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STEVEN W. SQUYRES
INTERVIEWED BY SANDRA JOHNSON
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JOHNSON: Today is September 14, 2017. This interview with Dr. Steven Squyres is being conducted for the NASA Headquarters Science Mission Directorate Oral History Project. Dr. Squyres is speaking with us today by telephone from New York and the interviewer is Sandra Johnson. I want to thank you again for joining us for your second interview. We really appreciate you taking time out of your busy schedule.

SQUYRES: I'm glad to do it.

JOHNSON: Last time we did talk a little bit about the Mars Exploration Rover mission [Spirit and Opportunity rovers]. So much of it is documented in your book, but one of the things I wanted to touch on—as a geologist, and designated as the lead scientist for these missions, part of what you did was negotiate with engineers. You worked with a variety of people to get those missions ready to go in a short period of time. It was an intense period of time. I was wondering if you could talk about the team, and how you worked with the variety of people that it took to get those going.

SQUYRES: Sure. As you say, the schedule was brutally tight. Between when the project was formally constituted and when we had to be on top of the rockets in Florida was about 34

months. Given the complexity of the task that we faced, which we underestimated from the start—it was actually harder than we thought it was going to be—but given the complexity of the task that we faced, I think a prudent amount of time for the job would have been maybe something like 48 months.

The schedule was terribly, terribly tight. That, plus the fact that our mission had been born as a response to a couple of very unfortunate mission failures that had gone before, put the team under even more pressure than teams normally face. Even under the best of circumstances, a mission to Mars is a pretty high-visibility, high-stakes game. Then this just compounded that.

You mentioned that the interactions involved scientists and engineers. Scientists and engineers come at this sort of thing somewhat differently. The scientists, if they think about it purely from the standpoint of the science, are interested in learning what happened on Mars. I've always said scientists are seekers of truth. They want to understand what happened or understand the nature of the universe in some way.

Engineers, on the other hand, have to make it work. They've got to actually build something that will do a specific job and not fail. The interaction between scientists and engineers is a very interesting thing. It's a critical part of these projects, and it can be wonderful or it can be kind of confrontational.

One of the things that I think I'm proudest of about the Mars Exploration Rover project—and I give an enormous amount of the credit for this to Pete [Peter C.] Theisinger, who was the project manager and an engineer by training. But I think we did as good a job of breaking down the communication barriers and the cultural barriers, if you will, between engineering and science than on any project I've been part of. It really, really went well.

It was bumpy at first, as these things can be. But Pete intuitively, instinctively realized that our mission was engineering in the cause of science, and that it was going to work best if the engineers and the scientists worked well together. I was of a common mind with Pete on that. I had seen past projects that I'd been in that tended to be on the confrontational side between the scientists and the engineers. The scientists saying, "Oh, those damn engineers won't let us do this, won't let us do that." The engineers saying, "Oh man, you've got to watch those scientists, they'll try to get away with everything."

The reality is that we're all striving towards the same goal, but we all have our own set of priorities. It's really simple, but if you simply take the time and put in the effort to understand where the other side is coming from—scientists learning some engineering, engineers learning about the science—if you simply put some time and effort into that, you can dissolve away those barriers in very effective ways. And rather than a confrontational atmosphere between science and engineering, build a very collaborative and trusting one.

We worked really hard to do that on MER. Pete did, I did. I would hammer into the scientists on my team, "Look guys, we don't get any science if the engineering isn't good, and we're going to get better science if we understand this vehicle." It's a tightly integrated system.

The science systems don't exist in a vacuum. They are mounted on this vehicle with deployment devices, and all kinds of constraints. The same electrical power that we use to take pictures is the electrical power that we use to drive, is the electrical power that we use to heat the actuators and keep the electronics warm at night. There's only so much to go around, and if any of those things fail we don't get our science.

So let's start thinking as a team, not as a team of scientists and a team of engineers, but a project team. That was really fundamental to what we tried to do on MER. This is something

that Pete and I were working on 15 years ago before we launched, trying to build this into the DNA of our project.

But I'll bet you, if you today sat down and listened to one of our integrated sequence team meetings—the meetings where the scientists and the engineers get together and come up with the commands that are going to go to the vehicle to make it execute its tasks on the coming day—you'd have to sit in that room or sit on that phone line and pay attention really hard for quite a while before you would even figure out who were the scientists and who were the engineers. I think you'd have a hard time telling the difference for a while.

Eventually you'd probably work it out. But we've got scientists who think like engineers, we've got engineers who think like scientists. Some of our best suggestions for science observations now come from the engineers, because they're motivated to do good science, because they're into it, they're interested. They understand the vehicle really well and they know what it can do and what it can't do.

Sometimes we get some of the best science suggestions from the engineers. Then also what'll happen is we'll have some kind of engineering problem come up where the engineers will turn to the scientists for help, because the science team might include the people who best understand how the wheels interact with the soil or what have you. It's become a very integrated—we don't separate the science and engineering the way a lot of projects—well, the way projects sometimes do. I feel like we've blended them in a very efficient and effective sort of way.

JOHNSON: Obviously, you've been involved since the beginning, but are there a lot of the same people still working on these teams?

SQUYRES: That's an interesting question. The reason that's an interesting question is because the culture of the project. Every space project has its own project culture, its own project personality. The thing that's interesting to me—I've seen this many times, I've been doing this since the '70s and Voyager—is that once a project takes on a certain culture, takes on a certain personality, it tends to persist even as you have turnover in the personnel, which is interesting.

On MER [Mars Exploration Rovers], there are a handful of us who've been with the project from the very start. Generally speaking, there has been, I would say, less turnover on the science team than on the engineering team. But despite the fact that there's been quite a bit of turnover across the project, the project's basic feel and personality and culture has remained fairly constant. That's because you don't turn over everybody at once. You don't all of a sudden clear the room, everybody leaves the project, and a whole bunch of new people come on. New people come on one at a time, and they learn the ropes. They get the feel of the project from the people who've already been there, and so there's this passing down from generation to generation of the MER way of doing things. It really has persisted despite the fact that there has been quite a bit of turnover.

JOHNSON: Yes, that's interesting. I was wondering because it's such a long-term project if some of that feeling, or that team, or that culture that team had, came because people had worked together for so long. But it sounds like the culture was there and it's just worked its way through the team.

SQUYRES: Yes, I think it has persisted despite the turnover. There have been a few people—I'm one of them—that have been there from the start, and we still try to set the tone. If you see anybody who's not quite with the program, somebody whose prior experiences, say, are on a project where the interaction between engineering and science was more confrontational—if it's one of the scientists, I'll take them aside and just have a little chat. If it's on the engineering side, one of the more experienced engineers who's been at it for a while will have a little chat with them, and make them understand that "That's not how we do things here, and let's work together on this." So it's not something you have to police or enforce, it's actually happened very naturally.

JOHNSON: Is this something that you've seen, or been able to take to other projects that you've worked on? This type of relationship?

SQUYRES: I've tried to, yes, very much so. Very much so. Once you've experienced a project where the interactions are for the most part positive, and things work the way you would like them to, you definitely try to carry that on to other projects you're involved in. The tone, the feel of the project tends to initially be set by a small number of people right at the top of the project.

Like I said, MER, tons of credit to Pete Theisinger. He was the project manager all the way through launch and landing. He was the project manager, his word was law, and he set the tone, he really did. So I give him an enormous amount of credit for what still persists today.

JOHNSON: While we're still talking about that, let's talk about some of the big moments with these landers and these rovers. First of all, when they made it to Mars, and then also when you first started seeing the images coming back.

SQUYRES: Yes, sure. The big moments for me were maybe a little different than what constitutes the big moments for a lot of people. Let's go through three obvious big ones, none of which are my biggest one. One is launch, one is landing, one is when you start seeing the first pictures. I will describe each of those for you.

Launch wasn't anything like what I expected it to be. My experience of launch, just in terms of my feelings and how I perceived it, was dramatically different from the way I had always pictured it. I had always pictured launch as this triumphant moment where after years of struggle—writing proposals and building hardware and testing hardware and having calamities and figuring out solutions and solving them—you finally get to the launchpad, and you're ready to go into space and you fire it off, and it's this beautiful glorious triumphant moment. Wasn't like that at all. Was not like that at all.

As you mentioned at the start of our discussion today, our schedule was brutally tight. We were constantly talking about what tests we had enough time to do and what testing we were going to have to cut out. We had a set of tests that we called the "incompressible test list," and every test on that list had to be done before we launched, and if it wasn't, we didn't launch. But then there was a long, long, long list of other tests we wanted to do to gain more knowledge, to gain more confidence, to be more ready to operate when we got on Mars. There's a bunch of tests we didn't have time for.

When we launched them, I didn't feel like we were done. It was frightening. We had done the best we could. We had done the very best we could to make the best vehicles that we could. We had done due diligence, we had done all the incompressible test list tests. We felt that that was enough, but man it was not a comfortable feeling. It was not a comfortable feeling shooting those things off into space, because we could have been a lot more ready than we were. But it gets to be time to launch and you have to launch.

The other thing—and this was really weird, this I did not see coming at all—it was hard to say goodbye. That sounds strange right, because we build them to go to Mars, but you pour so much of yourself into these machines. Your hopes, your aspirations, your dreams, your ambitions. You work with them and you bring them to life slowly, laboriously, and you turn them from a concept into these functioning, almost living, sorts of things. You touch them and you caress them and you baby them. They're so important to you.

Then man, you strap it on top of a rocket and you shoot it off into space and it's as gone as anything's ever going to be. Even though Mars was where we wanted them to be, I found it a little hard to let go. I wasn't ready to say goodbye. I wasn't ready to let them—it's like when your kid goes off to college or something. You're just not quite ready for it, but it's time. I didn't anticipate that aspect of launch at all.

Now landing—landing was exciting. It was one of those frightening events where things can go terribly wrong. I saw landing as a necessary step, like launch, where there was potential for disaster that we had to get through. But it was just one event along the way.

Our rover—when it's perched on a lander and can't drive, is not a very good exploration vehicle. You can't reach the soil, you can't touch it. Four of the six instruments won't function at all. All you can see is the terrain around you. So landing was a necessary step. Maybe the

equivalent for an orbital mission would be orbit insertion. Yes, it has to happen, but it's not the big event.

Getting the first data down—honestly, I remember that really well. When the first data from Spirit starts coming down and the pictures are coming in, and they look great—and I'm a planetary scientist, I should be looking at the geology—all I could think was, "Oh my god, it all works!" I was just so thrilled that all this hardware was working the way it was supposed to. For the Spirit landing, it really took tens of minutes before I started to pay any attention at all to what was in the scene, because I was just so focused on the fact that these cameras and actuators and all this hardware that we had built—the software, everything—was actually working. That was just a wonderful feeling.

On the Opportunity landing it was a little different for two reasons. One, Spirit had already landed, so I'd been through that once. The hardware on Spirit worked, so it ought to work on Opportunity too. But the other thing was the Opportunity landing site was so crazy-looking that I got sucked into the geology much more quickly.

To me though, the big event—the most important event of the entire mission from its very beginnings until today, the one event that meant more to me than anything else—was Spirit's sol [Mars solar day] 12. Spirit's sol 12 was when we drove the Spirit rover off of the lander and we had six wheels in the dirt on Mars. It had been 16 years from when I had first begun on the path of trying to make something like this happen until that moment. Now, 16 years later, I had six wheels in the dirt on Mars and we were ready to really start exploring. That was the moment for me. It went sort of unnoticed I think by a lot of people, but to me a rover that's perched on a lander and can't get off—we had to get off, we had to get our wheels in the dirt. At that point we're ready to explore Mars, and that, to me, was the critical moment.

JOHNSON: Those wheels were representing your boots in a way.

SQUYRES: Everybody's boots, we were ready to explore.

JOHNSON: The ultimate goal was to explore, and you couldn't do that on the lander, that's for sure. It's a different perspective, too. The rest of the world is waiting for photos, and you're waiting for the dirt.

SQUYRES: The whole thing is all about moving. It's about moving around. Imagine you're a geologist and somebody transports you to this wonderful new site where you're ready to explore new stuff, and then they nail your boots to the ground, you can't move. That's what we were until we got off the lander.

JOHNSON: One other thing I wanted to talk about—we touched on it the last time—about the fact that you do a lot of speaking about the rovers to the public. We talked some about your work with Carl [E.] Sagan and how he truly believed that that was important. But part of what you did—and this is just an interesting aside—being a scientist, being a planetary geologist, you had the opportunity to go on a variety of media events or shows. *The Colbert Report* [television show]—that's not where you would expect to be, someone in your position I would think, in your career, ever think you'd be on a comedy show.

SQUYRES: That was a funny—that was a really enjoyable experience, yes. The thing about a Mars rover mission is because it's so accessible, it's easy for anyone to understand. It's a robot driving around looking at rocks, doing geology, trying to figure out what Mars is like.

Another thing about the rovers is they're so humanlike in their behavior and their scale. They're about five feet tall. They've got an arm, they can move around, 20/20 vision. They're a lot like a human. That human connection to the robotic mission is so powerful for a mission like MER that it gives us a special opportunity, and I think as I said last time a special responsibility, to share that with the public in whatever way comes along.

Yes, I got invited to be on *The Colbert Report*, and Stephen Colbert on that show played a particular kind of character, particular sort of newsperson. But there was always a thoughtfulness to that show that, underneath the comedy aspects of it, there were thoughtful points being made. It was a show that I enjoyed watching, and so when I got the invitation, well, "Yeah sure, let's go ahead and do this."

It was fun. One of the first things that the producers say to you is, "Don't try to be funny. That's not your job. Stephen is the funny one, you just play it straight." Of course a big part of their shtick was interviewing people and getting them off-kilter, coming at you with crazy questions. They wouldn't give you the slightest hint what question was coming. They didn't say a word about what you were going to be asked about, because part of their thing is to get people a little off-balance.

I just had a ball. I couldn't stop laughing the whole time, it was really funny. I talked to Stephen Colbert in the green room before the show started, and in person he is completely different from the character that he played on that show. Very intelligent, very, very thoughtful,

big fan of the space program. We had a nice conversation. But yes, that was a lot of fun, and it was a chance through a completely different communication channel.

If you look at the interview—even though there was a lot of goofy stuff going on and a lot of funny questions being asked and I was laughing the whole time—what the mission was all about and what we discovered, all that came through. It was a chance to do it in a different way. It reaches a different audience. Everybody in that audiences paid taxes to help make that mission happen, so it's just another channel to let people know what they got for that investment.

JOHNSON: I can imagine it was quite different from, say, *60 Minutes* or *Nova* or some of the other opportunities you had.

SQUYRES: Oh yes, it's quite different. But in its own way just as effective, and a heck of a lot of fun.

JOHNSON: Do you enjoy that part? Obviously you enjoyed that one, but some of the others, like *60 Minutes* or *Nova*, or any of the ones that are more of a mass audience instead of, say, at a conference or smaller market.

SQUYRES: I do enjoy it. I do it out of a sense of responsibility, it's part of the job that I signed up for. But yes, I do enjoy it. I like teaching. I teach courses at Cornell that have 200, 300 students sometimes. I enjoy taking the stuff that I feel passionate about and sharing it with people. That's fun for me.

If I had to go on television and get interviewed about something I didn't care about or some topic I wasn't happy about, that would not be any fun, no. But getting to share something I'm deeply passionate about with people, yes, what's wrong with that? That's fun.

JOHNSON: I bet it would be. Because of that you actually won an award in 2009, the Carl Sagan Medal [for Excellence in Public Communication in Planetary Science] of the American Astronomical Society. They recognized you as a planetary scientist for excellence in public communication. Knowing him, and knowing that that was important to him and then to win that prize, I would imagine would be amazing.

SQUYRES: That was a good feeling, just because that award was inspired by Carl and named after him. To be one of the many recipients of that was a real honor.

JOHNSON: We talked about some of the other things that you were an investigator on, some of the other missions. There were a few that we didn't really discuss I thought maybe you might want to mention a few things about. One of them was the Mars Express mission in 2003 for ESA [European Space Agency]. You were a coinvestigator on the High Resolution Stereo Camera.

SQUYRES: Both that and the Cassini mission to Saturn—my participation in those two were effectively casualties of the long life of the MER mission. All of those happened in more or less the same timeframe, 2003, 2004. I thought we'd get more than three months—I thought we'd get six months, maybe a year out of Spirit and Opportunity. And then once that was done and

we wrote some papers, then I would be able to turn my attention to these other missions, Cassini and Mars Express, that I was involved in.

That opportunity never came. So while I was originally part of those teams and made the contributions I could make during the formulation phases of those missions, once they actually arrived at the destinations and started doing science, I was still so busy with the rovers that I didn't have much opportunity to participate. Unfortunately, my participation in those two missions and also the Mars Reconnaissance Orbiter—that's another one—has been very, very limited. Simply because the rovers have lasted so much longer than ever anticipated.

JOHNSON: Is that the same with Odyssey also?

SQUYRES: Yes, Mars Odyssey is another one. I was more involved in that one than I was in some of the others. But all of them, my participation wound up being much more limited than I would have liked it to be, simply because my role in the rover mission is of course very different. All those other missions, I'm a coinvestigator. I'm one of many making small contributions to the project, that's the idea. Whereas the role that I have on MER is all-consuming. It didn't end when I thought, hasn't ended yet. We're doing flight operations tomorrow.

JOHNSON: One that is coming to the end right now is Cassini, which is pretty interesting.

SQUYRES: Yes. What a magnificent mission that has been. Just hats off, man. That has been absolutely spectacular in every way. Just a brilliant piece of work.

JOHNSON: It really has, just unbelievable.

SQUYRES: Going out in style, too. It's great.

JOHNSON: Yes, definitely. One of the things, I guess we can talk about it—I'm not sure exactly what your involvement has been, other than with the decadal study, but the research on the habitability or the existence of liquid water on Europa.

SQUYRES: Oh, yes. That goes way back for me. This goes way, way, way back to early '80s. I did my PhD thesis on two of the other moons in the Jupiter system, Ganymede and Callisto, and I was always fascinated by Europa.

As we discussed last time, after I completed my PhD and I was deciding where to go for a postdoc [doctoral fellowship], I was so impressed by the work that had been done by this group at NASA Ames [Research Center, Moffett Field, California] and University of California at Santa Barbara predicting volcanic activity on Io, another one of Jupiter's moons, that I thought I wanted to go out and work with those guys. You surround yourself with really smart people, and good things can happen to you.

So my postdoc was at NASA Ames out on the West Coast. One of the very first things that we did when I got there was go ahead and apply that same tidal heating theory to Europa. Europa is a more difficult case because the amount of the heating is less, and there are other heat transport processes like convection and the ice that you have to worry about. But we delved into that, and one of our findings, which was a paper that we published in *Nature* [scientific journal], gosh, like the first or second year I was at Ames, was a theoretical prediction that there would be

a liquid-water ocean underneath the crust of the ice on Europa. Published that paper, provided a little bit—what there was at the time, not much at the time—in the way of observational evidence for that notion. Did another paper about the potential habitability of that ocean. So I was involved right at the start in the discussions of whether or not Europa might be a place that would harbor life in a potential ocean.

What then happened was I got distracted, not too long after that, by Mars rovers. Basically, I wanted to build hardware and fly something. If I could have figured out then and there in the early ’80s how to do a submarine on Europa I wouldn’t have done rovers on Mars, because a Europa submarine was even more exciting. But I just didn’t see a pathway to doing that. It was so hard and so complicated. That’s the reason it hasn’t happened yet.

I’m eating healthy foods, I’m getting lots of exercise, I’m hoping to live long enough to see it. But I’m 61 years old now and it hasn’t happened. It was very evident to me that of the science questions I was passionate about—“Was Europa, and is Europa habitable?”, “Was Mars, is Mars habitable?”—those were the science questions that drove me, that I was passionate about, and I didn’t want to just study them theoretically.

I’d been doing theoretical calculations for Europa, I’d been doing theoretical calculations for Mars. It was all well and good, but I wanted data, I wanted hardware, I wanted to help build something that would go there and answer a meaningful question. The timeframe that I was looking at, sitting there in the early ’80s and looking at the technology of the day and looking forward, Europa was just too far in the future for me.

Whereas the Mars habitability question with a rover looked like it might be achievable in the core part of my career, so that was the direction I went. So after writing a few papers about Europa very, very early, I turned away from it and went to Mars instead.

JOHNSON: Since Europa really had something to do with the decadal studies that you were a part of, let's talk about that for a while. You were the chair of the Space Studies Board's planetary science decadal survey. The report came out in 2011.

SQUYRES: Yes, 2011, 2012, that timeframe.

JOHNSON: Part of your job, of course, was presenting that at different conferences.

SQUYRES: Yes, it was. Let's talk about the decadal thing. I was the chair for the second planetary decadal survey, but it would be misleading to read too much into that. The decadal survey is a community-wide process. The decadal survey process was something that the U.S. astrophysics community invented back in like the '60s. What they recognized was that if the science community banded together—I cannot overemphasize the importance of consensus building. That's what a decadal survey is all about, building consensus. It's helping a community of hundreds or maybe thousands of highly opinionated individuals come together with a set of priorities that they can all get behind and speak with one voice.

The astrophysics community began this, like I said, back in the '60s. They started doing these, they came up with it themselves, and one of the things that they advocated was what eventually became the Great Observatories. Hubble [Space Telescope], Chandra [X-ray Observatory], Compton [Gamma Ray] Observatory—all of those were missions that came about as a consequence of the astrophysics decadals.

With the success of the astrophysics decadals, other science communities kind of took note and became interested in doing the same thing. The first planetary decadal was 10 years before the one that I was involved in. That one came up with a set of recommendations.

Basically what it is, it's a community-wide consensus on what should be the priorities for space missions to be flown by NASA, plus research and analysis and technology development—basically the whole program in that particular area of science. It's the planetary science community, as a whole, once every 10 years telling NASA, "Here's what we the scientists think should be the priorities in broad strokes."

I got asked to chair the second planetary decadal, and it was a wonderful experience. It was a lot of work, it was a lot of work. It's a big document. Let's see if I've got it here on my desk. Let me take a look, 379 pages. So it's a big document that attempts to give NASA actionable advice on how they should conduct their planetary program for the next 10 years. It's really a process of trying to establish consensus within the community.

I won't bother going into all the details of the steering committee and all the different committees and how it's all organized, you can go and look that up. But basically it's establishing a set of groups that then reach out to their peers in town halls, white papers, bringing people in to give presentations at meetings—every kind of interaction that we can to get good ideas from—and then discuss those ideas and try to come to consensus about what are the really potentially productive ones.

Then this is the most interesting part, and this for me was the most fun part. One of the parts of doing planetary missions that I've always enjoyed the most is the part they call "blank sheet of paper." You start off with an idea, "I want to put a lander on Venus," or "I want to fly a spacecraft into orbit around Neptune," or whatever.

Then you actually have to turn that into something tangible, something executable. What's the technology that you need? Can you do it on the schedule that you want to do it on? What are the instruments that you want to fly? How much is the thing going to cost? Where do the risks lie?

You need to understand all that before you can take this concept—you got a blank piece of paper in front of you and a one-sentence concept. "I want to put a lander on Venus." Then you start writing it down. You define it to a sufficient degree of detail that you can actually assess probability of success, likelihood of what the science return is going to be, probable cost, etc.

I've always found that early phase of a planetary mission concept to be particularly interesting because it's the part that involves so many challenges and decisions. We did that for about 25 different missions. All our work was funded by NASA. NASA deserves enormous credit for doing that. It was millions of dollars. We conducted studies for about two dozen missions so that we could assess the science return, assess the costs, and so forth.

In the end, we produced a document that described the primary findings. The big-ticket items, the items that were the highest priority, flagship-class missions that we recommended for the decade were actually the same ones that had been recommended by the previous decadal, and neither one had happened.

One of them was a rover to Mars to collect a suite of samples to actually be brought back to Earth someday. The other was a mission to Europa to investigate the putative Europa ocean. And both of those have been funded, both of those are under way. One of them is Mars 2020, the other is Europa Clipper.

A lot of credit goes to the community for maintaining that consistency of message from one decade to the next. The science priorities don't change that much with the blowing political winds. "This is what's important." It was important 10 years ago, it's important today, it's going to be important 10 years from now. That consistency of message was, I think, a big part of what helped the astrophysics community get their Great Observatories back in the '60s and '70s and onward, and it's worked out okay for the planetary community as well.

You get in this business a lot of committees, lots of committees. Something about scientists is they love to form committees. You get asked to serve on all kinds of these things, and they're all worthwhile to varying degrees. But the decadal was one where I really, really felt like my time was being well spent, like what we were doing was going to matter. I was glad to be asked to do it, I was glad to be part of it. I'm proud of the result that we came up with. I'm happy with the way NASA has responded to it.

JOHNSON: How much time did it take? How long were you on that?

SQUYRES: The real work was concentrated in a period of a couple of years, and it took up a big fraction of my time. I couldn't tell you what percentage, but it was tens of percent of my time for that period. But like I say, it was worth it.

I've got to say it was fun, once we were done, presenting it. It's done under the auspices of the National Academy of Sciences. One of the things about having this be a National Academy report is that it puts the full weight of the Academy behind what we've said. Having that National Academy of Sciences stamp of approval on what you've done really gives a lot of heft.

At the same time, as you would expect, the process of writing an Academy-approved report—there's a lot of reviews, there's an enormous amount of rigor, you're subjected to just real, real detailed scrutiny of everything that you've written. As you should be, but that really adds to the workload.

The interesting thing is that while the process of interacting with the community and getting the community inputs and trying to come to a consensus—while that's a very out-in-the-open kind of process, once the work is done and it's time to write it all down, the way the Academy operates, it sort of goes behind a curtain.

Nobody is quite sure what you're going to say, so there's this moment of unveiling that took place, in the case of our decadal, at the annual Lunar and Planetary Science Conference down in Houston. After laboring behind the scenes for months on this thing, to be able to just get up on stage and boom, show it to everybody, that felt good.

JOHNSON: It was received well?

SQUYRES: I thought it was, yes. I thought it was. Not everybody's favorite mission rises to the top in terms of priority. If you have created a plan that makes everybody happy, you have created a plan that has no value, because it doesn't set priorities. What we tried to do was follow the community inputs and give the highest priority to the missions that the community expressed the strongest support for, and I think we did that. Generally, I think it was well received and certainly the community has rallied behind it. There were certainly going to be some people whose favorite mission didn't make the cut, and that's the nature of priority setting.

JOHNSON: You did the testimony before Congress. Was that part of this study that you presented that?

SQUYRES: Yes. One of the things I didn't anticipate being decadal chair, is that there's an awful lot of presenting it and explaining it after it has come out. It's not like you say, "Here's the report," give one presentation, then you're done. There's an awful lot of explaining, describing, answering questions, clarifying exactly what we meant. We wrote it very, very carefully but people are trying to use this to make billion-dollar decisions, and everybody wants to make sure they're interpreting it right.

The way I put it sometimes—some of the guys at NASA Headquarters like to hold up the decadal report, and to give the community a sense of how seriously they take it they say, "This is the bible for us." But let's just say that I'm frequently called upon to interpret scripture. It's not uncommon for me to be asked.

And this is still happening today. Years after the decadal has come out, I'm still giving presentations about the decadal. But I felt good about it. I felt good about the product, I felt good about the result, I felt good about putting my time into it.

JOHNSON: I think it's interesting, especially when people from NASA with more of a science or engineering background, and then you have to present it to someplace like Congress. They don't necessarily have the same background, the majority of them. They all have different reasons for wanting to approve it or not approve it.

SQUYRES: Right. But you're spending hundreds and hundreds of millions of taxpayer dollars. If you cannot explain and justify those expenditures, you do not deserve to be part of them.

JOHNSON: Was that your only experience doing that in front of Congress? Or have you done that before or since then?

SQUYRES: Oh, no. I've been called upon to testify before Congress on a number of occasions about a number of different things.

I have certainly spent plenty of time wandering up and down the corridors on Capitol Hill expressing my views as a taxpayer to my congressional representative, yes. Any time as a citizen you feel strongly about a topic, you feel strongly about anything that our government does, exercising your right to communicate with your elected representatives is a good thing to do. There are many, many different ways that you can do it.

Let me just relate a story, because I think this is actually significant if anybody's thinking about this sort of thing. I remember many years ago I was on Capitol Hill talking to congressional staffers about—I don't remember the details—but a particular aspect of the Mars Exploration Program at the time that I felt strongly about and I thought was important. I was in the office of one of the members of the House Appropriations Committee that funds NASA, and I was talking to one of their staffers who handles space stuff. I brought this topic up, and she said to me, "Oh yes, we've been getting a lot of letters on that subject."

I said, "A lot of letters, really. How many did you get?"

She said, "I think we might have gotten five or six."

I went, "What? Five or six is a lot?"

And she said to me—these were her words—"When it comes to letters from constituents, we subscribe to the cockroach theory. If you see a few cockroaches in your kitchen, you know there are a lot more back in the walls."

In other words, if a half a dozen of your constituents have taken the time to write out a thoughtful letter—not send a form e-mail blast, but actually sat down and carefully and thoughtfully wrote out their thoughts and put a stamp on it and sent it—if a handful of them care enough to do that, there are going to be a lot, lot more who didn't quite get to that threshold but still care about it.

The point is that a few people making some thoughtful effort can really get a message across. The way our representative democracy works, if you follow your opportunities to interact with your elected representatives, you can have a lot more influence than you think.

JOHNSON: Let's talk about something else that you were appointed to, the NASA Advisory Council.

SQUYRES: Yes. That was another really fun and interesting job. NASA has, to their credit, an extensive process by which they seek advice from outside the Agency.

It's a multi-tiered advisory structure where you have the NASA Advisory Council, which directly advises the NASA Administrator, and then there are several subcommittees to that. One on space science, one on technology, one on human spaceflight, and so forth. Those can report to the Administrator through the council, or can report directly to specific Associate Administrators. Then there are subcommittees below that. It's this big pyramid structure.

It's a wonderful thing because it's the Agency acknowledging that not all the best ideas are going to come from inside, and reaching out to industry, to academia, to a number of different organizations to try to get inputs that will benefit the Agency. What these organizations provide is advice, it's not direction. We don't tell NASA what to do, but we answer their questions when they're asked. We sometimes provide advice that they haven't asked for. I think it's a really good process.

I had, over a number of years, served on and chaired various subcommittees at various levels in this advisory structure. And the shortly after [President] Barack Obama was elected president, Charlie [Charles F.] Bolden [Jr.] became NASA Administrator. The NASA Advisory Council Chair serves at the pleasure of the Administrator, and so Charlie was looking for a chair for his council. They called me up and asked me if I would be willing to take the job.

It came at a good time, because the decadal was done. I'd just finished the decadal survey, so that very time-consuming job was now mostly off my plate. The rovers had been on Mars for a number of years, and the rover mission was proceeding really quite smoothly, didn't require my day-to-day involvement. The reason I'm involved day-to-day in the rover mission right now is just because I like to be, it's fun.

When I was asked to chair the NASA Advisory Council, it came at a time when I had enough time to do it, and it struck me as an interesting job. I had been a member of the Council some years before. One of the things I always enjoyed about it was that at the NASA Advisory Council level, you have visibility across the entire Agency. Everything that the Agency does.

Human spaceflight—a lot of space science people like me don't tend to necessarily get all that involved in what's going on in human spaceflight. The space technology stuff, aeronautics. NASA has this amazing, wonderful aeronautics program that as a space scientist you just don't

see unless you go to a website and read about it. So I had enjoyed my prior time on the council because I got exposure to all of that.

To me that was one of the real draws of the job, the opportunity to interact in a meaningful way across the entire Agency. That I always really, really enjoyed. It was fun, it was challenging, it was rewarding. Yes, there were times that it was frustrating. We would give them advice sometimes that they didn't like. But it's just advice, you know you get what you pay for. But we did our best, and I think we had some real influence from time to time. It was a real positive experience. I did it for about five years.

JOHNSON: I was reading an article and they were talking about how usually the chairman is someone who's retired or semi-retired, or someone that sits on lots of committees. You were quite different than that because you were still very active in many things at that point, as you are now.

Before we end, I wanted to talk about your NEEMO [NASA Extreme Environment Mission Operations] experience and how that came about.

SQUYRES: That was wonderful, what a great experience that was. We touched on this briefly last time. I have always been fascinated by exploration, by the notion of going someplace nobody's ever been or doing something that nobody's ever done, seeing something that nobody's ever seen. It's, as I said last time I think, almost a selfish kind of thing, "Ooh, I want to see it first, I want to do it first." But I'm like that.

I always wanted to do some kind of exploration. I initially was thinking of some kind of exploration on Earth, then when I got hooked on planetary science, I realized that in my lifetime

the meaningful exploration was all going to be robotic. And that means Steve doesn't get to go. I get to help build the robot, and it goes, and then I get to help operate the robot, but that's different.

While I have had an enormously enjoyable career doing that, there was always this unscratched itch of wanting to get in the water myself, get out on the glacier myself, get out in the desert myself, and do that kind of stuff. In addition to the flight projects, I have on the side—a little bit here, a little bit there—it's certainly not the main thing I do with my career, it's a small fraction of it—participated in a variety of different expeditions of various sorts. There's been underwater stuff, there's been polar stuff in the Arctic and the Antarctic. Most recently I've been doing some stuff in some caves out in Idaho.

In all of those instances, I'm not the leader. I'm not in charge, I'm not the principal investigator. I go along to help and to contribute, but it enables me to make a meaningful contribution to something that I find interesting and it helps me scratch that itch. I actually get to go out and get dirty and get wet and get cold and do all the stuff that I wish I could do more of.

NEEMO was a fascinating thing, and I just feel so lucky to have been part of it. NEEMO stands for NASA Extreme Environment Mission Operations. It is a series of essentially simulated space missions that take place in an underwater habitat called Aquarius off the Florida Keys. It's situated in about 60 feet of water and conducted typically with a crew of four NASA individuals.

Most NEEMO missions have had the crew primarily made up of astronauts. It's a wonderful training opportunity for astronauts. It's a chance to enable young astronauts, astronauts who are early in their career, to be subject to the kind of confinement, the kind of stresses, many of the kinds of difficulties and challenges that one experiences on an actual space

mission, and a chance to experience that and to train on it and to be evaluated on how they perform.

It's a chance for someone who aspires to be, say, the commander of a mission, the commander of the International Space Station, to be a commander of a NEEMO mission, and demonstrate their abilities to do that. It's a wonderful training opportunity for astronauts, and NEEMO crews are usually mostly astronauts.

But NASA uses NEEMO for something else, too. They use it for research. They use it as an opportunity to conduct exploration research, to conduct research into exploration activities. "What's the best way to do this in space? What's the best way to do that? Let's simulate it on this mission and see if we can learn something that we can then apply to flight."

Because NEEMO missions have this research element to them as well, NASA has typically, on most NEEMO crews, brought in maybe one—maybe two, usually just one—individual from outside the astronaut corps to participate as well, to provide an outside research perspective.

I have done a fair amount of underwater research. I've done research diving in various settings—Antarctica, a few other things. I've also been very interested in asteroids for a long time. I was a member of the science team for the Near-Earth Asteroid Rendezvous mission, for example. The NEEMO 15 mission was using the Aquarius habitat to simulate an asteroid mission, simulate sending a crew to an asteroid and then basically using the neutral buoyancy that's afforded by being underwater to simulate low gravity, simulate microgravity.

Essentially the research question they were trying to answer was, "How do you do field geology in zero gravity?" We've got plenty of experience doing field geology in a gravity field, we do it on Earth all the time. It was done on Apollo in a one-sixth g [gravity] field. But there

you have gravity. We have plenty of experience doing spacewalks, extravehicular activities, on the International Space Station, on the Shuttle, but asteroids don't have handrails.

Just the simple act of taking a rock sample—you hit a rock with a hammer, in zero g you're going to go flying, right? Newton's laws [of motion]. So how do you do it, how do you actually do it? The idea of NEEMO 15 was to try to simulate that. I was incredibly lucky. I got a call from Mike [Michael L.] Gernhardt at Johnson Space Center, who was putting this together. He knew my background and he asked me if I wanted to be on the crew, and I said, "Hell yes."

There was a whole training process, got to know the crew. We trained together at Johnson Space Center, we trained together down in Florida. Before you can get in the water—it's not scuba equipment. It's a very different set of dive equipment that's much more similar to the kind of stuff that you would use in space. Then we got in the water and went down, lived in the habitat.

It was intended to be a 13-day mission. We were just kind of hitting our stride—the conditions were terrible. The visibility was poor, the currents were poor. Wind doesn't blow in space. There's no current to move you around. When you have those kinds of conditions it gets very difficult to simulate space activities. And then about five days into the mission we had a hurricane bearing down on us.

So six days into what was supposed to be a 13-day mission, just as we're finally kind of hitting our stride, they said, "Sorry guys, we're going to have to evacuate you from the habitat." And that's a complicated process. You're saturated with nitrogen, there's a 17-hour decompression process you've got to go through. We got out of the water with a very strong sense of unfinished business.

The next mission, NEEMO 16, they changed the crew around. Like I said, this is a training opportunity for astronauts. The three astronauts who I was with on NEEMO 15 had had their chance. NEEMO 16 they had three new astronauts come in—new commander, and then a British astronaut, Tim [Timothy N.] Peake, and a Japanese astronaut, Kimiya Yui—but they invited me back. I guess they just didn't want to go through the trouble of training another scientist. But threw me in the water again, and everything went right. We were down for 13 days, terrific visibility. I remember there was one night dive when I could lie on my back on the bottom at 70 feet, I could see stars.

JOHNSON: Oh my goodness.

SQUYRES: It was incredible, yes. Just dead calm—some of the time. We had some pretty rough water, too. But really good visibility, very light currents, everything went our way. We got everything done.

We had little submarines in the water with us to simulate small spacecraft. The idea would be that when you were maneuvering near an asteroid you would have a crew member mounted on the outside of one of these spacecraft, and the spacecraft would position the crew member in proximity to the asteroid surface.

You could reach out—and your feet are fastened to the front of this spacecraft, the front of this submarine. It was fun. The submarine is flying around underwater, and we were mounted on the front of the submarine like a giant hood ornament. The submarine, the "spacecraft," would position us, and then you could reach down and you could touch the surface and you could interact with it.

I think we really came to the conclusion that using these small spacecraft as positioning tools for crew members so that they could use their hands on the asteroid surface was definitely the way to go. So we learned an awful lot. It was just a wonderful, wonderful, wonderful experience, and just tremendous fun.

JOHNSON: It sounds exciting. Do you have any idea or any plans that you'd like to do that again?

SQUYRES: Oh my goodness, no. It is such a privilege to be part of a NEEMO crew, and then to be on two—hardly anyone has gotten a chance to do that. I was so lucky to be on two crews. I would do anything to go back and be a support diver, if I could make it work with my schedule.

You've got to realize—you got this crew of four in the habitat. There are two more individuals in the habitat whose job it is to run the habitat, be safety divers, keep everything working. But then there's a top-side crew, mission control, the submarine pilots. There's a huge top-side crew that's working, and a lot of support divers.

The support divers are bringing down groceries and taking up our trash and just looking after things. We would dive with helmets and then there would be these hoses, these tethers, that would bring air into our helmets, and there'd be a diver just tending your tether, just holding your tether so it doesn't get tangled up.

These are scuba divers who are just working, working, working, doing two, three dives a day, on a boat that's pitching and rolling around in the waves overhead. It's hard, hard work. We were completely dependent on those support divers who just did an amazing job for us. I

would love to go back as a support diver someday and just do that to pay off that debt, because they took very good care of us down there.

JOHNSON: The Aquarius, does it stay there?

SQUYRES: Yes.

JOHNSON: So with this most recent storm I'm hoping everything's okay with it.

SQUYRES: I have not heard. I have not heard, and believe me I've been worried about it. When Hurricane Irma came through—the thing is designed to withstand a substantial hurricane, but I simply have not heard what's happened as a consequence of Irma.

JOHNSON: Yes. I hadn't either until we're doing this, and I haven't seen anything online about it, so I was just curious. Because that was a substantial hurricane.

SQUYRES: Yes.

JOHNSON: It sounds like it would be just such an interesting thing to do. There are so many things that you've done that you probably did not imagine doing when you first started out going to school and becoming a planetary geologist. Are there any other projects that you've worked on that we haven't talked about that you'd like to mention?

SQUYRES: Not really, I think we've hit most of them. I'm sort of at the stage in my career now where I'm still busy paying off debts. I had the good fortune to have so many people help me at different stages of my career, give me opportunities to do things. Right now I feel like the best thing for me to do is what I can to provide opportunities for young scientists and young engineers to advance their careers, give them opportunities, find ways to create things that'll benefit other scientists.

Back in the early days when I worked on Voyager, there were very senior scientists on Voyager. They were late enough in their career, they weren't going to get anything out of it. It wasn't like it was going to get them elected to the National Academy of Sciences, they already had been. They were just in it for the love of the game and for what they could do for ambitious youngsters.

I'm at the point where if I can help some ambitious talented youngsters, that's a good thing to do. So that's where I'm focusing a lot of my energy these days.

JOHNSON: That's very good to hear, because we need people to do that. We definitely do, and to instill that interest and that excitement.

SQUYRES: Believe me, I'm still having fun. Like I said, I was doing Opportunity rover operations all day yesterday, I'll be doing it all day tomorrow, and I just love it.

JOHNSON: That's exciting. I do appreciate you giving us this time again and giving your time for this project. It really means a lot and we appreciate it.

SQUYRES: I've enjoyed it.

[End of interview]