We didn't start anything. There's a little hiatus here [demonstrates] in terms of what we started. This curve, if you go like this, this little dip right here are the missions we weren't able to start until later. Our budget has got to come back up before we can start doing them.

This also means that I switch gears from NASA being the prime mission moving forward to partnering more. I did a lot more partnering during that period. Now our partners are BepiColombo [ESA/JAXA (Japan Aerospace Exploration Agency) Mercury orbiter] and ExoMars [ESA/Roscosmos Exobiology on Mars] and JUICE [ESA Jupiter Icy Moons Explorer], and then the [JAXA] Martian Moons Exploration [MMX]. So there's three ESA missions and one JAXA mission, which is the Japanese space agency. That's a partnering block that I stuck right in there. They were moving ahead, and in some cases it took a lot of work to get that going, but they were very receptive. They really came to my aid internationally to help us out and keep my science community getting involved in new missions at a fraction of the cost.

But this dip right here [demonstrates] is due to that. All these would have moved over this way if we had the money. If this was filled in—if this went like this, and then we had this money, all these missions would be here. They'd all be started earlier. But that's how we took that money out of the budget.

ROSS-NAZZAL: Are there any constraints that you found when you work with international partners?

GREEN: Sure, they do things differently. You want to honor your agreements. There was also a time when we had made an agreement, and then the previous administration [under President Barack Obama] forced us to back out of that agreement. That was really hard, I really hated that.

ROSS-NAZZAL: What project or program was that?

GREEN: It turns out it was a Mars program. It was the 2016 ExoMars trace gas orbiter, this one right here. [Demonstrates] This guy right here, we made all kinds of international agreements, but we had to back out of them. Fortunately ESA was kind enough to allow us to keep a piece of it, but we were not very good partners. I hated that. It was not a personal decision I would have ever made. I was forced to make that, and they knew that. They knew it wasn't what I decided, it was what the administration decided. Sometimes you can't see that coming. That's nothing that you can predict necessarily. What was happening is we were making agreements here, our budget was tanking, so the administration forced us to get out of those agreements. But they [ESA] were nice enough to allow us to come back and be part of JUICE.

We really have some tremendous international partners. You can look back on the history of NASA and its relationship to ESA, and there are things that NASA has agreed to in the past that it's had to back out of. That's just part of the business, and you can't take it personally. You have to do everything you can once you make an agreement to honor it no matter what.

When I cut deals like working with all these other missions, I'm going to do everything in my power at my level to honor the decisions we've made to be part of these missions. But I'm not in complete control of it. It'd be nice if I was, but I'm not. There's all kinds of levels above me, not the least of which in the end is Congress has got to appropriate the money to allow us to do that. I can make all the agreements in the world and not get the money from Congress and then I have to back out of them. I don't want to do that, that's terrible, but that does happen, regrettably it happens. That doesn't make us good partners.

ROSS-NAZZAL: What about issues of ITAR [International Traffic in Arms Regulations] or export control? Those ever pop up?

GREEN: Sure, they're part of our business. We have a working arrangement with all the other space agencies about what we build, what they know we build, and then how we interface with what they build, how to launch it, and then manage it and operate it. That's done on a basis that doesn't provide the knowledge of a technology for what we build to that other country, the knowledge of how that technology is actually implemented. We have a number of instruments that we've built that are pretty high-tech that actually have flown on other agency missions. They really don't have the insight as to what's in that box that we deliver. The laws are set up that way for us to make sure that that happens that way. That's what ITAR is. It's part of international traffic in arms. That bill talks about technology transfer, that's why it's called ITAR.

That's an important element of our business, and our Centers know how to work it, they're trained. We have ITAR specialists in this building. Whenever I have a variety of things that we're doing, I consult our ITAR specialists, and I work with our international affairs group so that we get it and do it right.

ROSS-NAZZAL: What's your role in negotiating some of these pieces of hardware or programs, missions, with your international partners?

GREEN: It's me.

ROSS-NAZZAL: No staff?

GREEN: Yes, I get this bear and I bring it into the cabin and my staff has to skin it. That's the story of how that goes.

ROSS-NAZZAL: Can you give an example?

GREEN: Yes, of course. The last one we did is the Martian Moons Exploration mission. It's a Japanese mission. About a year-and-a-half ago when I learned what the Japanese space agency was doing—they're going to go to a moon of Mars that is in our planetary decadal. It's also important for human exploration. I also work quite hard with human exploration, because planetary scientists are actually their guides. We should talk a little bit about that too.

What happens is I approach them in what we call a bilateral. The division heads and my boss, the Associate Administrator of the Science Mission Directorate, arrange every year or so a meeting where we get together with the heads of those agencies and talk about our program. "What are you doing?" "Here's what we're doing." Then begin the discussion of "Well, what can we do together?"

I wanted to get on that JAXA MMX mission right away. So I got involved in it as fast as I could possibly get involved in it, once I knew what they were doing and the importance of that mission. In the end we negotiated that NASA is going to provide basically two instruments for that mission—that actually could be built as one unit—a gamma ray spectrometer and a neutron spectrometer and one sample acquisition system. We have developed and operate many of those type of instruments for which we can actually do it in one box. The Japanese didn't have the experience and capability to do that; that was a perfect thing for us to step into and negotiate to do for them, so we did.

What happens next is once I knew a year-and-a-half or so ago that we're going to be able to be part of this mission, the first thing I do then is start to identify in my future budget, how I'm going to pay for it. I have to identify that once I figure out how the final agreement will go. Then I get approval through the front office, the AA of SMD, and everybody says, "Yea verily, we see that's your wedge." We call it a wedge, a set of money in the future that you're going to use to pay for this instrument. Once you get all that set up, you keep working it, you keep moving forward with it until Congress approves the funding then you have to go get the instrument.

Then you have to write a call for proposals. One of my people, I turned to them a year ago and I said, "You're assigned to write the call for proposals. Let's go get these two instruments." They did that, and that was released in March [2017]. And now proposals will come in, in another couple months, and we'll evaluate them. By fall we'll have already picked who's going to build those instruments, and we'll be part of the JAXA team. It's all about that future planning, it's an element of our future.

What will happen to that mission? We'll deliver the instrument, JAXA will launch it, we'll help track it. There's two moons of Mars. One is called Phobos, the other is called Deimos. They'll survey both of them, they'll get all kinds of data, and then they'll go down and grab a sample and bring the sample back. We want to have a part of that sample. We have the ability to analyze that.

Now we want to know what those moons are. Are they captured asteroids or actually are they accreted Mars material? Where is their origin? Plus getting the knowledge of them is important for human exploration, because one idea is as humans go to Mars they may first stop at one of the moons of Mars, probably Phobos, and then stay there for a little while before they come home. Or actually be on the surface of Phobos and manage and manipulate experiments and rovers on the surface.

There's a whole variety of new ideas being kicked around, so the more we know about Phobos and Deimos the better. This is the mission that's going there, so the train is leaving, and you're either on it or you're not. Once you cut the deal, if you're not part of that mission, you're just watching it. That's somebody else's mission, it's not yours. You have to know what's happening enough to go get it, and that's what we did with that, as the most recent example.

Human exploration is not *Star Trek*. It's not go where no human has gone before. It's not that at all. I love the series just as much as anyone else. But how NASA does human exploration is when they launch and go to the moon, or when they launch something that's going to go to Mars or Phobos or Deimos, they need to know everything about their destination that's possible, because they have to plan for all contingencies and all problems that may occur.

The concept is we're bringing the humans back to Earth. If we weren't bringing them back, we could just go do anything we want and say, "Okay, it's your turn now. Bottom line is they need to know the resources that are there to be used. They need to know what water is there, what minerals are there. They need to know how to land safely and what it takes to return.

There's an enormous amount of stuff human exploration needs to know that planetary science can provide because we are the ones that are collecting that data. I have a spacecraft orbiting Mars right now that's 11 years old. It's called the Mars Reconnaissance Orbiter. The Mars Reconnaissance Orbiter could easily see half this table we're sitting at if it sat down on Mars. Easily, easily. And it's at 400 kilometers in altitude. It has a high resolution camera that then can spot and make images of huge areas on Mars where we actually can land, because we can look at the boulder distribution and we can say that's a safe spot and that's not a safe spot. It's been in orbit for 11 years, and it's made all kinds of fabulous measurements at high resolution. The camera and stuff work all the time. In that length of time we have imaged a total of three percent of the surface. That's it.

ROSS-NAZZAL: That's it?

GREEN: Yes. Mars is a big place. It's a planet; it's huge. One of these days it's going to run out of fuel, and that'll be the end of the mission. What we use it for is not only to do science but to get high-resolution imaging blanketing a whole huge area so that we can create a landing strip, so that we create knowledge of a huge area where we can actually land something. The high-resolution imaging is absolutely essential.

Right now we're doing that to land any of our missions and any ESA missions. ESA uses our high-resolution imaging, too. From an international perspective, I can look at our resources to help another nation. They want to use our resources. I might want to be able to get involved in their mission. It's a quid pro quo arrangement.

We have another high-resolution imaging system called the Lunar Reconnaissance Orbiter (LRO) and that's orbiting the moon. That particular mission can also easily see this table if it's sat on the surface of the moon. In fact, for all those people that believe that humans never set foot on the moon, you actually can see their tracks as they walked out and deployed instruments and came back.

You actually can see where they took their backpacks off and threw them on the ground and walked into the LM [Lunar Module]. You can actually see the lunar rover that they used, and you can actually see where on the moon they actually drove and where they went. We have that imaging data, and LRO has been doing that for six or seven years now, doing great. As more nations are going back to the moon they're going to need that high resolution imaging, and we're the ones that have got it. We can work with them and use that.

As this planet, this species, decides to move out, any space agency—we're going to play an integral role in being able to do that. Our relationship with human exploration, going to Mars, the MRO (Mars Reconnaissance Orbiter) is really quite important, because we started a process of trying to help them find a landing site for humans.

The first thing that happened is they defined a region on Mars called an exploration zone. It's a circular area that's about 200 kilometers in size. In that zone they're going to land in one place. They're going to live in another place, and they're going to tap water resources where they're going to chew up regolith [surface material] and create material for their habitats. They're going to do 3D printing [additive manufacturing process to print three-dimensional objects], go outside, and pull in the martian dust. It's perfect material to do 3D printing. What do you want? You can build something. You can literally print things with the material that's on Mars.

There's all kinds of ways to live off the land on Mars if you pick the right spots. Right now we're looking at about 48 sites on Mars that satisfy both exploration and scientific requirements so that when we go there, they can live off the land and we can also do a variety of science that we want to do, because that's what they're going to do.

This is not like *The Martian* where Mark Watney [astronaut] lived in an area called Ares 3, and he had to go to Ares 4. NASA's plan is we're going to create our site, and we're going to go to that same site over and over for quite a while, for decades. It's not that we're going to continually do one site and then another site and then another site and then another site. Picking the right site first is critical.

I have the resources right now to be able to do that. I can get the mineralogy from orbit. What you get from orbit is reflected light. You can look at material and you can say, "Okay, here's the spectrum of that material." Then the rover goes over, bores a hole in the rock, tastes the rock, and says, "Ah, it's hematite." That's the spectrum of hematite. Anywhere on Mars we see that same spectra, then that's hematite.

Literally, we can map the mineralogy of the planet this way—based on what we call ground truth—comparing orbiter and rover data. It's critical that you take your rovers and you actually go to these places, check them out, figure out what material it is, because it relates to what the orbiter is seeing over the whole planet. The sites that we're considering, we don't have any rovers there, but we know what they are because we know the mineralogy from this ground truth technique. The mineralogy we figured out in a different site, and then applied it to these sites because they have the same spectra.

We do that same process here on Earth. Earth spacecraft, they fly over, they get a spectrum from an area on a farm in Iowa. Somebody goes out to that farm and says, "Ah, it's corn." Everywhere you see this type of spectra, it's got to be corn. Next we fly over other places we can estimate the amount of corn under cultivation. We can determine if that state is going to export it or import it. That's why space is important here on Earth. It gives you a completely different view and a completely different opportunity to bring in information that's critical in managing resources, in surviving. Mars is no different. Of course there's no corn on Mars. There might be a few potatoes left over from what Mark did. Sorry only kidding.

Curiosity is sitting in a location. It's drilled a hole, it's tasted that soil, and that soil has nitrates in it, which is a great fertilizer. In addition to that, that soil is moist. It's got carbon, hydrogen, oxygen, nitrogen, sulfur, and phosphorus. That soil has all the right stuff. You could actually grow crops in the soil on Mars, and we know that right now.

A lot of what's in *The Martian* actually is true. It comes from things that we've been doing all along that Andy Weir [author] just got on the web and said, "Oh, they're doing that now. Good, I'll put that in the book." He must of done something like that anyway.

ROSS-NAZZAL: You mentioned *The Martian*. That was one of the things that I wanted to ask you about. You worked on that. You were involved in that.

GREEN: I did, I was a consultant. It was a blast.

ROSS-NAZZAL: Talk about how you got involved with that and why you thought that that was invaluable to be a part of that production.

GREEN: Andy Weir wrote a book called *The Martian*, and let me back up and say Andy loves science fiction. I now know him pretty well. I didn't know him at all until recently. But he loved science fiction and read a lot. His father had all kinds of science fiction. His father was in the science areas [a physicist]. Andy, when he graduated from college, wanted to be a science fiction writer. He wrote a book called *The Egg*. Didn't do very well. In this business of publishing, if you write something and get it published, it darn well better be spectacular or you don't end up doing much after that. He found out that he's going to have to make a living somewhere else, and it's not going to be writing. He got a computer science degree, so he ended up being a programmer at one of the laboratories out in California.

But Andy couldn't get over the writing bug, so he had to keep writing. The next thing he started was *The Martian*. He had a website. He would write the first chapter and post it and then let anybody read it; it was completely open. He'd get comments, and he'd formulate more ideas of what he wanted to do. He liked the idea of writing it as a serial and liked the idea of getting Mark Watney into trouble and then trying to figure out how to get him out of trouble. He told me at one time he got Mark Watney in so much trouble that it took him two weeks to figure out how to write the next sentence or two. He did a masterful job pulling NASA material off of the web and learning about Mars, because we were doing the research and putting it on the web. I was really delighted how that went.

What happens is he ends up finishing chapter 36 and thought that was it. By that time he had 3,000 people reading this serial website. Some people said, "Andy, can you put it all together as a pdf [portable document format]? I want to put it in my Kindle" [electronic reader].

So he decided, "Okay, here's what I'll do. I'll create an e-book on Amazon [online retailer], so you can log on to Amazon and get it, let's do that."

He found out he had to sell it, which he didn't want to do. You could get it free on his website, but by creating an e-book it was more accessible to many more people. So he did that, he sold it for 99 cents. He got 29 cents; Amazon got the rest. But that was the minimum amount of money that it took.

It wasn't too long after he completed the book that it popped into the number one science fiction purchase on Amazon. Amazon does popular books in any field. You can to go history and you can see this, or science fiction, nonfiction. You can see what the popular books are. This attracted a lot of attention and a book publisher saw it and contacted Andy and said, "Look, I can be your agent. I can broker this into a book deal."

This is really strange when you think about it. What's strange about that is you typically write the book, and then they make an e-book out of it. This way he had the e-book and they wanted to make a hard copy out of it, but by working with a publisher, they wanted to do it in a whole bunch of languages and sell it all over the place. It's that connection that makes it international. If you're going to really break into this industry, that's what you've got to do.

So he said, "Yes, sure. Okay, you're my agent." He started working with Random House [Crown Publishing Group, Random House subsidiary].

Then what happens is a week later Fox Studios [Twentieth Century Fox Film Corporation] is looking for science fiction material, runs across this book, contacts Andy, and says, "We'd like to buy an option for your book. We want to be able to create a contract for which the book is only ours to write a script and create a movie and nobody else. Whether we ever do this or not, it takes it off the market." He agrees to do that, not thinking that it's ever going to go anywhere. It may or may not ever be a movie.

Fox gets the contract. Immediately a guy by the name of Drew [Andrew B. H.] Goddard who writes scripts, is a good scriptwriter, loved the book, and wrote a script for it. He was going to be the director, but what happened was Drew got the opportunity to direct a Marvel [Cinematic Universe superhero] movie. Doing a Marvel movie, you're going to make $100 million at the end of the first weekend. So he jumped at that, and then [director] Ridley Scott walked right in and said, "I'm doing this."

By that time Drew Goddard, who knew [actor] Matt Damon, had already brought Matt Damon on. Ridley interviewed Matt and said, "Okay, you can be Mark Watney. We'll make you Mark Watney." Then Ridley made a whole series of decisions with his team that really was spectacular. The first decision is "We want to make it realistic. We want the look and feel of Mars, how are we going to do that?" You're going to contact somebody at NASA. So Ridley Scott calls NASA Headquarters. In this building is the Office of Communication, OCOMM. In OCOMM there's an individual, his name is Bert Ulrich [multimedia liaison at NASA Headquarters]. I don't know if you've met Bert yet.

Bert handles all the movie and audio industry quarries that want to come and use the meatball [NASA logo] and can't, because we never let anybody do that unless they're approved. You have to go through Bert. Bert talks to Ridley and Ridley says, "Look, I want to talk to somebody about Mars, and I'm going to do this movie called *The Martian*." Bert says, "Okay, I'll organize a time for it."

He comes running down to my office. You know Bert. Bert is this naturally grinny guy that just is so excited. He must have one of the most fun jobs around. I have the funnest job around by the way, so he has the second funnest job. He comes down looking for me, and I'm at the cafeteria. Terri [administrative assistant Theresa Carta] says, "He's downstairs eating."

I meet Bert as I'm coming out of the cafeteria. He comes up to me and he says, "Jim, can you talk to Ridley Scott this afternoon at 2:00?"

I said, "*The* Ridley Scott?"

He said, "Yes, of course, who else would it be?" Right?

I said, "Sure."

I talked to Ridley and his team probably for at least 45 minutes to an hour and answered everything I could answer. Then I would take their questions to get back to them—I believed I knew the answer to these, but I wanted to check it out and get back to them with the best answer. At the end of the conversation, I realized that Ridley is going after a realistic look and feel for the movie, and he really wants to do this as best he could. He sends me the script the next day. I read the first script that Drew Goddard wrote. It was spectacular. This was like on a Wednesday, and by the weekend I went to Amazon and bought Andy's book. It was no longer $1. It was like $15 or something like that.

At the end of the weekend, I'd already read the book and had read the script. The next week, that Monday I went up to Bert and I said, "Look, this is fantastic. I don't know if you've read this, but we've got to get in this. It is the most realistic Mars movie ever. Ridley wants to make it that way, and it's a great script. It's got everything in it that NASA ought to get behind." Bert agreed and OCOMM said, "Okay Jim, go do it. You're now the head contact to Ridley."

I said, "Great, I can handle it." Instead of 12 hours a day, I was working 14 hours.

I started a relationship where we would tour several NASA Centers. The first place I took them was to [NASA] JSC [Johnson Space Center, Houston, Texas]. I called up several people I know at JSC and I said, "We need to organize a tour. Let's go into the Mars hab [habitat] and let's show them what we're really developing, and what the look and feel really is like." We did that.

Then they went to [NASA] JPL [Jet Propulsion Laboratory, Pasadena, California]. We went in the control rooms at JSC so they could see what the human [International] Space Station control rooms looked like, and also the JPL control rooms.

Every week from then on I'd get a glut of questions, I'd get 20 or 30 questions. I'd go down the list and go, "I'm going to answer these, I'm going to farm those out, I'm going to answer these." I would then farm some of those questions out to people I knew who would knew the answer. Over time we just communicated that way, and it worked fantastic. They got what they wanted.

I could see what they were interested in. They wanted to know about ion engines, and they wanted to know about radioisotope power. In fact, to backtrack a little bit, when I first took them to Johnson Space Center, I had already read the book and read the script. The first half hour or 45 minutes I gave them an overview of what Mars looks like relative to the book, and then I made a bunch of suggested changes in the script.

ROSS-NAZZAL: How'd that go over?

GREEN: They were very patient; they listened. I recognized by the end of the day that more than likely nothing was going to change. But it turns out they listened so well, I made three or four suggestions that they actually took, which I was very happy about, very proud about.

But I recognized they'd already written the script, they were already rolling, they weren't going to make major changes in it. It's really all about time and money, and they were on a schedule. Even though you could continue to improve some things as you go along, you've got to call a quit to that and go on.

I know that, because that's what we do when we build missions. If we had a mission on the ground and we kept making it better, hey that's great, but you never get it launched. You've got to say, "This is it, we're building and launching it." That's what they have to do.

That went on June, July, August, September, and at the end of September it quit. That was it. Nothing, I didn't hear anything from them. The reason why is in October they were building sets. They had already scouted out locations in Europe where all the Earth scenes were going to be filmed. All the NASA Headquarters and stuff was filmed in Europe because you could get those places cheaper than you could here in the United States. That's the way it goes these days.

Then in November they got rid of the people in the Earth only scenes and then brought in the *Hermes* crew. Everything done on the *Hermes* was done in November in a studio in [Hungary], a studio in Europe. In late November or early December they brought in Matt Damon, and Matt Damon and the *Hermes* crew did all the stuff that they did together. Then in December they took Matt and went to Jordan, and they filmed all the outside desert scenes in Jordan. Then they started in January putting the movie together.

In September [2015] they released it, and I was invited to the premiere, which was great. I went to the Toronto [International] Film Festival [Canada]. That's where the movie was going to be released and premiered. They invited me, but they had to write orders. I couldn't fly on their jets and I couldn't stay at their hotels, which was above per diem [daily allowance for government travel]. I had all the NASA regulations to follow. That's the way it has to be, so I don't care, that's fine.

The limo [limousine] driver came over to pick me up that night of the premier at 7:00 where the party was going to be, the pre-movie party. Then the movie was going to be at 9:00. The party started at 7:00, but I was running a little late and I didn't get out there right away. I was really mad at myself. I thought "Geez, how could I be late to this party? My God, what's going on?"

It was like 7:10 when I got there, and I walked in. The party started at 7:00, and I was the only one there other than the servers! I thought okay, this is Hollywood time. I'm really doing great, so I go over to the potato bar. They have mashed potatoes and you could make your own dish will all kinds of condiments. I had servers just shoving food in my face. I never turn down that kind of environment, so I was having a great time.

What I wanted to do was talk to Matt Damon. I hadn't talked to Matt Damon at this point. People were filtering in. Andy came in with his mother and his fiancée, and then Ridley and more of the team came in, and it was great. We were chit-chatting and having a good time. How this was going to go—I don't know if it was 8:30, or maybe it was 9:00 because the movie started, maybe it was at 10:00.

They came to get me—they would come every 10 minutes and pick up somebody to take him over to the red carpet. I was going to walk the red carpet. "What do you mean I was going to walk the red carpet? I just want to see the darn movie." I'd already seen it about three times at various stages of completeness. But they come pick me up, so I was at one end of the large reception room. They came in and got me, and I'm walking through all the crowds as I'm trying to go through it, and then Matt Damon walks in.

He walks in, he gets in about 20 feet, he's absolutely surrounded by people, just mobbed by people. "Okay, there goes my opportunity to talk to Matt Damon, that's the way that goes." As I was walking by him, the crowd opened up a little bit, and I thought "Okay, this is my chance," so I stepped in and I introduced myself. I said I was one of the consultants on the film.

I pull out a NASA meatball, and I give Matt Damon a NASA meatball [pin]. "Oh, this is great." I opened it for him, and I put it on. He wore that that night, and any interview that he gave with the movie that night, he had the meatball. He did a bunch of them that night. You could tell he had the meatball on. That meatball is our sign that says NASA.

I get over there, and the red carpet is in the shape of an L. You walk down one part and these are all photographers [demonstrates], and then you walk down the other part and these are all reporters. The door opens up and oh my God. I step out, the crowd yells, and I think to myself, "You don't even have any idea what you're doing."

ROSS-NAZZAL: They ask you, "What are you wearing?"

GREEN: Fortunately I had my best suit on, which was fine. But I thought "God, this is crazy. Do I do ingénue [pose]? What do I do?" I've got to pose now. I'm walking down this long gauntlet. At the very corner, just before I turn to go talk to reporters are the NASA photographers.

ROSS-NAZZAL: We need a picture of this for this interview.

GREEN: I know exactly the one to show you. I get down there and I'm making this turn. They go, "Jim." I turn, I see them, there's Bill [Ingalls] and there's all my NASA photographers. I go, "Yeah!" I just did that [thumbs up gesture]. I didn't even think that that was in the movie, but Matt Damon does that. As soon as I do that, flashbulbs everywhere were going, all up and down the line.

I thought Jesus, "If I'd known that I would have walked on doing that the whole way." I didn't know what to do. Totally unskilled in runway anything, never advised on anything. Then I walked down and gave these interviews, and that was great. As I was doing this, you'd hear the crowd go, "Yeah!" Somebody else would be behind me and then somebody else and somebody else.

I get down at the end of the reporter line, and then I'm going to go into the greenroom [waiting area]. I'm looking down where the reporters are, and they're all the major cast members there. They're all being interviewed. It's really neat; it was very nice. I go into the greenroom, first one in the greenroom. They've got all this food. There's Milk Duds and popcorn, all this movie stuff.

I go over and I'm just having popcorn, just eating up a storm. I don't know what else to do, waiting for people to come in. Andy comes in and [actor] Jeff Daniels comes in. I hadn't talked to Jeff. I went over to Jeff, and he and I had a nice conversation. I said, "One of the movies I really loved you in"—and I could see it on his face, he's thinking, "Don't say *Dumb & Dumber*"—and I said, "was *Gettysburg*." He really lit up. We had a great conversation on *Gettysburg* because I like Civil War [history]. That was really nice.

By that time everybody was in the room, and they were trying to escort us out. We got out of the room, and then I ran into [actor] Patrick Stewart. I had a wonderful chat with Patrick

Stewart, who was there for a premiere of another movie that he had made. But he didn't go to that, I found out later he went to this one.

Then we sit down, and the theater is huge. You've got the main floor and then you've got a balcony. The balcony has three sections, and I'm in the right side. All the stars are in the middle, and others are on the other side. Place is absolutely packed, must be 2,000 people in this. I get my seat, I've got a number, and I'm sitting down, just chatting with people. There's astronauts and people I know I was talking to.

On the screen, they're filming what's happening up and down the red carpet, so you can see [actress] Jessica Chastain coming in. You can see Matt Damon. Matt Damon is there; he's got his meatball on. That was fun. Then finally when he makes it there, then Ridley and his team are on the stage. Ridley says a few things, and they go back, and then we watch the movie. That was great.

The next day we had interviews all day long. I was on panels with Ridley, and I was on panels with Andy Weir and Matt Damon. I had a great time. Matt was just wonderful, just wonderful to talk to. We had come in and there was a panel with a bunch of reporters, and it was myself and Ridley, and on the other side of him was Andy Weir. They were just really super people. Really a class act.

JOHNSON: Great PR [public relations] for NASA.

ROSS-NAZZAL: That's what I was thinking.

GREEN: They were. I knew it. I could tell as soon as I read that script. I thought "Man, we've got to get involved in this. Really do."

I have a presentation. It's called "*The Martian*: Science Fiction and Science Fact." I've given it all over the world, from Beijing, to Canada, in the U.S., to Tokyo, to England, to Germany. Whenever I'm abroad and they know I'm there, they grab me and I end up giving it. I've been all over the place with it. It's unbelievable.

ROSS-NAZZAL: What a great opportunity.

GREEN: It really was. It's got a little bit of the backstory, but it also compares what we really know about Mars and how they implemented it. That's what makes it fun. NASA approves the use of the meatball and also provides the ability for consultants and people in NASA to work with film producers. It doesn't happen a lot, but there's a lot of civil servants that get involved in that.

For instance, at least one or two people in my organization have been consultants on several films. But they haven't been as popular as *The Martian*. This was the very first one I did. If there was ever one to be on, this was it.

ROSS-NAZZAL: I think it was the best Mars film, like you said, I've seen. I've seen a lot of Mars films. I was going through them as you were talking, and I thought yes.

GREEN: I do too.

JOHNSON: The book was good.

ROSS-NAZZAL: The book was excellent, too.

GREEN: The book was good, yes. Right.

ROSS-NAZZAL: The book was hilarious, especially the comment about duct tape, something NASA couldn't improve on.

GREEN: One thing I wanted them to do they didn't do in the film was flip the rover. He flips the rover getting in Schiaparelli [Mars crater]. That would have been great to do, but they just ran out of time.

ROSS-NAZZAL: You can't put everything in.

GREEN: Which is too bad, can't do everything. Another thing I wanted them to do that they didn't do was in the end scene where Mark talks to the class. Early on in the movie he's out in the field and he's collecting samples, and he puts one sample in this little container. He talks about oh, the graininess, etc., etc. They have this banter back and forth while they're deploying instruments.

What I wanted them to do is when he leaves Ares 3 to go to Ares 4—he almost walks out of the hab without his helmet. He walks back in to get the helmet, and there's that sample container. I wanted him to pick it up and take it with him. Then at the end of the movie where he's at the class, and at the end of the class the kids are all filing out, and somebody comes in and says, "You've got to come downstairs in the lab, it's about your sample." Then end the movie there.

ROSS-NAZZAL: Oh.

JOHNSON: That would have been good.

GREEN: That would have been great, because it's all about sample return. Which is Mars 2020, it's bringing back the samples. That's the next thing we have to do in this next decade, develop the missions and the capability to bring the samples back. This mission called Mars 2020 is going to core rock, put them in sleeves, and then we're going to pick them up and bring them back. I wanted sample return to be a theme in the movie. I was driven to do that, but it didn't go anywhere.

ROSS-NAZZAL: You tried.

GREEN: I tried. It was a great idea, didn't happen.

ROSS-NAZZAL: I think this might be a good time to end. Thank you for taking so much of your afternoon and sharing this.

GREEN: It was fun. Hope you got everything you needed.

[End of interview]