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DONALD E. JENNINGS
INTERVIEWED BY SANDRA JOHNSON
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JOHNSON: Today is June 9th, 2017. This interview with Dr. Donald Jennings is being conducted for the NASA Headquarters Science Mission Directorate Oral History Project at Goddard Space Flight Center in Greenbelt, Maryland. The interviewer is Sandra Johnson. I thank you again for joining me today.

JENNINGS: Thank you for inviting me.

JOHNSON: Let's start out by talking about your background and your early education, and where your interest in spaceflight first came from.

JENNINGS: I have this early memory of having a book about a trip to the Moon that showed a rocket sitting on the surface of the Moon. This rocket was shaped like a bullet, and the spacemen were standing on this ridge overlooking this complex, this Moon base. And the book was explaining that this would probably eventually happen, but not at least for another hundred years. That was the early '50s, so things happened a little bit quicker than I think anybody realized at the time.

I have another aspect of my early life. My grandfather on my mother's side was a very successful astrologer. Now, that might sound like it would lead to an astronomy career or not, or make somebody skeptical or not, but all I remembered was that this was a very smart man who was very lively and had lots of good ideas, and I admired him a lot. But, I also knew that there was something a little odd about astrology, because what I was interested in was how things worked, how things really worked, and I thought that I couldn't make the connection in astrology. That's a lesson I learned at an early age, and it probably was good to have the example.

As time went on, when I got to about nine years old, my father took me out one night and showed me Sputnik [Russian satellite] going over, and I saw this light going over. I couldn't hear any beeping, but people were saying it was beeping. He explained to me how important that was, because some other country had put that up, and it was flying over our country. I thought, "Well, that does sound important."

But I didn't have an interest in astronomy *per se* in those days. I was very aware of it. One time, I thought I had discovered a comet. I keep mentioning my father, but he was always keeping me involved in this stuff. He would always tell me if there was a comet coming, and we'd go out and try to find it. One time when it was after dark and we were going back to the house where we lived, I looked up and there was this comet. I said, "Wow, a comet!" And he said, "Where?" So I figured if my father didn't know about that comet, I must have discovered it. I don't remember what comet it was. I was probably about 10 years old at that point.

After that, things started happening pretty quickly. We had Yuri [A.] Gagarin and Alan [B.] Shepard [Jr.] and John [H.] Glenn [Jr.], and all the Mercury and Gemini and Apollo [spaceflights]. I kept track of all those, again maybe because my father kept telling me about them. He taught school, and he noticed that people had stopped paying attention after the first couple of flights in any series, and he made sure I knew what was going on.

Even in college, when they were walking on the Moon, I would still go out of my way to watch every mission. Sometimes things snuck up on me a little bit, like Apollo 13. I knew they were going there, but I wasn't paying attention, and all of a sudden I hear on the radio they are having a problem. But I was always kind of tuned in.

On the other hand, I didn't really think about working for NASA until graduate school, because in school I had always been interested in physics. The stuff that I was interested in was always making things work, how the universe works, all the time I was growing up. My father asked me if I could figure out how to make a perpetual motion machine, and I tried very hard for a long time. I think I gained a lot of skills designing things, and thinking in three dimensions. That was my early childhood, and it took me several years to find out that what I was trying to do was impossible. At least, we think it's impossible.

I was kind of interested in physics when I went into graduate school. I got an undergraduate degree in physics. I still wasn't really tuned into astronomy all that much because I would rather do something with my hands in front of me, and I thought all that stuff was out there somewhere and you couldn't reach it. But then, of course, I found out that that wasn't true.

In graduate school, I worked in the lab [laboratory] studying molecules that were in planetary atmospheres, and at the end of graduate school, it was natural for me to apply for a post-doc [doctoral fellowship] at Goddard here because they were doing planetary work, and they were using that kind of information. So, I came here in 1976 to do lab work again. They were doing a very unique kind of lab work using diode lasers, which were new at the time. I used diode lasers for several years, but I also did other things, and I kept tuned into the people who were doing flight work. Eventually, over time, that developed into actual involvement in flight programs.

By the late '80s, I was involved in Cassini [-Huygens]. We built that instrument in the early to mid '90s, and it launched in 1997. During that time, I also flew a couple of experiments on the Space Shuttle with a group that was studying the Space Shuttle glow, and we also looked at the Earth with that. This is all in the infrared—most of my work is in the infrared part of the spectrum.

When I was working on Cassini, in about 1993, an opportunity came along to work on the Pluto mission, at the time called Pluto Fast Flyby, and eventually evolved into New Horizons. That was another thing that I pursued for a long time. It took a long time before that was actually given the go-ahead, and then we built that and flew it. Between Cassini and New Horizons, those are my two main big missions. I did get to touch stuff that went somewhere, so the things that I thought about astronomy when I was a youngster turned out not really to be true. You can do stuff with that stuff out there, and I have always enjoyed it.

Coming to Goddard gave me an opportunity to do that because it's a great place. People here are very, very good at what they do, and they work well together, and the opportunities that come along are huge challenges and very interesting, exciting. I came here in 1996 as a post-doc, switched over to civil service in 1997, and I've never really considered leaving since then.

JOHNSON: You mentioned in the email that you sent me that you did the laboratory research, but you did ground-based observatories also?

JENNINGS: Yes. I still do that. It hasn't been in the mainstream of what I do, but the ground-based work, what this is is we build instruments to take to telescopes on the ground. We look at the same kind of things we look at in space, but from the ground you can do it a little differently.

You have a bigger telescope. You can't get as up close, but you can still collect a lot of light. You can work at maybe a higher spectral resolution, or with more sensitive detectors than you can fly, just because the technology on the ground is different than it is in flight. So it's complementary to the flight work, and I also gained a lot of hands-on experience with that that I end up using to help build flight instruments, a lot of practical experience building things.

The ground-based stuff was very important, but it's always been kind of a sideline. Whenever there was a conflict between the flight programs and the ground-based programs, the flight always had to take precedence. But I managed to go to observatories in Hawaii and Arizona, and several other places in my career, using instruments that we built here at Goddard and put on the telescopes. That is its own type of challenge, because you have to make it work at the observatory. It's not like space, where you don't get to fix it, unless it's on the Space Shuttle or something. At an observatory you can fix it, but you still have to make it work during the time that they have allotted to you. And if you don't make it work, then you have to come back and try it again later. So, there is a certain type of challenge there. I have always enjoyed that. It's not so much fun staying up all night, but the work is very interesting, and again, the people are very good to work with. So ground-based has been an important sideline to what I do. And I still do it.

JOHNSON: Talk about some of the instrument development for the ground-based, or even the flight instruments—the things that you develop for these programs, or for the Shuttle glow. Talk about some of the process of that development. I am assuming the study is proposed and a team gets built to work on it, but if you can walk us through one or a couple of those, and just examples of how that works?

JENNINGS: It happened in different ways for me, and I think probably people should understand that it's not always the same procedure. The formal procedure that you always think of is that you come up with a scientific goal, you write a proposal, and develop an instrument concept that will address that goal. Then you propose that, you get funding, you build that instrument and fly it, and then you collect your data and so forth. But it doesn't always happen that way.

It kind of happened that way with Cassini. There was a proposal phase for an instrument investigation which then we developed the instrument over a few years, and then launched it, and waited until it got to Jupiter or Saturn. Saturn was the ultimate goal. And then we collected data and we published papers.

But something like this Space Shuttle mission, somebody came to us one day and said, "We have this idea of looking at the glow around the Space Shuttle, and we see that you have worked on some instrument like this. Could you join with us?" So there was no proposal involved. Somebody got the money some other way and wanted to do this—we were working with the Air Force at the time—so we didn't have to propose for that one. We just had to join a team. Sometimes that's what happens, you join a team. We had an instrument on the Earth Observing-1 [EO-1], a New Millennium [Program] satellite. It's still up there. It's being decommissioned now, I think, but it's still up there, and we got on that one because they were looking for an instrument that did something like what we were doing.

For ground-based, you do write proposals, but usually you are using facility instruments—ones that are available to you at the telescope that they have already built and operate for you. We have always been a special case there. We have always had our own instruments, so we had to have instruments that could do something a little unique, a little different, from what was available at the telescopes. Then we would apply to use that.

The instruments themselves—working in the infrared, you have to cool to at least liquid nitrogen-type temperatures. Like 77 degrees Kelvin is liquid nitrogen, and we typically work at that or helium, which is around a few degrees Kelvin, so extremely cold. You have to use liquid nitrogen or liquid helium. Those are for the ground-based instruments. That presents a challenge, just the cryogenic part of that.

In flight, for flight work, you usually can't cool that much, although it's getting so you can now. But our instruments haven't been cooled that much, so we have to find other kinds of detectors that will still do the job, probably with less sensitivity. With flight missions, because you are getting up close and you maybe spend a lot of time—like in the case of Cassini, you can work with detectors that are less sensitive and still get the data that you want. So it's a matter of taking the science goals and matching them to what the technology can provide. Sometimes you don't really know if you are going to be able to do that when you start.

I don't know if that completely answers your question on that.

JOHNSON: Yes, it gives a good idea that not every one of them, of course, is exactly alike.

JENNINGS: And one thing I forgot to mention is what I do is mostly spectroscopy. It's not always. Spectroscopy, so we're building spectrometers. They look at the individual wavelengths of the light coming in and see how they are absorbed. By looking at that signature, we can tell what molecules there are in an atmosphere, how much, what temperature they are at, whether they are moving like winds—there is a lot of information in a spectrum. Both ground-based and in flightwork, that's been spectroscopy. And in the lab, too.

JOHNSON: And the Shuttle glow, was that on STS-39?

JENNINGS: [STS-]39 and [STS-]62, yes. Those were called SKIRT, Spacecraft Kinetic Infrared Test. What we did was we took what was called a circular variable filter—it was an infrared filter that you could vary the wavelengths just by spinning a disk. We put that inside what was called a Getaway Special Can [canister], a GAS Can, at the time. This allowed us to have the housing already space qualified, and we could drop whatever we wanted into the middle of it.

So we adapted an instrument that had been used in sounding rocket experiments—not by us, but had been developed at Space Dynamics Lab, and Space Systems Engineering, out in [North] Logan, Utah. Anyway, we worked with them. We developed this spectrometer with a circular variable filter that a lid would open in space, and it would look out. There had been reports of a glow, a surface glow, around the Shuttle when it's going through—the Shuttle is in space, but there is still an atmosphere where it is. It's a billion times less atmosphere than it is here in this room, but it's still a billion times more than it is in deep space. So there is some oxygen and nitrogen there that's impinging on the surface—on any surface—and it can cause a fluorescence and a glow as the material comes off and then relaxes, and releases energy. We wanted to study that in the infrared, and we were able to see it very clearly. We also saw thruster firings, and we looked at the Earth so we could get spectra of the Earth.

One interesting thing we did with it was we looked directly up out of the [payload] bay of the Shuttle. We could aim the Shuttle so that we were going directly into the direction of travel.

In that direction the glow is very bright. What we would do then is rotate the Shuttle so that it would go to the anti-direction, anti- what we call "ram direction." And we could watch the glow actually decrease. It decreased from a maximum in the direction of travel to a minimum in the anti-direction. You could study the geometric pattern, you could tell people what to expect. If you are flying an instrument in the Shuttle, you don't want this glow around it necessarily. It might interfere with what you are looking at. We could tell people what to expect, and we could study the chemistry. That was very interesting.

The second mission, STS-62, we decided we wanted to see if we could enhance the glow. One of the investigators thought we could enhance the glow by blowing extra nitrogen up out into the bay, and that extra nitrogen—just like the nitrogen in the atmosphere—would cause an increased glow. So we tried this in flight, and what we found out was it turned off the glow. Absolute opposite. And of course as soon as it happened, like a lot of things in science, as soon as you see the evidence you realize what's going on even though you weren't thinking about it before. What was going on was we were putting slow-moving gas out into the bay. It was gas moving along with the Shuttle. We were hitting gas that was coming in at 8 kilometers per second, but the slow-moving gas was now keeping the fast gas from reaching the surface. So the gas we were putting out was actually buffering the glow.

I don't know if anyone ever made use of that, but that would be a technique people could use if they wanted to reduce the spacecraft glow. We published that, but I don't know if anyone ever made practical use of that. It was fun to see something you weren't expecting. I always think it's fun.

JOHNSON: I would think so. With science generally, that's kind of what you are looking for.

JENNINGS: Yes. Science in general, it's basically curiosity. But organized science, you try to predict what you are going to see, then you go see if you see it. Some people would be disappointed if they don't see what they were looking for, because maybe they had predicted this based on their own theory. Other people, like me, if you see something unexpected I think, "Wow! That's what we're here for."

JOHNSON: That's right, new discoveries.

JENNINGS: Yes, we just learned something.

JOHNSON: That's exciting. Talk about how that early experience working on those different things—you said you moved into the Cassini program, and it's the CIRS?

JENNINGS: CIRS, yes. CIRS is Composite Infrared Spectrometer. The "IR" in the middle is for "infrared." It's a Composite Infrared Spectrometer, and it's the thermal part of the spectrum that we look at. There is no other instrument on Cassini that does that. We look at it from wavelengths of about 20 times the wavelength you see with your eye in the infrared. It's long wavelengths, out to about 2,000 times what you see what your eye, so very long wavelengths. It's still not radio, but it's what we call "far infrared." A micron is a millionth of a meter, so in microns, it goes from 7 microns to 1,000 microns.

It was a follow-on experiment following up on what a similar instrument did on Voyager, and that instrument was called IRIS, Infrared Interferometer Spectrometer, on Voyager. We tried to be about 10 times better in a lot of ways than that instrument, because we wanted to improve. We were going again to Saturn; we were going to spend a lot of time at Saturn, and Titan in particular, its moon, was very interesting. Probably the main reason we were going to Saturn was to drop a probe into Titan, so we wanted to do a lot better than we did on Voyager, and we did.

In the '80s, when Cassini was being developed, we had our instrument on the strawman payload—you have to work with these missions. At least in the old days, when they had missions that everybody could be involved in, you want to work along with the mission so when the time came to actually propose the mission, you are one of the players.

Nowadays, it's a little different. You have PI [principal investigator]-led missions, and a PI puts together a team. You still want to try to get on one of those teams, but that team then proposes their mission against other teams proposing different missions. With Cassini, it was either we were going to get it or we weren't, and we had to just show we could, which was not an easy thing.

We started developing it in the '80s, and about 1990 or '91 we had a concept that was well-enough developed to propose, then they asked for proposals at that point. In '91, I think, we were selected and we started building. And for a couple of years we wondered if it was actually going to be possible, because we had proposed something very complex. Yet, after a couple of years they also had a de-scope in the program. The overall Cassini Program, there was a de-scope. They went to instruments and said, "Can you de-scope?" We actually used this as an opportunity to solve many of our problems. We made things simple enough to build at that point. We reduced the complexity of the instrument, and made it much, much lighter, and easier to build. It was kind of fortunate for us. Some of the scientists didn't like the fact that we had to give up a little capability here and there, but the alternative probably was that we wouldn't have been able to have been successful.

In 1996 that instrument was complete, we delivered it, and it was launched in October of '97. And October of '97, that's 20 years ago. Cassini is still up there, and it's going to be flown into Saturn in September of this year. So it's been 20 years.

JOHNSON: And that instrument, it's still working?

JENNINGS: Still working, still doing just as well, yes.

JOHNSON: Still gathering data?

JENNINGS: Yes. At Saturn, it was taking data all the time, and every time it goes past Titan it takes some data. We have probably finished our most useful Titan orbits because we are not going to get as close as we have in the past, but we'll still be able to take some. We have mixed feelings about the end of this mission. Some of us have half our careers been involved in this one. On top of that and parallel to that, I was working on New Horizons, and that's gone its full cycle during this whole Cassini development. I started Cassini before New Horizons, and New Horizons went past Pluto a couple of years ago, so that all happened during the time of Cassini.

New Horizons itself was hugely successful, and is going on to study a Kuiper Belt object, which it will in about a year and a half. So New Horizons is still going, and New Horizons will continue out in the outer solar system. It'll be around a lot longer after Cassini has met its demise.

JOHNSON: Like Voyager. They just keep going.

JENNINGS: Yes, Voyager. You get slower and slower bit rates, because the telemetry is weaker and weaker, but they can still talk to it, and they still are learning about the far reaches of the solar system. I did some work with this team that I am working on with Cassini. I originally started working with them when they were working on Voyager. In the lab, I studied molecules that were in spectra that were used to identify molecules in Titan. Some of the molecules that we found in Titan were identified, or at least in part, because of the laboratory work. So I started working with those guys a long time before Cassini, and Voyager at that point was just going past Saturn when I did that work.

JOHNSON: You mentioned when we were talking earlier that a lot of proposals are created, but not many get chosen, and that it helps once you have gotten something picked to get to the next one, too. And you talked about in Cassini, you had to work on it a long time and you took that opportunity to even make it simpler. Talk about proposing something, and maybe more of that process, how big the teams are, and maybe how you work on that.

JENNINGS: I would encourage people coming into the field, if they want to be involved in flightwork—I mean, some people come in and they have this pet idea that they want to promote that. And that's okay, they can do that. It may or may not get selected. But if you want to do flightwork, what you do is you look around for programs that need help with things that you could do and you try to attach yourself to them. You get to know the people, you offer your help. "Can I help?" is a very, very useful, productive thing. People understand that, and they quite often will say yes. So if you can attach yourself to it, then you have got some experience after the first mission, and people will then want you to help them on the future missions. It's much easier.

When I first started working on flightwork, I noticed that all of the people were—to me, they were all old people. A lot of them are still around. They are still old people, but they are a lot older, and I am one of them. But there were all these older guys who seemed to always be involved in these missions. When I started looking into it, I realized that they had all been involved in the first mission, like the first Venus mission, or something like that. They had been working on it since the very beginning, so now that meant that every time a new mission came along, why would you pick someone who hadn't done it before when you had people, maybe two or three groups, who had experience? You would want one of them to do it. And that's what happens.

So the problem is breaking into it, I think. It took me 15 years to break into flightwork really, where I could build instruments. I could do laboratory work, support ground-based work supporting flights, but if I wanted to build a flight instrument and put my hands on a flight instrument, they weren't going to let me do that until they were pretty sure I knew what I was doing. That took a while, and I think that's not always understood by people coming in.

The process is supposed to be that you come up with an idea, a scientific idea, and then you promote that. You figure out how to build an instrument that will do that, and then you propose it and so forth. The rigor in being selected nowadays is much harder than it was. I am not sure that they are getting any better product out of it, but the rigor that you go through in the proposal selection is much harder than it used to be. The proposals are much more involved, the review process is much more involved and detailed. There are Technical Readiness Levels, TRL levels, now that we have to adhere to, which didn't even exist when we were doing Cassini and the first part of New Horizons. We still get good missions, and all of these things help ensure that it works. But it does make it harder and harder to get into, I think.

On my side of that fence, since I am already in the game, it's hard for me to even appreciate how difficult it is for someone who comes in and wants to do something, because I see people writing proposals all the time. It's like they are spending all of their time writing proposals, and I think if you ask them they will say they feel like they are. That takes a lot of time, and someone's paying their time while they are writing those proposals.

But you need that pool of people doing that to get the few missions that are actually going to produce something. And if those people do it right, even if they don't get their own proposals selected, they might be able to get on a team that does get one selected. It's not as formal a process as we are led to believe sometimes, and I think that's good. I think it needs to be flexible. You want to be able to listen to ideas that maybe came down the wrong pike but are still good ideas.

JOHNSON: The scientists that work here and that are working on proposals—like you said, some people feel like they are doing that all the time—is there a lot of sharing of ideas, and sharing of work? Or is it very competitive?

JENNINGS: It's not competitive within Goddard. I think we are always helping each other here. People are interested in the work, and so by and large if you can help somebody out, you do. I don't see that there is a lot of compartmentalization within Goddard. There may be some that I don't see, where someone doesn't want to talk about his idea until it's ready to go, but if you are going to propose it you have to get everybody involved. It's basically a Center-wide thing. Even the smallest flight mission involves a group of people from different disciplines, different [organization] codes on Center all working together.

Where you see the secrecy is with respect to the outside. Now, it used to be that we just figured we are working for the government, so whatever we do has to be general knowledge because the taxpayer is paying for it. But it's not really that way, at least anymore, because competition is so high. Instead of a big project where everybody is sort of working on it, you have all of these teams competing with each other. There is a sense that you don't want to let them know what you are doing until you are far enough along that you either have a leg up, or they at least can't copy you or something. I don't think anybody copies anybody else, but it does help to know what other people that you are competing with are doing. And so there is some tendency to keep that from happening, yes.

JOHNSON: What about working with other Centers? Have you worked a lot with teams from other Centers?

JENNINGS: Well, the [NASA] JPL [Jet Propulsion Laboratory, Pasadena, California] ran the Cassini project, and our experience with them was excellent. There has always been a competition between Goddard and JPL. JPL, of course, is a national treasure. We wouldn't be doing what we are doing if they hadn't been there at the beginning when—you know that picture with [Wernher] von Braun and [James A.] Van Allen, and—who is the other guy? Well, the other guy is the head of JPL [William H. Pickering]. JPL was right there at the beginning, and they have always known how to play this game.

Goddard came in a few years later and had to learn how to play the game. We are very good, we are at least equal in our abilities. But one of us is a government agency, and the other can be a government agency or not, depending on what they need. I think JPL is great, and my experience with them has always been great, but there is sort of this friendly competition all the time. We do work with them. We work sometimes with Ames [Research Center, Moffett Field, California], or if you are flying on the Shuttle you have to be working with Kennedy [Space Center, Florida] and Johnson [Space Center, Houston, Texas],and so forth. I used to go to meetings there, too.

So there is definitely exchange among the Centers, but to a lesser degree than within the Center. We are kind of Goddard-centric. Again, I don't think there is any alternative to that. We have to be promoting ourselves all the time. We have to be looking for work here all the time; we want to keep the missions here, we want to make them our missions. But I don't think that that is unhealthy at all.

But, there is cooperation when there needs to be. I worked a little bit on the [Space Shuttle] *Columbia* [STS-107 disaster] recovery, where we were figuring out how to look for defects in the leading edges of the wings. We had meetings in Houston on that topic, with the astronauts in the room. We were proposing our infrared cameras. Our particular version didn't fly, but we worked with the people who did eventually put one up there. But in that case they came to us and asked for ideas, because they knew that they'd need infrared imagery and they wanted as many people working on that as possible.

JOHNSON: And that was after the accident for the next flight?

JENNINGS: Yes. We actually had a piece of the leading edge here at Goddard, and developed techniques for looking for the cracks in that, in a real piece that had been to—I mean, it's a little bit sad, but that's what we were doing. We were picking up pieces of *Columbia* and taking them in the lab to see what had happened, and see if we could figure out how to avoid it the next time.

JOHNSON: Talk, if you will, a little bit more about the New Horizons mission to Pluto, and the LEISA.

JENNINGS: The Linear Etalon Imaging Spectral Array, and that name [LEISA] was actually chosen to be pronounceable. I wrote the original proposal for LEISA back in 1993, and many of the people who eventually worked on it were on that original proposal. Dennis [C.] Reuter actually took the wedge filter much further than I ever expected it to go, and has flown it in other instruments now, on other flight missions.

But the Linear Etalon Imaging Spectral Array, the first incarnation of it was to be a very lightweight, small, compact spectrometer to work in the infrared on the Pluto Fast Flyby. Pluto Fast Flyby was originally going to be a 100-kilogram spacecraft—very, very small—that you put on top of the biggest rocket you could find and fire it as fast as you could to Pluto. So everything on that had to be small.

I always thought about how you would make the ideal spectrometer, and it had gotten to the point where you have imaging arrays, like CCDs [charge-coupled devices]—only in my case they worked in the infrared—and if you could just lay a filter over the top of that, that varied in wavelength along one direction, then you'd have a spectrometer. Because you could take that and put it in a camera, and just scan it across a scene. Eventually every point in the scene would see every wavelength, and you could reconstruct the spectrum of every point. That's an extremely compact thing. That's just like a camera with a little filter over it, not much more complex than any camera.

So we eventually proposed that. We started developing that ourselves separately here at Goddard, and at some point we combined with [S.] Alan Stern and his instrument that was being proposed for the same program. It was called the Advanced Technology Insertion program for Pluto. We had this infrared camera spectrometer concept, he had an infrared spectrometer on his which was more conventional. He liked our idea and adapted that, and so we started working with him. Eventually, that developed into an instrument package called PERSI [Pluto Exploration Remote Sensing Investigation], which was proposed for a JPL version of the Pluto mission. And at that point the Pluto mission was canceled because it was just getting too expensive. But someone at [Johns Hopkins University] APL [Applied Physics Laboratory, Laurel, Maryland]—I think it was Tom [Stamatios M.] Krimigis, with Alan Stern—suggested to NASA—we had some support from Congress at the time, you know, [Senator] Barbara [A.] Mikulski, and we had letter-writing campaigns going on—he suggested that we put the Pluto mission out for bid and see if anyone else could do it.

APL, Johns Hopkins Applied Physics Lab, had the idea they could do this mission, so we went through that whole process. Well now the PI on our instrument, Alan Stern, was now the PI for the whole mission. But we had been working with him all the way along, so here we were positioned to be on that mission. We went through the whole proposal phase with him, and we did compete with other people, against other teams, and we were selected.

So that's the instrument we built. It looked very much like the very first thing that we proposed. Since then, that idea of a variable filter over an array—that compact spectrometer idea—has been used on an OVIRS [OSIRIS-REx Visible and Infrared Spectrometer] instrument in OSIRIS-REx [Origins-Spectral Interpretation-Resource Identification-Security-Regolith Explorer], and is now being built for the Lucy mission to the Trojan objects around Jupiter's orbit, which will fly in a few years.

We have flown it also on the EO-1 instrument I told you about, looking at Earth. That was a variable filter over an array. So this has had much larger life than I ever thought it was. I was only interested in proposing for Pluto. I thought this was a compact, simple spectrometer just for the Pluto mission, but it's turned out that a lot of people like this idea. It's taken a life of its own.

JOHNSON: Yes. I was reading about it, and it said there were a lot of design challenges for weight, power, operational temperature, but there are no moving parts. It was described as an "elegant design."

JENNINGS: Who said that? Did I say that?

JOHNSON: No, actually, you didn't. I keep trying to remember who it was. It's in this paper, and I'll let you read this when it gets through. But I thought that's pretty nice that it was described that way.

JENNINGS: I'm glad someone said it and it wasn't me.

JOHNSON: Also what I read was in ’89, at a talk that Alan Stern was giving, you said you thought it was a wild idea, this New Horizons.

JENNINGS: Yes, I don’t know. I said that, and I think that’s probably the right word, “wild.” Some people might think wild means “crazy,” but I didn’t mean crazy. I meant that it was out there somewhere, that it was something that I hadn’t heard of before. I thought it was very exciting. I didn’t pay attention a lot at the time because I wasn’t thinking in terms of being involved in it, but I went to the talk and I thought that it was pretty wild.

It turned out to be very wild but doable. There was nothing impossible about it. That was part of the wild part of it. If you hear of the idea for the first time and you think it’s impossible, then you just ignore it. This one was not impossible. He had it all figured out, and I could see that. A few years later, when the opportunity came along, it sounded realistic to me. I still had no idea I was really going to be sending anything to Pluto.

Here is a little aside. One of the things about working on instrumentation is you actually touch stuff that goes a billion miles away, or 3 billion, or 50 AU [astronomical units] or something. You are actually building something—you are touching something—that’s going to go out there. You might say, “Well, you are wearing gloves.” Yes, well, you are wearing gloves. But at some point, you weren’t wearing gloves. It was something that you were working on before it was flight. But gloves or not, you are touching it, and that means a lot to me.

JOHNSON: And the idea was conceived in your brain, too, so I think that would mean a lot to you, I would think that would be a big deal.

JENNINGS: I guess that part, too. Yes, that's right. As far as going to Pluto, that actually was conceived in someone else's brain. But the idea for the spectrometer and seeing it all through, how it works.

JOHNSON: The instrument itself.

JENNINGS: See, this is the challenge. You come up with something like that, which is very simple, and then you have to figure out how to make it work because it hadn't been used before. There were a lot of things about that spectrometer that people just doubted that you could make them work. They did turn out to be hard, usually, partly because it was the first time we had done it. The spacecraft is building up the spectrum by scanning. You have to figure out how to coordinate with the spacecraft, and how to handle the data afterwards. You have flaws in the filter you have to work around. It turns out to be complex, but you know that you have the basic information, and some smart person, even if it isn't me, will be willing to go in there and extract it.

And that's what happened. We got to Pluto, and because the information was so important and so interesting, there were people—young people, I should say, who would know how to work computers better than me—enthusiastically figuring out how to make that data work. They did a great job. We have had several discoveries out of that.

JOHNSON: And as it goes on to its further mission to the—

JENNINGS: [2014] MU69 [Kuiper Belt object], they call it. It's probably going to have a name at some point. I think we are going to have a naming contest, but right now it's called MU69.

JOHNSON: Is the instrument still working, or is it shut down until you get to the next location?

JENNINGS: One thing—and this is kind of a "lessons learned," I guess—when you are proposing a mission, you want to keep the costs down, so you propose not to do anything during cruise. This is very common. But cruise is a very valuable time. It gives you a chance to check things out. Sometimes you learn that things aren't working the way you expected.

Jupiter, on the Cassini mission, wasn't even originally planned for science. We were just going to use it for gravity assist. If we had talked about doing science they were going to say, "Dollars." It wasn't until it actually was off the ground that we started talking about doing Jupiter. Did we think about doing Jupiter? Yes, we always thought about doing Jupiter, but we couldn't officially say anything about it.

So during cruise we have always been very busy, even though we probably propose not to be. We put New Horizons into some kind of hibernation mode for long periods of time, but we would always bring it back out and do some stuff with it to make sure it was okay. We are doing that now. To prepare for flying past the Kuiper Belt object we are looking at other things, like maybe trying to see if we can see that object itself, and making sure the instrument is doing what it supposed to, all the instruments are doing what they are supposed to do. Everything is very stable on that spacecraft, just like it is on Cassini. We really know how to do it now. And what we learned at Pluto is going to help us a lot when we go past this object.

I can't think of anything we did wrong in Pluto, though. I was involved in the planning, but the people who put their hearts into the planning did such a good job on that mission. You think about only getting one chance to do something that probably may never be done again, or at least not in your lifetime. You get one chance to do it, and you have to understand everything about what you are doing. One of the things we found out when the mission first started was that we were not going to be able to tell where Pluto is along track. You can tell where Pluto is on the sky left, right, up, and down looking from the ground, but you can't tell how far away it is exactly. It's hard because there is no parallax for that direction. So there is an uncertainty, it turns out, of about 100 seconds in the flyby time. That's a long time. Somewhere in that 100 seconds is Pluto, so that means you have to take data for 100 seconds in order to pick up Pluto, which is in the middle of that somewhere—a lot fewer seconds, whatever it is. That means you are spending a lot of time taking data of deep space.

You have to understand all that stuff ahead of time, and you have to try to bring that 100 seconds down as small as possible, because the less time you spend looking at deep space the more time you can spend looking at Pluto. But when you look at the results from the mission, you realize that they did an excellent job of optimizing all of that. We just looked at everything we could.

The same thing in Cassini. Cassini's a little different, because we were there at Saturn for 13 years. If we had things happen, we could go back and do them differently next time, or repeat it. We could plan ahead. There was a very different environment from something like a flyby, which is what we were used to from Voyager. It was a fire hose of data just pouring out at you all the time. But it also meant that if there was some glitch in one of the Titan flybys that you would just plan in the future to try to do it again, and usually there was some opportunity to do it again. It didn't happen very often, but we had some glitches and we always recovered.

One of the amazing things about doing this deep space work is that there always seems to be a recovery. Very rarely do you lose it completely. The people who design the spacecraft and the navigation systems and the communication systems, they think through all that. They figure what happens if there is a glitch. You put this spacecraft in safe mode, what do you do to recover it? Actually, we just don't lose them very often anymore.

JOHNSON: You listed some other missions in that email that you sent me. You mentioned EO-1 and some of the other ones, but speaking of losses, there was Lewis [satellite] that was part of the Mission to Planet Earth Program. Do you want to talk about that one, and what you were planning to do with it?

JENNINGS: Yes, right. That was the first opportunity we had to fly one of these wedge-filter spectrometers. We worked with TRW [Inc.], it was TRW at the time. They were building a spacecraft with several instruments on it. It was being funded at a fairly low level from [NASA] Headquarters [Washington, DC]. It was supposed to be a demonstration of how you could do things smaller, faster, [better,] cheaper. I don't think any of that contributed to the problems.

As far as I could tell, everything was done very well in developing that mission. Our spectrometer had a little moveable mirror on the front. It was going to demonstrate that technology. It was demonstrating our spectrometer, it was demonstrating a cooler that TRW built, and they still build. We were going to look at the Earth. So we were on the spacecraft, and I think we had to wait a year to get launched. I forget if there was a change in launch vehicle or something like that. When it finally got launched, after a few days the spacecraft went into a tumble and was lost. It went in the ocean about a month later. We never got any data from that one. That's just one of those things. You just be glad it doesn't happen more often.

The guys who worked in the early days, they would build two instruments. Maybe one of them would go in the ocean, because the launches weren't that dependable, so you lose one but the other gets there.

JOHNSON: I was reading this, and they were talking about that it was during that time of "faster, better, cheaper," and that may have led to some of the problems with it.

JENNINGS: Maybe. The actual error that I think happened had to do with the attitude control system, a thruster got stuck open or something. But as far as I know, from what I saw, everybody did everything very carefully. Sometimes, stuff just happens. I have worked on failure review boards for instruments that you just feel like there would have been no way to avoid this. People have been doing it this way for a long time. For some reason, on this particular mission, something different happened. It's still a risky business.

JOHNSON: Space definitely is a risky business.

JENNINGS: Yes, and that's part of the fun. When it comes right down to it, that's part of the fun.

JOHNSON: Because it's hard.

JENNINGS: It's hard, it's a challenge. You don't always know if you understand things. That's why we do so much testing. Sometimes, you can't do testing the way you want. You have to think through everything. It's hard, but like you say, it's a challenge and it makes it enjoyable, especially if you get something out of it at the end, right?

JOHNSON: Yes, right. We were talking about New Horizons, and I wanted to bring it up before we get off of that subject of Pluto, I was reading, "Thanks to the New Horizons scientist Don Jennings, we have our first clear glimpse of the entire backside of Pluto."

JENNINGS: Well, you have really been doing your work!

JOHNSON: Yes, I thought that was kind of interesting.

JENNINGS: Is that what the website said?

JOHNSON: Yes.

JENNINGS: Okay, I don't know who wrote that. It doesn't sound like anybody on New Horizons to me. I was on a trip on another mission when data was still coming in from Pluto, but I realized we had views of Pluto from almost every direction. So I made this figure up where I showed all those directions, as if Pluto was rotating. I put a little arrow on there to show how it was rotating—because sometimes it was rotated more than other times—but basically you could see all the sides. A version of this eventually came out where this was all prettied up. They didn't like the arrows, so they took the arrows off, but this was one I made from real images.

JOHNSON: Yes. I just thought it was interesting.

JENNINGS: Yes. Where did this one come from [referring to photo in article]? That's not one of my pictures, is it?

JOHNSON: Yes, maybe so. Just blown up?

JENNINGS: Yes. Somewhere on here was a dog's face [Disney cartoon character, Pluto].

JOHNSON: On Pluto, I know. It looks like Pluto's on Pluto. I just thought that was amazing.

JENNINGS: Yes. You can imagine when we were getting the first pictures, and they were pretty fuzzy to start with, and we were imagining all kinds of things. But one of the things we were looking for was "We have got to see a dog's face on here."

JOHNSON: No kidding.

JENNINGS: Of course, then there was the heart, and we forgot about dogs after the heart.

JOHNSON: The surprises you find when you are looking out into space.

JENNINGS: You were asking about other missions, and you asked about collaborators from other Centers, but I have worked with other countries a lot.

JOHNSON: I was going to ask you about international cooperation.

JENNINGS: Well, Cassini is a collaboration with Europe [European Space Agency], and the Cassini instrument is a collaboration among many institutions—[University of] Oxford [England], and [the Paris Observatory in] Meudon [France] and [National Centre for Space Studies] Paris [France]. So the space agency in France, and [UK] Space Agency in England. Then the detectors were made in Germany. It's an international collaboration. There is a paper that I just finished, it just got through the galley proofs, and so it's going to be online in a few days, I think, that you might look for that describes this instrument, and it lists all those different collaborators [Composite Infrared Spectrometer (CIRS) on Cassini, June 20, 2017, NASA Technical Reports Server, http://ntrs.nasa.gov]. [*Applied Optics*, 56, 5274 (2017).]

Partly because of that collaboration with all those people, because I kind of knew everybody, I ended up having a small role in Herschel [Space Observatory] SPIRE [Spectral and Photometric Imaging Receiver]. I suggested a design for a mirror carriage for them, which they ended up adopting and building. We built a prototype here at Goddard for that. Then with the Canadian [Space Agency], there is an ACE [Atmospheric Chemistry Experiment] mission, which is flying a Fourier Transform Spectrometer similar in concept to the CIRS instrument. I had some involvement in that. I suggested a design for that, and was involved in some of the early reviews. I was somewhat involved in ASTRO-F [AKARI satellite]. It was a Japanese

[Japan Aerospace Exploration Agency JAXA)] mission. They built a spectrometer similar to CIRS.

So other countries would come and ask us for some kind of collaboration just because they knew we were experts in FTS. FTS—Fourier Transform Spectroscopy, or Fourier Transform Spectrometer, which is what the Cassini instrument is. This is a whole class of instruments, and in the infrared they are quite often used. They fly in space quite often. Goddard has become known to be experts in that, because we have flown them all the way back to Voyager, and before that Mariner, and Nimbus, which was an Earth observing [satellite], they all flew these spectrometers. Nowadays, a lot of other institutions build Fourier Transform Spectrometers. I think ASU [Arizona State University, Tempe] builds them now for Mars. So there is a lot of international collaboration.

JOHNSON: You mentioned OSIRIS-REx. Is that the asteroid study?

JENNINGS: Yes, they are going to bring a sample back from an asteroid. So part of my history is that about five or six years ago I switched from science to engineering. Because of the kind of work I was doing, I was working a lot with the engineers, and it just made sense at some point that I go over there and work with them. I have to write fewer proposals over there because I can get involved in flight instruments as an engineer after the mission has already been selected, because the people at Goddard build the instrument, and now I am an engineer.

When I went over there, I started working on a calibrator for OVIRS, which is the OSIRIS-REx Visible Infrared Spectrometer. I built this little filament calibrator for it. The purpose of OVIRS, like many instruments on OSIRIS-REx, is to characterize the asteroid before they collect the sample. You learn as much about the asteroid as possible, and then you can go collect the most interesting—or at least a place where you are most likely to get a sample. That's what it is. They can fly it back to Earth. I don't remember the exact timescale, but it's going to maybe make it back to Earth in 2023 or something like that?

JOHNSON: Yes, I think that's what I saw.

JENNINGS: That was a lot of fun, because I got to actually come up with a design for this filament calibrator, and pretty much, with a small group of people, see it all the way through to completion, and now it's in flight, working. I always wanted to be able to do that. As a scientist, I was always working with other people who were doing that. I had some hands-on, but it was never something of my own that I had to see all the way through. So it was an opportunity to do that.

JOHNSON: It goes back to that perpetual motion machine that your father wanted you to build.

JENNINGS: Right. Except I hope I didn't design something that couldn't possibly work.

JOHNSON: But it's that hands-on.

JENNINGS: Yes.

JOHNSON: I thought that was interesting that you said you switched over to the engineering side. I know through a lot of the interviews we have done with people—scientists, engineers—when they talk about each other, sometimes there is a different way of approaching things. Scientists approach things as a certain way, engineers do it another way. If you want to talk about that, since you are seeing it now from both sides, maybe the way a NASA scientist might approach something as opposed to a NASA engineer?

JENNINGS: One of the reasons I could switch to engineering was because I kind of always thought about things from an engineering standpoint—and the engineers always accused me of that. They liked it, because I would try to solve their problems with them, and not just be complaining about it.

JOHNSON: "Make it work?"

JENNINGS: Yes. "You are telling me it won't work, you always tell me it won't work." Well, no. An engineer has to make it work based on what can actually be done, and I always understood that. Whenever we were solving a problem, even when I was a scientist, I have to be very practical about it.

So I may be the wrong person to ask. From my perspective, I never had this problem of a difference in outlook between science and engineering myself, but I did see it happen. The engineers do look at things differently. Scientists are very flexible in their thinking. Quite often, if they can get things within a factor of two, that's very good. They think of uncertainty in terms of things that can't be controlled.

If you talk to an engineer, he uses a different language. He doesn't talk about "uncertainty" or "error bars," he talks about "tolerances" and "margins." To him, those are things that can be managed. So you understand what the limitations are, and then you build the instrument so that it encompasses all the possibilities so that it will work, so that you don't have any surprises outside the box. The engineers think about it fundamentally differently, and they have to. You can't work at the one-sigma level usually in a design. You have to work at the two- or three-sigma level to make sure it works. If you have something that's got a thousand parts and each of them has a one percent chance of failure, then something's definitely going to fail, so you can't even think about it that way. Everything has to be completely controlled to better than one percent. Part of that is redundancy and things like that.

There is definitely a difference, and yet, the missions I have been on that have been successful—and I have fortunately been on a lot of them—are where the scientists and the engineers do somehow work together and complement each other. It's very important to have communications, and not just among the engineers, but also between the engineering and the science side.

Sometimes, there will be some requirement, for instance, that was written by a scientist where he didn't really care within a factor of two. But the engineer sees that requirement as hard and fast. If he can't achieve it to within 10 percent, in an environment where he doesn't feel like he can go back and question that—he doesn't feel like he can go back and ask the scientist, "Where did this come from?" or bring up the fact that there is a problem. If he feels like he just has to solve it, it could cost hundreds of thousands of dollars. And yet, if he goes back and asks the guy, he says, "Oh, well no, that doesn't matter." So, that's what you can actually do sometimes. "Well yes, that's good enough."

We cut through a lot of complexity by having those kind of conversations both early in the development and also maybe even later when things start happening. Being able to talk to each other, and not feel like you are just being given instructions and you have to go away and do them. Sometimes, there is an idea that that's the way things work, that everything is written down, formalized. You take your part, you go build it, and you bring it back. You have got to be willing to think across the boundaries.

The teams that I have been on, like Cassini was highly successful because the engineers would try to solve each other's problems. You would have optical people looking at mechanical problems and vice-versa. Everybody just wants to make it work, whatever it takes, and they will use their creativity across boundaries. And the scientists were right there in the trenches with them all that time. You would be there when they were testing a piece of equipment and seeing what the limitations were. You have to have that, I think. I think any manager of a successful project would tell you that communication was a cornerstone of the success.

JOHNSON: I think communication sometimes is overlooked, unfortunately.

JENNINGS: Yes, or taken for granted.

JOHNSON: Or taken for granted, yes, that people understand each other. And some people communicate better than others.

JENNINGS: Yes. It's part of the atmosphere, too. You want to have an atmosphere where people feel free to speak up. I haven't been in one where that wasn't the case, but I can imagine that if there was a case where people didn't feel like they could say what they are thinking without being afraid of being wrong, or being shouted down, that some things wouldn't be addressed. That could be disastrous, yes.

JOHNSON: And talking about communicating, what about communicating with the public? Education has always been a big part of NASA, depending on [presidential] administrations and NASA administrations. The funding has been there sometimes for educating the public, sometimes not—especially teachers. Talk about your feelings about educating the public, and if you have ever had any involvement in helping to educate teachers or students. I know here at Goddard especially, of course, we have had a lot of graduate students working. Talk about the importance of disseminating the information that NASA has, and the opportunities that NASA has, to the general public.

JENNINGS: Well, the taxpayer pays for what we do. We are working for the American people, and they seem to be happy with what we are doing most of the time. It's important to give back to them. We think, "We are not just taking pretty pictures," but those pretty pictures carry a lot of weight. You can see an iconic picture like the Earth rising over the Moon, you don't have to have any science in that picture. But you can't just go there to take that picture, and you have to make people realize that, that you are doing more than that.

You go back to [explorers Meriwether] Lewis and [William] Clark. [President] Thomas Jefferson sent Lewis and Clark west. Why? He wanted to establish a presence, but he had to also make it look like it was completely peaceful. So what did he do? He did science, he told them to do science. That's why we do science. Science is a peaceful, international thing in principle. It's always been that way. First of all, it's based on fundamental human curiosity, and everybody can understand that. It produces very interesting things that people aren't usually insulted by, or have a problem with. They can just have fun with it. And so it's important to keep that going.

Now, as far as my own involvement in public outreach, I used to do all the science fair projects when my kids were little, or give lectures at schools. I have given lectures to private astronomy clubs, and over the years, it's a lot that I have forgotten that I've done, but I have done a lot of talking to the public, and they deserve to have us spend part of our time doing that. They are paying for it, and sometimes they don't know what they are paying for, and they usually enjoy hearing about it.

As far as bringing people in, yes, I have had lots of summer students and visiting faculty from universities, or sometimes even high school. They come and spend a summer working—hopefully I will give them something actually useful and interesting to work on, not just sitting in front of a computer. Most of the time they really like it, and they go off and do something similar, or take the information back to their schools or whatever.

I had one girl who came in. She thought she wanted to do something in astronomy and she got a summer job with us. By the end of the summer, she decided she was going to be a lawyer. Well, that's good too. That's good too. She got to come in and experience it. She was very, very smart; I would have been happy to have her work with us. But she decided it wasn't for her. Too much number crunching, I guess, in her case. And I hope she is doing well today.

So it's very, very important. Sometimes we get awards, our teams get awards, and I have a really funny, mixed feeling about that, because I don't think that we do what we do to get awards. But it's important because it is a way of advertising what we are doing. It's an excuse to tell people what's important here. And I hope that everybody eventually gets an award.

JOHNSON: Everybody gets an award, that's a good idea.

The presidential administrations come and go. Everyone has their own ideas, and they want to put their own stamp on things. Along with everything else, they want to put their stamp on NASA. So the funding gets changed, and the budgets. Nothing set yet, but from what we are hearing, there may be less funding for education and Earth science and those kind of things. You have been here long enough to see these presidential administrations come and go. What are your feeling on the effects of these changes on science at NASA?

JENNINGS: Well, the NASA Administrator answers to the president, so he can direct us to go look at doing things, if not actually doing them. He can't tell us to do something that's impossible, but he can ask us to look into it. And this happened recently. I guess someone at NASA was asked to look at whether we could put men on the first demonstration of the SLS [Space Launch System] launch vehicle. That would probably not be possible because the reason we had a test flight was to make sure it worked, and we had to do everything in order. I think that's what they decided with it, that they wouldn't be able to do it. But in the past we have had other presidents say study going to Mars or returning to the Moon.

When I first got here I had a strange experience. I had a NASA [Federal] Credit Union credit card, and I was buying something at a store. It was in the mid-'70s. The clerk looked at my credit card and said, "I didn't know NASA existed anymore." It was between Apollo-Soyuz [Test Project] and the Shuttle. There were a few years when NASA wasn't making any news at all. I think it's good whenever we get in the news, for whatever reason. I feel that way about Pluto, too. Pluto was kicked around and demoted and all this, but Pluto is more popular than ever. It's because it's in the news all the time. So I think it's okay to do that.

Now, as far as what we work on, to some extent we are directed. It's really hard to tell a scientist who has been doing something his whole life that he can't do it anymore. He will do something similar, probably. I am not one of them, I am pretty diversified. Most of what I've talked about is space science. Of course, I have done some Earth observing, too. I am involved in Earth-observing missions. I know that we study the Earth, and we are always going to study the Earth. There are a lot of missions going on right now that maybe don't look as much like they are studying climate change or something, but they are going on just fine. There's other missions I'm on that aren't, that may be having problems. We will have to see.

But that's the prerogative of whoever is in charge. We are being paid to do something, and I personally think that we should be studying as much about the Earth as we possibly can. The population growth on the Earth, and the connectivity with technology, and everybody knows what everybody else is doing—it's going to be a hard thing to manage if we don't keep track of everything about the Earth.

I myself am marginally affected by this. I don't like to see things that we have been doing for decades just all of a sudden end because someone's opinion changed, but we do get paid by the public. I don't really know how to walk that line, except to say that most of what I do is astrophysics, which nobody seems to have a problem with at the moment.

The one thing, though, is the education part. We have to keep telling people what we do. It's easy for people to think about things in their own way. They are welcome to do that, but they at least should have the information available. So even if we are not giving them the same kind of data, we at least need to tell them what it is we do and what we can do, so that they can make the decisions for themselves.

I think that's a fairly diplomatic answer, don't you?

JOHNSON: I think so. It's an interesting conversation right now. You mentioned technology, and technology has definitely changed over your career, especially at NASA. Sometimes when designing these instruments, you are working on it and then it may not launch for 15 years. So the technology changes, and you still have to get the data back. Talk about that evolution of technology and how it's helped, but maybe problems because it's evolved quicker than you can necessarily get instruments on.

JENNINGS: Yes. What's going to fly is cast in stone. Before you start building it, you have had to propose stuff that you know is going to work. That means it's not today's technology, usually. It's something that's been proven previously that people trust. So already, when you are selected to build an instrument, it's obsolete. The technology is obsolete, but you have to keep that going all the way through.

You can imagine a mission like—well, New Horizons, we at least were designing a new type of spectrometer. It was still pretty new when we got to Pluto, but in the meantime we had flown on other things. But something like Cassini, by the time you get halfway through the mission, it's 15 years later and certainly everything has changed. I have heard of CIRS being called a dinosaur. It's up there doing all this fantastic work, but it's ancient history.

But what does change is what you can do on the ground. In fact, there is a lesson to be learned there. In the very early missions, they would base the way they took data on whether they'd be able to store the data on the ground, whether they had storage. But the storage was growing exponentially, so they sometimes should not have limited themselves to how much data they were able to handle. Plan on being able to grow into it, because what we found on Cassini was that we were limited in data rates and data volumes at the beginning, but we just kept expanding our storage capacity through the mission. Something like Cassini, you have to because you are getting so much data. You never want to throw away your raw data, that's my rule. A lot of times people will say, "Well, I just want the information," but you want to keep your raw data.

Some missions in the early days wouldn't keep their raw data. They would process it and then not have any requirement to keep the raw data. Sometimes there's things in the raw data you didn't realize were there, and you'd like to be able to go back later. We are in the process of recovering data from Voyager right now that we found were on 9-track tapes in a basement in the previous building. All the data was there, but we didn't realize it. The archive, the NASA archive, only had the processed data from Voyager. So we were able to go back and take all those tapes and put them on DVDs, and now they are available to go back in and reprocess if anybody wants to. But they could have just been lost.

JOHNSON: Very easily.

JENNINGS: Yes. This wouldn't be the first time.

So there are two aspects to it. There is what you are going to fly, which has to be very stable in technology, and then there is what you do on the ground, which doesn't have to be. You can be very flexible on the ground, sometimes get a lot more out of your instrument than you ever planned, just because the capabilities are much better. And you solve a lot of the problems on the ground.

Almost every flight, you get up there and there is some anomaly. There is something about the instrument that wasn't what you expected. In the case of Cassini, our instrument was just quieter. It had a quieter environment in space than it ever did during testing on the ground, so there were these things that we never saw on the ground buried in the noise. We get into flight, we could see them. With the ground processing capability, we were able to extract those, or suppress them, or cancel them out. So there is noise in the data that we could correct for on the ground. If you had known about it beforehand, you might have not let that happen on the instrument itself, but it does happen so we developed ways on the ground to correct it.

So that's the two things. You do have technology that has to be stable in flight. You can't do anything about it. Even up to the point where you propose, it's already old. Then you have the stuff you are able to do on the ground, which can evolve. And don't sell yourself short. Whatever you think you can do today, double it in two years.

JOHNSON: Yes, that's interesting about the Voyager data. That's always good to hear. We were talking to someone a few weeks ago about a project and the data, the original, so much of it was gone.

JENNINGS: Yes. Go back to the early '60s, there were Venus probes and Mars probes and all that. How much of that data—they didn't take very much, but you sure hope it exists somewhere. The media changes. Back then it might have been on punch cards, and then at some point it's on 9-track tape, and then it's on tape cassettes, and then it's on DVDs or floppy disks. And it keeps changing. Now everything has got to be on a memory stick [removable flash memory card], and even that's going away. It's all going to be on the cloud or something. As data goes through that process, it gets lost. If someone doesn't go to the trouble to convert, then it's just lost.

JOHNSON: It is. It's a big process, and it costs money, so we are dealing with funding again.

JENNINGS: We have home movies that my father took on 8-millimeter film, and my brother transferred them to VHS tape. Now that's obsolete, and I, a couple of years ago, transferred it all to DVD. And now I may end up with a computer that can't read DVDs anymore. Nothing's permanent.

JOHNSON: Nothing is permanent. And even the DVDs erode, so you go to the digital files, but then that standard changes. It's just constant.

JENNINGS: And sometimes it requires a certain program to be able to read it, and that program doesn't exist anymore, or some operating system doesn't support it. A few years ago I read about a study. Some group was recording sounds, songs or something, and they wanted to find a medium that would last as long as possible. What medium can you hope to be around in 2,000 years? They ended up with clay tablets. They figured out how to make a record out of clay.

JOHNSON: Oh my gosh. They go back to the original.

JENNINGS: Yes.

JOHNSON: Well, some of those things are still here. And we talk about paper, too. It's still here.

JENNINGS: Paper is better than DVDs, for what you can put on it. Some things you can't put on paper.

JOHNSON: Obviously, yes. That's true.

Are there any other missions that you worked on that we haven't talked about, or anything that you wanted to mention?

JENNINGS: Probably. So there were two SKIRT missions, which were the Shuttle missions, and Cassini, EO-1 I mentioned. Lewis you brought up—and by the way, Lewis at least flew. Clark was canceled. "Lewis" and "Clark" were the names of these two missions. We had a few missions along the way that didn't go, of course. You work on lots of things that don't go anywhere. That's just the way it has to be. I think we transitioned into New Horizons at some point around the end of the '90s. I worked with the Canadians and the Europeans on the Herschel and ACE missions, but I didn't build any hardware for those. I am sure I am forgetting some missions.

JOHNSON: Well, something you mentioned, I wasn't sure what it was—RRM [Robotic Refueling Mission]-3 CTI [Compact Thermal Imager]?

JENNINGS: Oh my gosh, yes of course. That's my current mission. That's what I was working on this morning when I came in here. When I went to engineering one of the guys over there, Murzy [D.] Jhabvala, has been working on modern upgraded types of infrared cameras called QWIPS [Quantum Well Infrared Photodetectors] or SLS [Strained Layer Superlattice], or whatever you might hear about them. They are cameras that don't require as much cooling as some of the ones that have been used in the past and are much more uniform, and there's a lot of advantages. We have been promoting those and using them for various things. We are taking two of those cameras to the [solar] eclipse in August.

A couple of years ago we were asked if we could build a demonstration unit based on one of those cameras to fly on the [International] Space Station. That's called CTI, which is Compact Thermal Imager. And RRM-3 is the package that already exists, that's being developed already. It's a robotic servicing mission, a robotic mission, but we are just going to be attached to it to demonstrate this. So after they do what they do, then we'll be able to look down and map small strips of the Earth. We are going to look at it in the infrared, to a couple of wavelengths in the infrared. What was really fun about that was that we were supposed to do it very quickly, like within one year. We could have done it in one year, but things got delayed. That often happens in the flight business. You don't worry about the schedule because it's going to slip.

Anyway, we are just now putting it all together, but it's been fun. It's been a small project. We didn't have to propose, people came to us. Hopefully, it's going to be flying within the next year. That's what I was working on this morning.

JOHNSON: You mentioned the eclipse, and that's something that you are involved in, right?

JENNINGS: Yes, out of the ground-based astronomy has developed—we have done a lot of work on the Sun. It turns out the infrared has not been used on the Sun very much, at least the wavelengths we are working at. There are a lot of phenomena on the Sun that you can study differently in the long wavelength of red than you can in the short wave, where people tend to work, or in the visible.

We have these same cameras, and it turned out that they would do a really good job on solar flares, so a few years ago we built an instrument that sits at the McMath-Pierce Solar Telescope at Kitt Peak [National Observatory, Arizona]. It just sits there on one of the auxiliary telescopes, and whenever there is any activity on the Sun somebody can open it up remotely and look at that active region on the Sun in case flares occur. We have captured a few that way. That's been really important. As a result, we had kind of got these cameras involved in solar work. Some of my previous ground-based astronomy before these cameras had also been looking at the Sun, so I knew some solar physicists. I was actually on the first version of the panel that helped develop the new solar telescope in Hawaii. There is a telescope going up on Maui called DKIST, Daniel K. Inouye Solar Telescope, a four-meter telescope in Hawaii. So I actually have been involved in some solar work for a long time.

What we are doing now is we are working with a guy at Kitt Peak, Matt [Matthew] Penn [National Solar Observatory, Tucson, Arizona], who is involved in a campaign, has people looking all along the track. Ours is a little bit different experiment than the one that most of those people are doing. We are going to go to Weiser, Idaho and set up our equipment, and on the 21st of August we are going to hopefully have it all working and we are going to watch the eclipse.

We have done eclipses before. We had an experiment [in 1991] on the Infrared Telescope Facility [IRTF] in Hawaii, on Mauna Kea, where, at the last instant, we pull some plastic off the telescope and we look at the spectrum in the edge of the Sun as the Moon clips across it. Then a few years later [1994] we did the same thing with the annular eclipse in New Mexico using a telescope there at Apache Point. So we have done eclipses before. This is the second total eclipse I will have seen, assuming the weather holds. And in all cases, we have a rule, that you press "return" on the computer, and then the observation runs itself and you get to watch the eclipse. You don't have to watch it on a monitor. You can actually stand outside and look at the sky. So we have a rule that we get to see the eclipse. If you want to see what we did in Hawaii on the first eclipse, there is a program on *Nova* [science television series] called "Eclipse of the Century." It's fun to watch, you will see just what it's like. We came very close to not having our equipment work.

JOHNSON: Really?

JENNINGS: Yes. And that's the way it is often in eclipses. With an eclipse it has to be working at a particular time, and it was touch and go for us. But a very happy memory for me because we managed to pull it off.

JOHNSON: That's always a good memory, right, being able to pull it off.

JENNINGS: There was one time that I saw that video on YouTube, so it might still be there. It's about an hour long.

JOHNSON: Yes, usually it's not that hard to find those. In this day and age, things are everywhere, even when you don't want them to be.

JENNINGS: That was a funny experience, just talking about public outreach, because there was a *Nova* team on the mountain, and there were teams from other news media and other programs. Some of them even interviewed us afterwards. But *Nova* was right there. They had a team doing the program right there, and they would go around to all the people at the other telescopes and they'd cycle around through us. Then everybody got to be on that program. You will see that. But it's funny, because about the second day that they were filming, the director asked me if I would wear the same sweater every day, because he wanted to be able to edit the scenes in time, which he did.

JOHNSON: You just wore the same clothes every day?

JENNINGS: Yes. That was tough on some of my colleagues. They were starting to think this was really surreal. But *Nova* did an excellent job, and they really showed the excitement. If it had failed it wouldn't have been exciting, but the fact that it was successful made it very exciting.

JOHNSON: Always a good thing. Talking about successes and failures, over your NASA career what do you consider your biggest challenge?

JENNINGS: Wow. The biggest? Can I have a few biggest?

JOHNSON: Oh, you can have a few.

JENNINGS: Every flight program has been a big challenge. I have regarded every one of them as equally challenging. Some of them were bigger projects than others, so I would say that the most challenging that I was most involved in was the Cassini instrument development, CIRS development. That involved not only building an instrument, but all the stuff afterwards to make sure it worked. It took a large group of people to do that, so I don't take credit for that necessarily, but to me it was a big challenge.

New Horizons was like that, too. We went from people not really taking us seriously to actually having to do it, and then a very successful outcome. Any time that you say, "Okay, your money starts here, and you have got to deliver here"—and on both of those missions there was a hard date, because we had to use Jupiter as a flyby assist. You had to launch on a certain date to have that advantage. So you really had to be done by a certain date, and at the beginning of it, it seems impossible. "How am I going to do all this?" It was particularly hard to see how we were going to do it with CIRS, the Cassini instrument. It just was so complex.

What can I say? It's just good people. I think a lot of it was that we were all young at the time and we didn't realize how impossible it was. We just kept doing it, kept solving the problems. When it launched, it was so complex we figured some things weren't going to work, but it all worked. I think that probably had to be Cassini CIRS, with New Horizons a close second.

The ground-based stuff, it was very challenging but it doesn't have that same aspect of you have to have it done by a certain date. If a ground-based observation fails—and they do quite often—it's not a big deal. You just come back and do it again. Nobody is standing around watching you, or figuring out whether you are on schedule or whatever. Even though I enjoyed that a lot—I always enjoyed doing ground-based astronomy, it was a big challenge—it was not the type of challenge as holding your feet to the fire during an instrument development for flight. That's a very different thing.

JOHNSON: What would you consider your most important accomplishment, or your achievements?

JENNINGS: What am I proudest of?

JOHNSON: Yes.

JENNINGS: Achievement. I'd say I feel like I took the infrared instrument on New Horizons from just a basic concept—and I can't take full credit for that because, of course, I worked with people and we all contributed. But we really started from scratch on that. Other people were developing similar types of instruments, but from our standpoint we really invented that and figured out how to do it here at Goddard. So I probably am proudest of that individual thing.

But overall, as far as legacy, I think a lot of people think of me as a Fourier transform spectroscopist because of how successful CIRS has been. And I have always been heavily involved in that. I was the Instrument Scientist on that all the way along. So probably, as far as what outside people see, it may be the CIRS thing. I also have to say I am quite proud of the fact that I was able to not only build the instrument, but go and do some science. I was able to do that on Cassini. I had been working in that field beforehand in the lab, identifying molecules in atmospheres like Titan. When I started working on Cassini, it seemed like I was just going to be doing the instrument side, but I got involved after launch in making sure the operation went smoothly, and I also had access to the data so I started trying to do some science. There were a lot more capable scientists on this project than me, but I was able to find a couple of areas basically because I knew how the instrument worked, and I knew what its limitations were. So I have gotten to do some science out of that. I am quite proud of that.

With New Horizons, I am on a lot of scientific papers because the PI is very fair, and the team members are very fair, and they always want to make sure that the people who developed the instrument get as much credit as the people who did the science. That's always been a very good thing. But I didn't actually do any of that science. I was looking over people's shoulders, because the people who handle that data are way beyond me. I know we built the instrument, and of course we have looked at all that data for troubleshooting, but to actually get the science out, that takes somebody with real dedication, and a computer capability, which I don't have.

JOHNSON: Well, is there anything before we close today that we haven't talked about that you wanted to mention?

JENNINGS: You asked me what I am proudest of achievement-wise, but if I was to look back over things that really impressed me the most that I have seen—the things that stand out are like the Cassini launch, where you have this huge rocket going up into the sky. You are watching it arc away, and it's carrying your stuff.

JOHNSON: Did you see the launch itself?

JENNINGS: I saw the Cassini launch, and it was dark so it was very spectacular. The New Horizons launch I saw also, but it was during the day. It was very spectacular, too. But Cassini for some reason stands out.

There are some other things. Working on the Shuttle projects, I was able to go down to the Cape [Canaveral, Florida] and I was in the clean rooms down there when we were working on our instrument. Our instrument that flew on the Shuttle was filled with liquid nitrogen to cool it, but they wouldn't let us fly liquid, so just before they closed the Shuttle bay we went in there and froze the nitrogen to a solid by flowing liquid helium through it. Liquid helium is a lot colder and you can freeze the nitrogen into a solid block. Then that would stay solid for 60 hours, through the launch window, at which time you could go in and do it again if you had to. So we were doing something at the very last minute, and that in itself was a challenge. Both missions, we were the last ones to leave before they closed the bay.

On the second mission, we were going out to the clean room, and the crew is coming in to close out the Shuttle, and they asked us if we would like to help them. Well, the guy I was with had something to do. The poor guy, he had family with him or something. He had something he had to go do, so he didn't do it. But I went back in with them, and they had me stand at a particular place and watch the clearance on the door as it closed. I saw them ratchet in the door, which then becomes part of a structure of the Shuttle. That made a big impression on me. I was standing in the Shuttle when they closed it out. And that was *Columbia*.

Then there was one other thing about the Shuttle. One night, on a previous mission—this was the first mission—they were rolling the Shuttle out to the launchpad. This was *Discovery*, and I got up early in the morning and watched them roll it out of the Vehicle Assembly Building on this crawler [transporter]. It took them—I forget, what was it—like six hours to get it out to the Launchpad. So I went out and I watched them when they came out of the building, and I watched them for a little while, then I went back and slept a while, and then I came back and watched them set it up on the launchpad, and then I went to the airport.

But when it was still dark and I was standing next to this thing crawling along at two or three miles an hour—it must have been maybe one mile an hour—and I was looking up, and I could see the Shuttle just like the spire on a cathedral, pointing up, and right above it was this star. I think it might have been Arcturus. I am not sure, I would have to go back and look. But it was just the right place, and it occurred to me—this is like a modern version of the cathedral. We built this huge technology to go to the stars. Cathedrals were built with these spires to point up to heaven, right? I am standing next to this thing, and it looks a lot like that. So that has stayed with me, too. That's something you couldn't get a picture of, and I didn't try to take a picture of it. I just try to remember it.

JOHNSON: It's those moments where sometimes you just have to appreciate the moment, and not worry about trying to capture the moment.

JENNINGS: Yes. I am sure that if I thought about it, I could think of other things like that. I could think of things where I did something smart or did something dumb. But that's the kind of thing that if I think back over it later in my life, that's probably what I am going to remember, are those kind of things.

JOHNSON: And the opportunity to have a moment like that, looking at that star after going out with your father and looking at the Sputnik fly over and realize that, like you said before, that's another country, that we should be there, too.

JENNINGS: Yes. I mean, there was that political aspect with Sputnik. But that never really affected my thinking about any of this. Politics are something somebody else can figure out. And I hope they do a good job.

JOHNSON: Don't we all.

JENNINGS: Yes. It sounds a little selfish, but I'd like to just do what I do. And other people, I am glad that they want to do what they do. There's a lot of it that I wouldn't like to do, but I am glad they are doing it.

JOHNSON: We definitely all have our place.

JENNINGS: Yes. All God's children got a place in the choir.

JOHNSON: That's right. Well, if there is not anything else, we can close for today.

JENNINGS: Okay.

JOHNSON: Unless you have something you wanted to mention?

JENNINGS: I can't think of anything. If you let me sit here for 15 minutes, I might think of something. But if I think of something, I can tell you offline.

JOHNSON: And we can definitely add it later. All right, well thank you.

JENNINGS: Thank you.

[End of interview]