DISCOVERY 30TH ANNIVERSARY ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

ARLIN BARTELS
INTERVIEWED BY SANDRA JOHNSON
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JOHNSON: Today is June 16, 2023. This interview with Arlin Bartels is being conducted for the Discovery Program 30th Anniversary Oral History Project. The interviewer is Sandra Johnson, and Mr. Bartels is joining me from Goddard Space Flight Center [Greenbelt, Maryland]. We're talking over Microsoft Teams. I really appreciate you taking time out of a very busy schedule to talk to us for this project.

BARTELS: Thank you very much.

JOHNSON: You're welcome. I'd like to start by having you briefly describe your education and your background, and how you first started working for NASA, and where that interest in doing these types of missions came from.

BARTELS: Absolutely. Well, certainly, I had a lifelong interest in working NASA projects. I'm right at the age that my first formative memories were of the original Apollo Program landing on the Moon, and so that planted the seed in me for my whole career. I always knew that I would work for NASA and space somehow. I just didn't know where, or would I fit in, or how. But I always knew that I would be here. It was just a matter of how was I going to get there? I grew up throughout the West, but mostly in Colorado and Washington state. I went to college at the University of Colorado Boulder. My degree there was in engineering physics. I took a short break after college, but when I started in the industry, I was working for an aerospace contractor in Boulder, Colorado, called Ball Aerospace. They were hiring technicians at the time, so I said, I can do that.

With an engineering physics degree, I started working there with them as a technician working on Hubble [Space Telescope] instruments. Then I worked for some of the defense missions, as well, once my clearance came in. But the first work I did in space was on the COSTAR Corrective Optics [Telescope Axial Replacement] for the Hubble. Then I moved over into, like I say, some defense work on the Ball side.

During that time, then, I moved from being a technician into integration and test, into being what they call a test operator, a test conductor, a test lead. I designed some fairly simple systems. But as a technician, I did mechanical, electrical, and optical technician work. Then I moved into design of support equipment, fixturing and things like that, and from there into flight hardware design. I did some simple mechanical and electrical design for a set of missions through the early '90s. One of those that ties into this team was a NASA mission called SWAS [Submillimeter Wave Astronomy Satellite] that was one of the Small Explorers in the '90s that NASA led. That will come into play a lot later, because it turns out that that Small Explorer team became part of the heart of the team at Goddard that did LRO [Lunar Reconnaissance Orbiter], actually. That's an interesting background. I'm sure we'll talk about that some.

But after working on that as the system engineer of that instrument called SWAS, then I went back into the systems group at Ball Aerospace, and also worked on some of what they called the Great Observatories, like Chandra, the x-ray observatory, and the Spitzer [Space Telescope] infrared observatory. I was just starting to work a brand-new project they had called Deep Impact when the opportunity came to move to Goddard. I had an offer to come to

Goddard. That was when I had left, then, Ball Aerospace and then came to NASA. That was in the summer of '99. My career has been here ever since.

JOHNSON: When you first came to NASA in '99, what were you working on?

BARTELS: It's an interesting question, because my first job here at NASA Goddard was as the combination project manager and system engineer for a small airborne instrument for what's called the SOFIA [Stratospheric Observatory For Infrared Astronomy] observatory, which has a very interesting setup. It's a stubby, short 747, that has a 10-foot hole in the side of it that they fill with a telescope, and they fly at a high enough altitude to be above the atmosphere to get really good seeing.

I'm not sure it's appropriate to go into this. It is part of the happenstance, though, that happens in the careers. When NASA offered the position to me, it was with the thought that I would be working on a Venus Discovery mission that Goddard had thought that they would win. But it turned out in that selection process that another mission was selected instead, which was MESSENGER [Mercury Surface, Space Environment, Geochemistry, and Ranging]. They had already offered me the position, though, thinking that they were going to have me work this Venus mission based on my previous work on SWAS, which was very similar to what the Goddard Venus mission was as proposed. So I wasn't necessarily hired in because of the SOFIA mission, but because they'd already hired me and they had this need, I went and worked SOFIA as my first assignment. It was the instrument called HAWC [High-resolution Airborne Wideband Camera]. That was my first NASA mission.

JOHNSON: You went from that to LRO in 2004?

BARTELS: No, a couple steps in between. In between, I worked for a while on the Gamma-ray Large Area Space Telescope development, their main instrument. I always had the love for planetary missions, and so although Goddard doesn't really have a large history, at that time, of doing full-up planetary missions, we did have a history of doing a lot of smaller instruments that worked on planetary missions. That goes all the way back to the '80s, I think, with gamma ray spectrometers, and lidars, and things like that. Because of the defense work I'd done at Ball, I had a background in lidars. The opportunity came up to move on to the MESSENGER mission to be the Goddard project manager for the small laser altimeter, which was delivered to MESSENGER, called MLA [Mercury Laser Altimeter]. I was working on MLA, and we got that delivered to the [Johns Hopkins University] Applied Physics Lab, because they were responsible for MESSENGER. Then I took a short detour of time working on weather satellites. Then the opportunity came to start up on LRO. So I had been at NASA for five years, I guess, when the opportunity came to join LRO.

JOHNSON: That's interesting, the timing of all that. President Bush, in 2004, announced the Vision for Space Exploration, of course, and pushing to start exploring the Moon, and getting ready to go further out. Did you know about LRO at that time, when the announcement came out, and is that something that you wanted to work with, or did it just fall in place for you that you got to work with that team?

BARTELS: No, thank you for asking. Yes, I absolutely pushed for that position. I had been following it very closely. I don't mean to take us too long a detour on this, but it is interesting about how the LRO team came together. I knew about the lunar mission partially from that work all the way back on that small explorer called SWAS. In the '90s, here at Goddard, they had a structure in place that we don't have as much anymore, where there were some programs in-house here at Goddard that were intentionally targeted towards giving young engineers experiences being in lead roles very early in their careers. It's a chronic problem in the industry that sometimes bright young engineers aren't able to get into a lead position until several projects into their career. It holds back some of their development. In the '90s, Goddard had two programs ongoing in parallel that were both intentionally and happenstance targeted towards having young engineers developing. One of them was the SMEX program, the Small Explorers, led by first Orlando Figueroa and then Jim [James] Watzin. That was a series of several small spacecraft that were built in house here in Goddard that typically had instruments supplied from academia or from industry.

That's where I had come in from the project called SWAS, because I had been a system engineer on the SWAS instrument, which was delivered to Goddard to be integrated as the main payload of the SWAS mission here at Goddard. So there was that entire group that had done these small, quick turnaround, mostly single string, but fast development, inexpensive spacecraft. The SWAS was one of several missions in what's called the SMEX program. That went on through most of the '90s. That program still exists, but now it's pretty much been sent out to industry. The spacecraft now are being built by industry, and Goddard manages them, but most of the work is completely out of house.

I should take a step back. It's important, probably, to note for folks that Goddard in particular, but NASA has a whole range of how we actually lead and implement missions that have two extremes. One extreme is where the mission is fully designed, and built, and operated almost exclusively by NASA personnel themselves. Typically that's in a case where industry can't supply one of the needs of the mission, whether programmatically or technically. The other complete far extreme is one where the missions are managed, and the system engineering and mission assurance is done by NASA, but it's almost exclusively built by contractors in the industry, defense contractors. Like the weather satellites are pretty much almost all exclusively out of house. So there's a whole range in between of missions that have some form of in-house NASA development and coordination with out-of-house teams.

These Small Explorers that I mention, the spacecraft buses, the spacecraft themselves, like I say, were all built here in house with the intention of being quick turnaround, low-cost ones for maybe a little higher risk class, what would now be class C or D, and a chance for younger engineers to get started. There was a second group here, working in parallel with them, that even worked on ones that were slightly smaller and faster that were called Special Payloads. Sometimes they were called Hitchhikers and Getaway Specials. Those were small payloads that were intended to be delivered to Johnson Space Center and actually go up on a shuttle, up to the space station or free flyers, as they were.

This is a long preamble to say, those two groups had been working in parallel with each other through the '90s. They came together, then, in a mission that was started in the late '90s called Triana. Triana was a mission that was a follow-on to that whole line of Small Explorers. When the original line of Small Explorers was complete, the team actually had the funding to create what was going to be the next generation spacecraft bus, which might have led to a whole second generation of Small Explorers. That program never really took off, that follow-on program, but they had a spacecraft bus basically sitting there waiting for a mission. That was the mission that then-Vice President [Al] Gore identified as being an Earth-observing monitoring system. It was in the news derisively called GoreSat, but its real name was Triana.

It turned out that in that Triana mission, both of these two groups that I mentioned came together and merged together. That group called the Special Payloads and Hitchhikers folks, they had the upper stage, the boost stage, for the spacecraft, and this group which had been called the Small Explorers now had just one single mission called Triana, where they were building the spacecraft that went on top of this booster stage that was called the GUS [Gyroscopic Upper Stage]. So then these two groups that had been working side-by-side but not together for that decade of the ’90s came together with this Triana mission, where the Special Payloads people worked with the Small Explorers people with one mission called Triana.

When that mission was temporarily put to storage—it eventually did launch many, many years later—but it was from a lack of funding, administration changes, and priorities. It was put in storage. Then that now-combined team wanted to stay working together, because they had developed across a decade’s worth of working with each other a very good, very efficient teaming. They really liked working together, and they had a lot of great results. There was the hope that that team can stay together. The project management for Triana, the two people who had led those earlier groups, two very dynamic individuals, amazing leaders, named Jim Watzin and Craig [R.] Tooley, who became the LRO project manager, they started in work with Division of Space Exploration, because Goddard had the first role in that. Now that finally brings us to LRO.

In 2004, in parallel with Division for Space Exploration, Goddard was given the role of what was called the Robotic Lunar Exploration Program, RLED. From that, LRO was the first mission that was designed. Now, I wasn't part of the team yet, but I had been—you asked if I had been following this. Because I had gotten to know the Small Explorer folks from the '90s when I had delivered that instrument to them, I was so taken by the manner in which they worked and how efficient they were, and just how extraordinary engineers they were, that I was still paying attention to their work that they were doing, even when I was still working on SOFIA, and GLAST [Gamma-ray Large Area Space Telescope], and on MESSENGER, and on the weather satellites. So I was always watching, because those were some of the folks that I'd known and admired. As they started crafting the Robotic Lunar Exploration Program, that was at the same time, like you said, as VSE [Vision for Space Exploration] was starting up, and there was a science group that was called the ORDT [Objectives and Requirements Definition Team]. They were defining the sort of payload packages that would be necessary for the first reconnaissance mission, the first scouting mission.

As that mission came together under Robotic Lunar Exploration, the first mission in it was the LRO spacecraft. It was intended to be the precursor mission. There was a lot of pressure on it to make sure that it was successful, but it had to be done very quickly. As that team came together, it turned out it was that Triana leadership team of Watzin and Tooley that first created this mission and worked with Headquarters, obviously, and to direct it to us. It turned out that the timing worked out very well, then, for those teams, that they had been leading on Triana, to still be available. On the spacecraft design of LRO, the heart of it at the start was formed by that Triana spacecraft team coming together to do the initial design concepts for LRO.

Since my specialty at that time had been science instruments, there wasn't a position for an instrument lead, what was called a payload manager, because they were first just working on the basic mission design and the spacecraft. Later on, when they were looking for a payload manager, it was a competitive mission, but I was selected for that role, partially because of my instrument background and partially because, frankly, I knew that team and how they worked, as well, and so I knew that I could be a good bridge liaison between these instrument teams, which all had to deliver to the spacecraft. I was hired by Jim Watzin, the program manager of the Robotic Lunar Exploration Program, for that role.

That's a very long answer to a very short question, I know.

JOHNSON: No, no, no. That's great to have all of those connections. That's part of what we're looking for, is that background on how things happened, because if you just read about what the missions did, you don't always get that information of how they were formed.

BARTELS: Yes. Even in the history of LRO, when I've looked at things, I really hadn't seen much that talked about everything that I just said in the last few minutes about how that team had been crafted and groomed to work together so well and had stayed successfully working through the '90s, but then the timing was perfect to be able to keep the efficiencies and synergies of that team together as part of this quick turnaround. That was actually, as I recall, one of the arguments that was used to have that work come in house to Goddard, was they already had a team that was already formed, and was efficient, and demonstrated the ability to do quick turnaround missions, and they were available to take on this new challenge. The timing worked out just right. That was important for another reason. As the first mission in Division for Space

Exploration, it was very important that they get results, they being Headquarters, as soon as possible. They were looking for results by the end of President [George W.] Bush's second administration. They were really looking to have results by election day 2008, originally. That's not typically the reasons we use to drive missions, certainly, especially not planetary missions where physics determines the launch dates more than anything else. But sometimes political directives can be just as fixed as Newtonian mechanics.

In a case like this, what's very interesting to note for folks is, the reason it was given to Goddard to lead was partially because of that need for a quick turnaround. NASA does missions several ways. Sometimes they're competitive bids against announcements of opportunity, like all the rest of the Discovery missions have since become, where you do all of those partnerships and things ahead of time and select the spacecraft vendor and such before you even propose against the AO [announcement of opportunity]. A mission like LRO, though, is what's called a directed mission, where Headquarters doesn't necessarily run an industry-wide competition. They say, "This is the mission, and here is how we're directing it to be implemented."

When they did that with LRO, part of the initial trade they had to make was, if they were to go to industry to have industry build and integrate the spacecraft, it would have been almost impossible to get it done by the fall of 2008. The reason is, when we buy a spacecraft, we spend the first, sometimes, year pulling together a team to craft all of the requirements just right and to specify as much as we can of the spacecraft that NASA needs to meet that goal. Then after you've taken that whole serial amount of time, then you go through the whole competitive process where industry gets to bid on it. Another team then has to come in and evaluate those bids, make a down selection, put a contract in place, and then you can start. That process can take as long as two years, even in an accelerated timeframe.

In a case like this, where from the idea or the approval to forward with LRO, needing to have results in four years meant that we really couldn't go through that pattern of develop requirements, go out for bid, assess bids, award a contract, and then begin. We just had to get started. So that's how the job came to be in house at Goddard through the Robotic Lunar Exploration Program, was the need for having results to show, with a launch to show already by, hopefully, the fall of 2008.

What happened in that time period, then, is in 2004, as that team was working on design concepts for the spacecraft—of course, the spacecraft by itself needs to have instruments to do anything interesting, to have any interesting results. In parallel, NASA was sending out announcements of opportunities for instruments that would end up flying eventually on LRO. Again, that wasn't done as a single integrated mission type. It was almost more individual instrument opportunities. What happened then with the LRO team is, through the summer and fall of 2004, probably more in the fall, NASA would come to the LRO team with a proposed complement of instruments. They said, "If the instruments we select is this collection of instruments here, can you run through an initial concept to see how you would package those instruments? Are there any showstoppers? Is there any reason why you could not fly this particular complement of instruments?"

During that phase, I hadn't yet joined the team. It was the folks who were mostly the spacecraft team and Watzin and Tooley. There were several combinations they looked at of possible instrument complements that could be chosen, and then NASA Headquarters made that final choice in the November or December 2004 timeframe. I came on just as those trade studies were wrapping up, as Headquarters was coalescing on the instrument package they wanted to fly. I came on the mission right about the time as the last permutation set of instruments was being proposed, and for a final accommodations check. I don't remember exactly, but it was sometime in December of 2004 that the announcements were all made. Then we had our first full kickoff meeting with the full mission in January 2005 with all of those instrument teams in attendance.

JOHNSON: Were all of the instruments that were going to fly already there? I read that there were three selected and then they added more as things changed with the mission.

BARTELS: To my understanding, that's true. As I said, I came in during that process. They did start with a very focused set of scientific goals that could be met with the first three instruments they thought they could have. As we went along, they found that they still, within their funding, could afford some additional instruments. The final how we got to seven was, there was a time when they were looking at first four, and then five. What happened fairly late in the game is, an opportunity came for the Russians to contribute the neutron detector instrument called LEND [Lunar Exploration Neutron Detector].

Then when NASA Headquarters decided to accept that foreign contribution, then the funding that they had allocated for that neutron detector, which would have been an American one, allowed them to add on two inexpensive instruments that weren't part of the original package, and that was the instrument called CRaTER [Cosmic Ray Telescope for the Effects of Radiation] and the one called LAMP [Lyman-Alpha Mapping Project]. They were not part of the design exercise that they were doing until the very end. They had been proposed, but they hadn't been assessed as part of that instrument complement until the Russian neutron detector then freed up the funding to allow CRaTER and LEND to be accepted. That got us up to six.

Then the other unanticipated addition was the large technology demonstration called Mini-RF [Miniature Radio Frequency], the synthetic aperture radar, which was supplied by the Science Operations Mission Directorate in partnership with DoD [Department of Defense]. As the team was doing their initial accommodations, they had originally looked at that tech demo, but the team had actually recommended against it, because there was so much engineering development that had to go. That was the point of a technology demonstration. It means they don't have build to print heritage. There's extensive development to go. Because it is such a large instrument, and because of the possible risks, people thought, to the schedule, it was actually not recommended through the Exploration Directorate that had supplied the initial funding. But then another directorate at Headquarters, the Science Operations Mission Directorate, actually supplied the funding and basically supplied the instrument to the Exploration Group. So it was added to the team fairly late. That brought us up to our full complement of seven instruments.

JOHNSON: I was going to ask you about the Mini-RF. I was speaking with Cathy [Catherine L.] Peddie. She was telling me that in some of the meetings and everything, that it was more difficult dealing with them because of that DoD component than it was some of the other instruments. They were a little more secretive about things, and sometimes it was hard as far as the integration and that sort of thing, and that it was going to be more difficult. Can you talk about that since you were the integration manager?

BARTELS: Yes. Yes. I should be really clear, too, and I didn't want to misrepresent anything. I was the payload manager. We actually had an integration and test manager, as well, Joanne

Baker. So I was just the payload manager, but I was responsible for getting them at least as far as installed on the spacecraft. It is true. Because we were working mostly with the other instruments with either universities or NASA Centers, it's a different culture when you're working in a DoD development. Mini-RF was part of, I believe, a three-stage overall development funded mostly by DoD. I felt that having worked on the defense side before earlier in my career, there's a different culture involved in working with DoD-developed hardware, especially when DoD hardware is integrated onto a civilian mission. There was nothing intentional about it. It's just that it is a different culture that they have.

The bigger concern from my standpoint was just, the design was very young for the Mini-RF instrument. Many of the other instruments that we selected were partially selected based on their heritage or the fact that it was only going to take minor modifications to their previous iterations to fly on LRO. Mini-RF, as a technology demo, was a whole brand-new technology, a groundbreaking advance in synthetic aperture radar technology. Nothing that capable had ever been put in something so small. It still was larger than all of the other instruments put together, but still, the large antenna was very innovative.

But with that, it meant that they had extensive development they had to do, which meant that the things that mattered to a spacecraft team, like, what are the interfaces? How do we communicate with you? What is your data rate? What kind of thermal design do we have to present you? The other six instruments could all talk in a mature way about that, because their design was mostly done. With that Mini-RF radar, if we were to use a NASA TRL, technology readiness levels, they were probably a four or a five. A five would be generous. So there was so much work yet to be done with them that they were considerably behind everyone else because we were all pushing to that same launch date, but they were starting from so much farther back, they had so much more to catch up to. I really wouldn't want to say that there was anything that was personality difficulties or anything with APL [Johns Hopkins University] Applied Physics Laboratory], beyond just the culture differences between working with a DoD development flying on a civilian mission.

JOHNSON: Working with those instruments after they were selected, I would imagine there's a lot of cultural differences just because people were coming from these labs, and others were coming from universities, and you're an engineer, and you're dealing with engineers but also scientists, and everybody has their own way of doing things. Talk about that for a minute, just some of the day in and day out types of interactions with these different folks with the instruments, and how you communicate working toward this one big goal with all these—kind of like herding cats—all these different instruments that you're going to have to get together.

BARTELS: No, you said it very well. Herding cats is definitely the analogy we used many times. One of the earliest characteristics I noticed of the teams was that these seven teams all had completely different characters, working styles, and cultures. You had the DoD mission on the one side, we had two from NASA missions, we had the Russian mission, and we had the ones that were developed by institutions like Southwest [Research Institute] and universities. One of the things I came into the job was assuming that because we were trying to all integrate them on the same spacecraft and work in the same with each of them, that we would—although the engineering had to be common across all of them, certainly the team cultures weren't.

One of my initial challenges was to decide, "Do I try to pressure each of the teams to all fit one mold so that we had one specific way of working, or was it better for me to try to be their translator and work with them in their styles?" I came to decide within the first month or two of working with them that the answer for each of these teams to be effective was for me to not try to change the way they were, and try to make them all be exactly the same, but actually try to make sure that each of them was being the best versions of themselves that they could be, recognizing that their cultures and the successful developments they'd done within those cultures, is what had gotten them selected for this mission in the first place. So rather than try to treat them all like wild ponies that I was trying to break, that I had to actually let each of them try to be the best versions of themselves. I thought it's going to be easier for me to try to translate or to adapt to them than to force each of these teams to try to adapt to just one way of working.

It was a little chaotic every once in a while, because they were so different in their work styles. I think in the end, that worked very well. It was one of the lessons learned that I've taken with me ever since then, is everyone is so different. You mentioned Cathy. You know, Cathy has her own style. I have a style. We all, as individuals, have our own styles, as well. Good leaders sometimes try to build on the strengths rather than trying to get them all to conform, and that's a different type of diversity, but it's also another type of diversity.

In this case, what I realized pretty quickly was, I was in a very interesting communications role between the instruments and the spacecraft, in that the spacecraft team here in house looked to me and the small team, the payload team, that I led as basically their entry into all of the instrument teams. But from the instrument point of view, they looked at me, and they saw me as their project representative on their side.

One of the most interesting things about how these instruments were selected was, although we had a project scientist, there was not an overall mission principal investigator [PI]. It was actually seven principal investigators for each of the instrument teams. That was important here, because sometimes those titles, whether it's instrument scientist—there are all sorts of titles on different missions, and you all think it’s the same role, but it was different here. It was more of a confederacy of how these instrument teams all worked. So part of my job was to represent the project to this team of seven people, seven PIs, if you will, and make sure that I was providing consistent input from the project to them, and then I was trying to take all of those different styles from these different teams and provide unified information to the spacecraft team for them to work from.

You mentioned they all had different styles, and we could spend the full two hours just talking about each of those teams and how they were all different. There were certainly different cultures between—one of the instruments was a Goddard in-house mission, which was mostly the team from my MESSENGER MLA team that was still constituted under a different project manager now, so it was like seeing your old girlfriend being with someone else now. But we had a JPL [Jet Propulsion Laboratory, Pasadena, California] instrument, as well, that had heritage from Mars Reconnaissance Orbiter. So we had two from NASA Centers. We had the Russian instrument from their Institute for Space Research that goes by IKI, translated over to us. Obviously, they have their own very different culture there. We could talk for hours just on that. We have the DoD build from APL.

We really should spend some time talking about the LROC [Lunar Reconnaissance Orbiter] Cameras, because they’re one of the most interesting teams that you come across in this industry, a small, private company started by a scientist who wanted to be in control of the cameras he used for his own science. That company, called Malin Space Science Systems, are the ones that have built—almost all the images you’ve ever seen from Mars, especially the ones that are on the surface, all the ones that are on the rovers, they’re all from this company called

Malin Space Sciences. The one that they built for LRO was, to my knowledge, the first time they'd ever built cameras for someone else, because typically, they were building them for Dr. [Michael C.] Malin himself, and the teams—the lead engineers are mostly PhD scientists, as well, who are all co-Is on the missions. So we had there a private company who was used to basically only working Mars missions, though, and so this was a whole brand-new thing, both working for and building for an external PI, Dr. Mark [S.] Robinson, who started at Northwestern [University] and went to Arizona State [University], but also then for Goddard, because their only previous customer had really been JPL. So you have those.

Then we had, from Southwest Research in San Antonio, we had a small spectrometer called LAMP, the Lyman-Alpha. That was actually started as a flight spare from the Pluto mission, the New Horizons mission. So the Southwest folks also had their own culture, as that research institute works. Then the last one, we had an instrument built by the MIT [Massachusetts Institute of Technology] Kavli Institute [for Astrophysics and Space Research], who had been working on the Chandra X-Ray Observatory before. That was a very small instrument being built within MIT, not so much by students, but within that instrumentation group at MIT called the Kavli Institute.

We had a range of NASA institutions, we had private companies, we had DoD, we had Russians. Every one of them had their own way of working, their own styles, even just down to simple things like how they liked to define their hardware connection outputs and things. The central challenge of my job was to try to translate seven different languages into a common language that could be spoken with the spacecraft.

JOHNSON: Yes, and I can see how communication was central to that position and being able to communicate.

BARTELS: Very much so. Yes. In the role they had me in, it was very much about communication. As much as I would love to have been spending my time helping them design their instruments, it really became a very communication-centric program.

JOHNSON: One of the other things Cathy mentioned is—and you've said it, too, because there was this expectation that this would be a fast turnaround. She mentioned that she could feel the pressure because of the President putting out these goals, then money was being thrown at this because of that, and sometimes she noticed that there was resentment, maybe from some other missions that she worked around. She got around it by—well, you've met her.

BARTELS: Oh, yes, absolutely.

JOHNSON: So how her personality was, she was able to explain to them that, "No, we're all working together—we can do this. We're not going to interfere with your mission. We're just trying to do our mission." That sort of thing. Did you feel any pressure because of that turnaround? Was part of your job communicating with these teams, like, hurry up, hurry up, or was it just making sure each one of them stayed on the timeline they were supposed to be on? Did you feel that pressure from that?

BARTELS: Absolutely. I had already experienced that on the MESSENGER mission, as well. It's actually a feature of all the planetary missions that have fixed launch windows. Because of the way the planets all line up and the way we do gravity assist to get to those destinations, almost all planetary missions have very short windows in which they can be launched from the ground, and then you have to wait some time for the planets to line up again to do it. So that's a feature of all planetary missions. The Moon, it's sort of half a planetary mission. People who work on outer planets missions don't actually consider it planetary, but certainly Earth-observing folks consider it, and Discovery program considers it planetary.

We viewed the challenge of the launch date in the same way the planetary missions view the challenge of their prescribed launch readiness periods. When you do that, it really isn't a panic, because that's no way to manage a mission. What it is important to do, though, is that you lay out a very realistic plan from the beginning, and you absolutely make sure that you stay on that path. That's been something that's been driven home to me continually on the missions since then, like OSIRIS REx [Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer] and Lucy, and now DAVINCI [Deep Atmosphere Venus Investigation of Noble Gases, Chemistry, and Imaging], where the schedule is the king. It means you manage differently. It means that schedule will force you to make decisions that otherwise you might be willing to defer. You have to make sometimes, based on your risk assessments of this—we have to make a decision, what decision is the best to make, and we just move forward.[1] [2]

[1] OSIRIS-REx is the first U.S. mission to collect a sample from an asteroid. The sample return capsule returned to Earth on Sept. 24, 2023, with material from the asteroid Bennu. After dropping off the sample, the spacecraft was renamed OSIRIS-APEX (Apophis Explorer) and sent on a new mission to explore asteroid Apophis in 2029.

[2] DAVINCI will study Venus from its clouds down to the planet's surface—the first mission to study Venus using both flybys and a descent probe—to determine whether the inhospitable surface of the planet could once have been a twin of Earth, a habitable world with liquid water oceans.

When you start a mission that has a fixed launch period like planetary missions or like we were given politically on LRO, your schedule is fixed. Your budget may or may not be fixed. On the other Discovery missions, you are cost capped at what you bid. With Lunar Reconnaissance Orbiter, there was a little more flexibility in the funding until we got to confirmation. But the goals are not really descopable, because this was largely single-string instruments and a single-string spacecraft, and so there really weren't descopes. We call that, in planetary worlds, the triple constraint of cost, schedule, and performance, where the only real variable you have there is risk that you can apply. You have to make sure that you're not taking too much risk, but you know that your outcome one has to be hitting that launch date. Matter of fact, when LRO—it's 2005 or maybe 2006 when NASA puts out its yearly plan and Vision for Space Exploration was lead. It must have been 2005. LRO was listed, I think, as outcome one of the Agency, and it was predicated on a Level-1 requirement that said, You shall be ready to launch by the end of 2008.

When you begin the job knowing that from the beginning, and you set realistic goals, there is a heightened sense of urgency from day one. There isn't a relaxation. There is no downtime. But what I've noticed is, the successful teams, you embrace that challenge, and it doesn't have to become chaotic, as long as you're able to continue to hit all your milestones along the way. You can run into a program from which you can't recover, or if you get too far behind, you'll never catch up. But I would say there was a very heightened sense of urgency on LRO, just like I've seen on other planetary missions. It comes with the territory.

JOHNSON: You're talking about that balance between the schedule and technical risk, and how important that is, because you are trying to meet that goal. It was more high profile because of that. There was an interest in this mission, especially as you got closer to launch, more in the public interest. Again, after talking to Cathy, I know she did a lot of public outreach.

BARTELS: She did. She's very good at that.

JOHNSON: Were you involved in any of that? Because I noticed a lot of the photos that I've seen online have your name underneath them, so I was wondering how much you were involved.

BARTELS: It's really interesting you say that. I'm not as fluent at it as Cathy is. She's very good at that. A lot of the products that I supplied, a lot of the photos you see, have my name. But you know what? That honestly was because I was spending a tremendous amount of time during that phase in the clean room with the hardware, advancing it forward and making sure my instruments were protected. We were testing the instruments, so I was there anyway with a camera in my hand. So I actually hadn't intended on becoming the videographer of the mission, but it turned out, in some ways, I noticed a lot of my pictures are—because I was taking pictures of the instruments. Because you know what was happening is, as we were processing the instruments after they delivered and installed on the spacecraft, most of the instrument teams went home, and me and my team was responsible for continuing to operate them. But as we would do things like install thermal blankets or add dressing to them, or other instruments could come in, ironically, I would be taking pictures of the spacecraft to send to the instrument teams to show them how their instrument was being taken care of. It just turned out that some of those photos have continued to be used. There was no deliberate aspect.

Cathy was a very effective communicator of the mission, and she's very good at that. She did an awful lot of that talk. She could probably speak more to that than me. I certainly had my opportunities, too, as well. But there were some people who naturally gravitate to it that are skilled at that sort of work. My skill was more clicking the shutter button.

JOHNSON: Is that something that you've done in your other missions or that people are doing, documenting all of that step by step to make sure that everything is documented with photographs of the instruments?

BARTELS: Yes. You know, it's actually even grown more in the years that have passed. During the time that I was on LRO, it was typically, the team did their own photography as we went along, just important items. People like me, who knew we were going to stay through the early operations phase, wanted to have everything documented in case there were questions later. We wanted to have the more detailed pictures to go to. The ones you've seen have been mostly full shots of the entire spacecraft, but we had thousands of photographs up close of details of it. But that's actually now a NASA requirement that flows down from 7120 that we photo document. People like me holding a camera have been replaced by—actually, all the centers now employ professional photographers who come around. You call them in, and they actually do professional photo documentation. The days of citizen photographers like me have been replaced by the professionals.

But yes, there are thousands and thousands of pictures taken during different stages of testing development, assembly, because you need to refer back to those sometimes. After you launch a mission, if you see a telemetry point you don't understand—maybe something's running hotter or colder than you thought it would be, or something—you want to go back through all those images to see if you can figure out why. Some of those images got used for publicity, but the rationale for taking them was actually more engineering documentation than it was a conscious attempt at public outreach.

JOHNSON: Maybe your team helped change some of that for NASA.

BARTELS: I wouldn't go that far. I think it was probably more that anomalies that folks were seeing on orbit on missions for which there were photos to go back and help them figure it out, I think is probably more likely what caused it. The intention behind those photographs that you've probably seen that are credited to me was more to convey to the instrument teams that their instruments were still safe.

JOHNSON: I'm sure they appreciated that.

BARTELS: There were times where the instrument teams would periodically come back out after their instruments were delivered and installed on the spacecraft if we had specifical physical operations we were performing on them, like putting thermal blankets that we were closing out, or if there were critical performance tests that we were running on the instruments. The people like myself and my small team, we were there for daily operations for what we call health and safety, just to make sure everything's okay. But when it came time to do detailed analysis of the instrument test results, to make sure they were still performing the way they needed to, then these teams would all come back out to Goddard to support a round of testing. When we did vibration testing or thermal vacuum testing, they would come out and support that. In between, they would rely on the Goddard team to just watch out for their instruments. So like I say, these photographs were to show, "No, we still have your covers in place. No, we still have the blankets installed."

JOHNSON: With so many instruments, that schedule, as far as them going through the different testing and the different milestones, it must have been pretty busy.

BARTELS: It was extremely busy, and especially because, although I was working with each of the teams, initially we were all starting it together at the same starting point, but naturally, as each of these seven teams went through their development, the delivery dates started to diverge and spread. We got to a point where instruments started coming in. There was probably, I believe, around the order of five or six months between the first instrument that came in and the last instrument that came in.

But in between them, the problem was trying to—again, with communication. Some of the instrument teams had already delivered and were in a phase of integrating onto the spacecraft and starting testing with the spacecraft, while my other teams were still trying to finish their delivery. Of course, the ones who were last were the ones who were closest to being late, so the pressure was on them, too. It was very difficult during that period of time from when the first instrument showed up until the last one did, because then we had such a range of work that was going on between supporting the spacecraft work with the instruments that were already on the spacecraft versus completing the ones which needed to hurry up and get there in time. It was a very challenging time.

JOHNSON: Yes, I can imagine. Did you have interaction with the LCROSS [Lunar Crater Observation and Sensing Satellite] team also?

BARTELS: We did. Yes, we did. Matter of fact, I still have personal friendships with some of them. I'm sure we'll want to talk about this some, because it was one of your questions, about the switch of launch vehicles, which permitted the secondary, which became LCROSS. I'm sure Cathy may have told you about this, as well. One of the really neat things about the LCROSS team is that because they were selected even much later than us, but still had to get the same launch date, they even had a more accelerated development cycle. Really, the only way that the NASA Ames [Research Center, California] folks were able to make that happen was, they built their electronics and computer processors—we call it avionics in the spacecraft. They built the avionics around a spare copy of what was flying on LRO. As part of that, we actually had a couple of young engineers from LCROSS embedded with us, living with us, because they were taking another set of our electronics, and building it, and taking it back home with them.

But then the way these missions are designed, we didn't have a lot of direct interaction with the LCROSS team until we both met at the launch site, other than these young engineers that I mentioned doing the avionics, because actually, NASA does that intentionally. When you have a primary and a secondary on top of each other, they intentionally design them so they don't have much engineering coupling between the two of them. The primary is not even supposed to know the secondary is even there. They design the way the rocket connects through the secondary to your primary payload to be identical, as if you were bolting to just the top of the rocket itself, so that you may not even need to know it's there. One of the reasons they do that is because if for some reason that secondary mission of LCROSS had run into delivery delays, and they were going to be a year late, we would have flown without them. So we didn't interact with them too much, other than these two young engineers, until we met up at the launch site, and integrated and stacked at the same time. I don't know if you've ever seen any pictures of us stacked on top of them, but you can see. They did something very innovative. Are you interviewing any LCROSS folks for this, too?

JOHNSON: I have talked to a couple of people from LCROSS. I talked to Dan [Daniel R.] Andrews.

BARTELS: The PI, Tony [Anthony] Colaprete?

JOHNSON: Yes, Tony Colaprete. I think they're the only two I've talked to about LCROSS.

BARTELS: They might have mentioned something to you. They did something very, very innovative, I felt, that enabled them to turn around their mission so quickly, and catch up to us, and join us for the mission. I think I mentioned to you that when NASA does these secondaries, they actually try to have them designed in a way that you're invisible to the spacecraft above them. They do that by means of having what's in between, a ring. It's called an ESPA [EELV (Evolved Expendable Launch Vehicle) Secondary Payload Adapter] ring. The way that's usually done is, there are little ports on the side of that ring, and from that, then, really small

CubeSats, SmallSats, deploy from that ring, but then the ring stays attached to the top of the launch vehicle. You can see this if you look at a picture of it.[3]

If I can find it super quick, I'll just show you now, because I think I should have a picture of this. Yes. There we go. So this isn't going to work for your oral history, but just so you can see this. You can see here. That's LRO up on top, and then we mount here. You see the way this is shaped where each of those little squares are, those would typically be small spacecraft that get just deployed off of there.

The genius of the LCROSS team is, they actually took that ring and turned it into the spacecraft itself. They built the avionics just into that ring, so it wasn't using that ring as a way to deploy a spacecraft. It was using that ring to become the spacecraft, which was really, really brilliant. What that meant was, then, again, we didn't have to interact with them much. When we got to the launch site and we were stacked up on top of each other, of course, we ran into little concerns there, like the nature of the mission didn't require it to be very clean from a contamination standpoint, but ours did, because especially that small instrument called LAMP. We had a little bit of a mismatch in expectations between the cleanliness, and so there were concerns about, could there be contamination getting up to our instruments? But really, that turned out not to be an issue, either. That was the concern we had until we met up at the Cape [Canaveral, Florida], of this very fast turnaround development that didn't have to have the same levels of cleanliness as us. Is there a way that it might pollute our cameras? But no, they were a really amazing effort to get turned around so quickly. Did Cathy or the LCROSS folks tell you the story of how it came to be available for us, the whole launch vehicle change and everything?

[3] https://appel.nasa.gov/2010/07/15/moon-mission-on-a-shoestring/ and https://appel.nasa.gov/wp-content/uploads/2010/07/1a1.jpg

JOHNSON: Yes, they talked about it a little bit, but let's hear it from your point of view, because it's always good. You know, you can get the same story from five different people and hear five different things.

BARTELS: Right. It's like watching that movie *Rashomon*, right? Everyone tells the same story from a different angle. Well, my version of this goes like this. In the summer of 2005, midsummer, from our spacecraft design team, we realized that the launch vehicle that we were on, the Delta II, was going to have difficulty actually being successful in launching our spacecraft. Again, my bad visual aids. The problem here with the—you have the Delta II with our spacecraft on top. Because of the amount of fuel it takes to stay in a good, safe, low orbit around the Moon, our spacecraft was nearly half fuel by weight. It was almost a flying gas tank, if you think of it that way. Because of the heritage tank that we had, the Delta II is what's called a spin-stabilized mission. It spins as it goes. What folks realized fairly quickly was that if you have that giant fuel tank spinning around, it's going to start to have the fuel move and fuel slosh, and that creates a phenomenon called nutation, which means that it starts to do this a little bit, so what should be just a nice simple spin starts to go like a top and might become unstable.

When the spacecraft systems engineering team, identified that in the summer of 2005, we did do a trade study and showed some examples of alternatives that we could do. It would have made it challenging to hit that launch date, though, because we had already started down the path of assuming we were flying the propulsion tank that we were going to have. There was another potential change called monoprop. I'm going to be too germane here, but it could have a little external motor that could get us to where we need to be. Or we could just accept the risk. Or we could redesign the propulsion system with baffling in it, so that we could slow down the sloshing. Or we could go to, always, a bigger launch vehicle.

The Atlas V is not a spinner. It just goes straight. So it's designed to accommodate spacecraft that have fuel systems like ours. When it was proposed to Headquarters, saying here are several options that we could go down. We haven't picked a launch vehicle yet, so we're notionally designing for a Delta II, but if you went to an Atlas, then we can still preserve that fall 2008 launch date. It will cost a little more because it's a bigger spacecraft. But any of the other redesigns would have endangered that end of 2008 readiness. So Headquarters had sufficient funding at the start that they said okay. We can put you on—at the time, they were just calling it an EELV, expendable launch vehicle, but it became an Atlas V that we were selected for.

Then they realized fairly quickly that, although it costs more to buy that larger launch vehicle, that also gives us a lot more capacity to launch additional mass. But LRO was already far enough in its design that it didn't make any sense to make us bigger. So folks had the realization that there's enough extra capacity—they call it launch capacity—that you could fly an entire other mission under us. People were really taken with that idea at Headquarters. That's, then, where they opened up this idea of flying a secondary beneath us, which became LCROSS. That all happened in the period from summer 2005 up till very early 2006. We had our mission preliminary design review in February of 2006. I believe we'd made that change by then.

It was very interesting, because LCROSS, which I think probably the public appreciated more at the time—or understood more than LRO at the time of launch. Certainly they got more visibility and more press. That whole mission presence was basically made available by what, at the start, seemed like a miss on our engineering, that we were having problems fitting on the launch vehicle that people had in mind for us, because it was spin stabilized. So that need at the time, which came with a cost impact, certainly, still kept us on track for our 2008 date, and then permitted the LCROSS team to join us, too.

JOHNSON: Let's talk about that, though, because the date did change.

BARTELS: It did.

JOHNSON: Do you want to talk about that for a minute and how that affected getting ready and the instruments? Exactly what was causing that delay?

BARTELS: Absolutely. That's a good question. The instruments—if I remember right, the last one came in June of 2008, May, June timeframe. The first one, I think, was in February. What we were finding, though, was that as we got closer and closer to the end of 2008, the choice came probably in the midsummer timeframe, we either really push for a date in 2008 and take the risk that comes with that, or just be a little more deliberate and make sure that we kept that risk posture commensurate with the importance of the mission at that point. Because what had started as being seen as a quick turnaround, almost scout type of mission, as the Vision for Space Exploration came into more authority, the expectations on the mission increased, and the risk tolerance for failure radically decreased. We made the choice. With the instruments, we could still have made the original launch date. But the choice was made. I mentioned that constraint about risk, cost, schedule, and budget. The concern was to make sure that we had done more testing and that we had fully checked out and kept a very low risk tolerance, because we were actually in thermal vacuum testing, I think, in November of 2008. Maybe it was October.

Even if you're a mission that has priority, you don't just get to launch whenever you want to. You have to fit in the Kennedy [Space Center, Florida] launch manifest. In addition to us slowing down the development towards the end a little bit to make sure the risk was acceptable, that also coincided with some launch vehicle issues in the Atlas line. Then finding our spot in the available order because military missions still take priority at that time for their launch windows. If it's a mission to Mars, or like my one to Venus, they typically block out the launch windows from other missions. But we do have opportunities once a month to launch to the Moon and still get the right lighting angles correct. There was less perceived pressure to launch early. And of course, the administration change in fall of 2008 relieved us of that responsibility of launching while the previous administration was still there. Then the new incoming administration certainly said that the schedule is not as important as success.

It was a combination of some of the hardware was a little bit later than planned, but we still could probably have made that original date, combined with the lowered risk tolerance, some difficulties on the launch vehicle side, and then fitting into the slot. We became fairly unpopular within the Center here, because we actually bumped one of our own missions and took their slot because of the priority, called the Solar Dynamics Observatory, the SDO mission. We actually took their slot and maybe even their launch vehicle, but that was because Kennedy gave it to the Center to prioritize the launch order, and because there was not a constraint—there were not the expectations on launch dates placed on SDO as on LRO. That might have been one of the examples that Cathy was mentioning where we had priority, and sometimes we used it, which the SDO folks still remind me about from time to time.

JOHNSON: I'm sure they do. Let's talk about the launch. Where were you during that launch?

BARTELS: Right. It's a fun question. During the launch, I was actually part of the launch countdown team, but I wasn't centered with the rest of them. Again, a long story. I'll try not to make it too long. When you deliver to the Cape, there's a couple of payload processing facilities you go to, and you spend several weeks doing your post-shipment checkout there before you're encapsulated in the fairing and then installed on top of the rocket. What we had done is, we had most of the team on launch day had moved over to the main Cape Canaveral, now Space Force, facility, where they do the launch countdown. Interestingly enough, I stayed behind, and I was doing launch day monitoring from the Astrotech payload processing facility, because one of the aspects of it is, instruments are typically not powered on at launch. You only have on the minimum amount of hardware that you need, because you don't want to drain the battery until your solar arrays can pick up the sun. One of the interesting aspects of a launch if you work on the instrument side is, your instruments are almost always powered off. I didn't need to be there as a go, no go, when it came at actual launch for, is my hardware healthy? But I had a part earlier in the countdown.

I was alone in the Astrotech facility on the net with all of the seven instrument teams. Before we got to the final countdown sequence, I had one last chance to check with each of my instrument teams. Based on your last set of measured data that you took, or the last time that we powered on to see what the temperatures were inside the fairing, do you have something so important that we need to delay the entire launch because of problems you see? That was a couple of hours before the actual launch. So I was on a headset just like this. I was calling in to the main SMDC [Space Missile Defense Command], and then I was running a poll of all of my instrument teams who were spread across the world, or at least across the U.S. I think the

Russians may have been at Goddard. So I was running my own, "Are you go for launch? Are you go for launch? Are you go for launch?" Then I gave one payload, "It's go," and then that was it, and I was a passenger the rest of the time.

So I was following along the countdown and everything, but the whole rest of the team was in one area that were responsible—because the spacecraft is powered on top of the launch vehicle, and I was 20 miles away in the payload processing facility, which had been the hive of activity until just about a week before launch. I was like the Maytag repairman, all by myself in this building on the line with all of my instrument teams and then calling in to the launch team. Then when the launch actually happened at 5:30 in the afternoon, if I remember, of course, I ran out the door and watched it go. But I was mostly by myself at that time, while the whole rest of the team was together.

I was able to join them fairly quickly. Cathy might have mentioned this, as well. Again, with these small teams, you have to wear multiple hats. Many of us who were there on launch day actually were trying to get back to Goddard as quickly as we could to pick up the first pass from the DSN [Deep Space Network] with the telemetry postlaunch. And so there were seven or eight of us who actually got to fly in a little NASA plane called NASA 8 from Kennedy, with a gas stop in North Carolina, and back to Goddard right away after launch. So at the launch itself, I was by myself, but I was able to get back with everyone then within that first hour, because we had a plane to catch to get back to Goddard.

JOHNSON: The lunar orbit insertion [LOI] was the next big moment. Were you in the control center when that was going on?

BARTELS: Yes. I was, because at that time, we were all back together. We had erected a temporary facility at Goddard for all of the engineers to be able to continuously monitor telemetry, and we were going around the clock. But I wasn't going to miss LOI for anything. No, we definitely—because it took us, I think, four and a half days to get there. We had that first burn to make sure we'd captured, and then we had some follow-up burns, too, to get to the right orbit size. That was a real feeling of euphoria when we realized that—now, none of my instruments had turned on yet, so I was only happy we'd gotten there. The real fun, for me, was as each instrument was sequentially turned on over the subsequent weeks. But if you don't capture correctly in that orbit insertion, nothing else matters after that. That was a real feeling.

The feeling of launch is one of exuberance and joy, and so much of seeing the work that you've done, knowing it's never coming back. But the real engineering satisfaction only happens when you see that it's doing what it was designed to do. Knowing that we had captured correctly in lunar orbit insertion was the first time, I think, that a lot of our team could relax a little bit. When you go to an outer planet, or to Mars, or something, you have many months of what becomes quiet routine in between. But here, with only the four days—if it's an Earth-orbiting mission, that payoff comes almost right away, because you're already in Earth orbit if things are going well. It can be a delayed payoff of many months for a planetary mission. This sort of heightens the anticipation. The anomaly responses—what happens if it's only partially successful? Our lunar orbit insertion phase lead, Martin, had run through several what we call off-nominal scenarios about what plans would we have to put in place if it didn't go the way it was designed but it was still savable. We were practicing and thinking about, what are we going to do if it doesn't go the way it's intended to go? What are our recovery options?

That was the first time I relaxed a little bit, was when we captured. But for me, because my instruments hadn't been turned on yet, each one of those was another—I didn't feel comfortable until all of our instruments had been turned on and had shown that they had all completely survived and were taking their initial data sets.

JOHNSON: Let's talk about those instruments and as they were coming on. Talk about some of those and some of those experiences, and any anecdotes about any of that.

BARTELS: Yes, yes. Part of the way we were able to do it, because the time delay to send commands to something at the Moon is only in the order of a few seconds, four seconds, most of the checkouts that we did were done by test scripts that we had run but that also involved some feedback back and forth with the ground operators. Some were more automated than others. Some of them, of course, the nature of the data that they take is very visceral to see at the time, like images from the main imager. Of course, some of the spectrometers had a very different sort of profile. It's almost as data squiggles that you see that the scientists have to help you interpret.

As each of the instruments were being turned on and commissioned, then typically for the first turn-on, each of those teams would come to us in the control room here at Goddard. They would be responsible for generating the sequence of commands that we do to make sure their instrument did exactly as planned. We had very specifically thought out through, what would these first initial turn-ons of each of these instruments—what functions and features do we need to demonstrate to show that everything is working, that it survived launch? We had a, I think, two-month commissioning phase, where we did more detailed checkouts of the instruments and things. But the first turn-ons, which were the ones that were the most nerve wracking, because you didn't know you'd survived until you turned on and you saw the telemetry come.

Each team came, and one by one, we ran through the test sequences, and we learned that each of the instruments had completely survived. Nothing had broken during launch, and all functionality that we could demonstrate was still there. Now, because we were in an unusual orbit, we weren't able to necessarily get some of the best imagery. We were in that highly eccentric orbit that would swing 30 kilometers on the south pole, 200 kilometers at the north pole, which turns out to be a really important orbit later on, because that's the orbit we spent most of the last few years in, because it minimizes the amount of fuel that you use. But we had that early on just to be what we called a commissioning orbit, because we weren't trying to take really high-resolution photos yet of the north pole or something. It was a great time for each of the instrument teams, though, to see them relax, as well. All of the work that they'd worked so hard to do over the previous four years is for nought if you turn on and your instrument's dead. Each of those instrument teams getting to share their excitement as the turned on and realized that their instrument was working exactly as they had designed it to was very satisfying.

JOHNSON: Yes, I could imagine so, and a relief.

BARTELS: That, too. That, too.

JOHNSON: Because they did have to go through a lot during testing, so I'm sure it's always a relief to know that the made it through the actual flight.

BARTELS: Yes, exactly right. Exactly right.

JOHNSON: You had worked on instruments before, so this was a flip for you, even though you—you weren't the instrument team. You were a management person. That's an interesting perspective that you had. Let's talk about the LROC and those photos, the first photos that came back. One of them, I know, people wanted was the Apollo 11 site by the anniversary. Maybe talk about that for a minute, when those first photos started coming through.

BARTELS: Those were some of the most satisfying times for me in the mission, because at that point, many of the people who were there during the development phase had moved on to their next jobs, but I'd stayed on for that first year, year and a half, moving to actually the operations center to stay with the mission. So when those first images came out of not just the Apollo modules still on the surface, but also the ones that could actually see the buggy tracks. It was really, really amazing. It really drove it home to me because the resolution of those images was really extraordinary. When you see them shrunk down and compressed on a small laptop screen, you can't really see some of the detail. But here at Goddard in the visualization center, on one of the large screens, they were taking some of those images and blowing them up so that you could really just walk right up to it. I definitely remember—maybe my favorite time on the mission was when I was able to do that, go up to this big wall of an image that was 20 feet across and just walk right up to see the Apollo module there, and to be able to see the buggy tracks, it was like you were just hovering over the surface and being able to see it. It was really amazing.

JOHNSON: I talked to Rich [Richard R.] Vondrak around 2017, and during the interview, he pulled out some photos. Again, still, even in 2017, he was so excited to show me those Apollo photos.

BARTELS: Yes. Those photos and some of the other really beautiful, shaded images we've seen of the surface that you can still find online are some of my best memories of my whole career here. The neatest thing about LRO to a lot of us is that you're able to go out at night and just look up and see the Moon there and know that something that you touched with your own hands and built is sitting right there. You know? Those images really drove that home, though.

JOHNSON: Like we were talking about at the beginning, this wasn't built to last this long. It's still up there working. Are all the instruments still doing the work, too?

BARTELS: Pretty much, yes. I still stay in touch with the operations folks, even though I'm not an active member of the team. I still go to the science team meetings. They've aged beautifully. Most of the instruments are what we call single string. It means if any piece fails, it goes down. The whole spacecraft is mostly single string, as well. Some of the instruments have aged and degraded a little bit, but they're all still operating. All the teams are still taking measurements. The laser altimeter, the laser power has dwindled over the years, and so now when we do this eccentric orbit to save fuel, they're only taking active measurements when they're at the closest altitudes. The tech demo, the Mini-RF, one of its electronics failed along the way. Again, though, an amazing success many, many years beyond what it was designed for. But it's still used for a special type of measurement they do called a bistatic. All of the instruments are still in use.

The LROC cameras, in particular, have really become the stars of the show, though, because of the science data that they've found. We've been imaging the Moon so long that we're now able to actually compare images taken now versus images maybe taken in 2010, and sometimes see small impacts or bombardments that have happened in the last 10 years, which was really interesting to folks, because people didn't realize—the science team is astounded by that, because what they're seeing is, there's a lot more impacts still coming, small impacts, than people had assumed was taking place. The fact that the LROC cameras are still chunking away, taking as many images as we can get down to the White Sands Ground [Terminal, Las Cruces, New Mexico]. We've imaged now the whole Moon, I believe—the attempt has been to cover the entire surface at least once with these really high-resolution images, where every pixel is like half a meter, which is astounding. Many of the places we've seen multiple times. It depends how the ground track coverage—as the Moon goes beneath us as we orbit, sometimes there are little pieces you haven't quite caught.

But the amount of imagery that LROC has done, the amount of terabytes of data returned from the LROC images alone, dwarfs, I think, almost all other planetary missions put together. It's really amazing. Each of those images that you see, it's not like a normal camera image that has an aspect ratio like a TV. The way the LROC camera works is, its whole camera array is only one line across. It's like a thousand pixels by one. What it does is, you point down, and as you go over the surface, you just continue to image and build up that array. We'll build up a strip that was like 25,000 rows long, one row at a time, just by the spacecraft going across it. There's so much more data than what you typically see online, where you see imaging that's formatted to fit a screen. The real images are just huge, the ones that go into the Planetary Data System.

JOHNSON: I was hoping Mark Robinson—I had invited him early on, and unfortunately, he didn't want to interview, but he sent me a list, an amazing list, of everybody that had worked on LRO. It's quite extensive. I could spend the rest of my career just interviewing people on LRO from that list. But yes, I was a little disappointed that he didn't want to talk. I did talk to Scott Brylow.

BARTELS: Oh, good. Fantastic. Scott's one of my favorite people in the industry. Even in retirement, I'm trying to hire him back to consult on the Malin cameras I'm flying on DAVINCI. That company called Malin is, like I said, they're one of the most interesting companies in the industry, and Dr. Robinson was their first external customer. It was very interesting watching him work with them, first when he started at Northwestern, and then he went to Arizona State. Dr. Robinson is a remarkable person. He doesn't like to draw a lot of attention to himself, so it is hard to get him to do interviews.

JOHNSON: That's the feeling I got, that that's why—he would talk to me through email, but he just wanted to make sure I had the whole team. He felt like there's a lot of people that you need to talk to, which was great. I love it when people give me names, so that's not a problem at all.

BARTELS: You know, that Malin company—and I'm sure Scott gave you a lot of the details. But as an outsider viewing them, I can say that what makes them so unique as a group is, that's a very small company in San Diego [California] that was started by a geologist who wanted to be in charge of building the cameras that take the data that he does the geology for. He started this small company where almost all of the original engineers were also PhD scientists. They were typically coinvestigators, or deputy PIs, or something on the missions, as well. It's not a typical company, at all. When we started working with them, I believe there might have been only 10 people working on the actual camera. They had a group doing operations, as well. It's a very different approach. Most of these aerospace industry ones, we compartmentalize and break up the work, and everyone has a little specialty that they do. The way the Malin company worked was, these very brilliant PhDs mostly wore multiple, several hats, and did multiple functions. They're so smart. Sometimes they're not the easiest to work with, because they are so smart. But they've become one of my favorite companies. After LRO, we've flown their cameras on OSIRIS REx, and Lucy, and now on DAVINCI, as well, where they're our main imaging cameras for the Venus surface.

They are a really extraordinary company to work with. The quality of the products they produce, because they have such a small team, their cameras are much less expensive than buying it from a big aerospace company. They have functionality as determined by what a geologist wants to see his camera do, rather than what optical designers or people who might want to complicate the technology, or something. They'll only put in the technology that they feel results in imagery that matters to a geologist. They are a remarkable team to work with.

Scott Brylow, in particular, was so helpful on our mission, because he was designated within the Malin team to be the interface to NASA, because we'd like to see things done a certain way, and Malin does things the way they do, and sometimes those things, they're not quite the same. It was up to me and Scott to figure out the right balance of what things would they do that they wouldn't normally do, because NASA was asking them to. We asked, sometimes, things that the Jet Propulsion Lab doesn't necessarily do. Then there were times where Scott would convince us that we didn't need to do the thing we were asking them to do, that what they were doing was just fine. Scott, he was the real engine that made that LROC camera go. Almost every one of these instruments had someone like Scott who was really the piston driving it forward. Sometimes it's a system engineer. Sometimes it's a manager. Sometimes it's a scientist. But each one of these groups had, typically, one person who would not see their instrument fail and saw it through to conclusion. For LROC, that was definitely Scott.

JOHNSON: That's good to know. Let's talk about some of the lessons learned. You mentioned a couple as we were talking. Are there any others that are outstanding in your mind that you learned and that you've been able to take to these other missions that you've worked on?

BARTELS: Yes. Yes, a little bit. The first one that I've tried to take with each mission is one that I mentioned earlier, which is, with diverse teams and diverse ways of thinking, the best results come from helping them be the best versions of themselves that their institutions know how to be. That's different for us working with the Russians, versus the Jet Propulsion Lab, versus Goddard, versus Southwest, versus MIT, versus Malin, in particular. Realizing that in the end, the point is to have the best functioning data sets and hardware to produce it that we can get, means accentuating their strengths. That's been one lesson.

There was one engineering lesson that we didn't really get a chance to get to yet that I do take with me. Because all of these instruments except for the tech demo had had previous incarnations on other missions, they all had a baseline design to begin with. A really important part of that baseline design is the way in which the instrument talks to the spacecraft and listens to the spacecraft. That we call command and data handling. Each of the instruments had a heritage approach to the interfaces that they had designed on a previous spacecraft. The interesting thing—I guess I haven't thought about this in a while. Each of those instruments, their previous examples that they built had been on a different spacecraft built by a different institution. They were used to doing things—the JPL instrument had flown on a JPL mission. The Southwest instrument had flown on an APL mission. The LROC cameras had flown on a different JPL spacecraft. Each of them had had a different set of experiences that they said, This is our heritage.

Early on, our program manager, Jim Watzin, and then Craig Tooley, our project manager, they pulled me aside and said one of my first jobs was to convince them all to standardize their interfaces and to be what the spacecraft already knew how to do. He said, "None of them are going to want to do this, because they're used to having the avionics interfaces that they had designed to in the past." We had two basic technologies on the spacecraft, and Mr. Watzin and Mr. Tooley said, "Make them pick one. They can pick one or the other, but they can't just have anything they want, because we can't design seven different kinds of interfaces to seven different instruments. We don't have time for that. It will be quicker to have them adopt to a standard that we give them." In the end, we only had one exception to that rule.

At the time, I thought that, because I was more worried about protecting my instrument delivery schedules and my instrument teams, I was concerned that the project was asking them to all, right off the bat, make a change at the very beginning in their design. I thought this is getting us off to the wrong foot. But we came to see, as we went along, that that really was the right answer, because it made everything simpler for integrating to the spacecraft later on for the instruments to be speaking in an avionics design that would be something the spacecraft could do and have commonality between the instrument buses.

I don't know how technical your readers will end up being for this, but we basically had a SpaceWire interface and a one, five, five, three, MIL-STD-1553 interface. The direction was have them pick one or the other. We did that. The one exception we made was for the instrument from Southwest, the LAMP instrument that Alan Stern's team was responsible for, because he already had a flight spare essentially complete. He said, "You're not changing my development, you're changing our whole instrument. I'm already ready to deliver you this electronics interface, and so please don't change that." So we allowed that team to stay with their heritage.

These two lessons learned are flip side of the same coin. The one side is allowing the diversity of communication styles and cultures for them to be successful. The flip side of that is standardization and conformity of engineering interfaces. You can have both of those things. You can have very different cultural styles of teams, very different diverse work approaches, but all still converge on the exact same standardized engineering approaches. Those were two really important lessons I took.

The other one is more of a personal one. It may not be appropriate for your folks, but making sure that you've staffed your team adequately. I understaffed my team and myself, and I should not have put myself or my team through the amount of work that I did. In retrospect, I would have insisted on a larger team than I had, because I worked my team and myself too hard. I haven't done that to a team since then because the human toll can be unacceptable.

JOHNSON: Yes. I would think with that many instruments, you would have to have a large team. So how many people did you have working with you?

BARTELS: Yes. On my team, I had two system engineers and one manager, as well. That was it to work with all the teams. I did have support from the integration and test team as we moved along to be deputized, and of course the instrument teams themselves helped. But what I hadn't anticipated was that there would be times when we were up to seven days a week, two shifts a day, for months in a row. It was really too late at that point to bring additional folks on, so we had some folks put in a workload that should not ever have been requested of them in order to make sure we could support this. That may not be appropriate for your audience here, but one thing that I've learned in the past is, the human toll of working people too hard is not worth the cost savings or the benefits that come with it. I've worked hard to make sure that we've never had payload teams like that in future of the same staffing. When I moved to OSIRIS REx, our payload team there was nine for one few instrument. That was a lesson learned from just making sure that the human toll, the impact of this is just as important as the engineering impact.

JOHNSON: Yes, it really is, because you are working with humans as well as engineering products and scientific products. We have about 15 minutes. I have a few more questions.

BARTELS: Oh, please. And we can do a follow-up session if that works for you.

JOHNSON: Yes, yes. You mentioned that you stayed on about another year. What were you doing during that time period? Like you said, a lot of people, as soon as it was up there, it's working, everything's good, they went on to a different mission.

BARTELS: Right. Yes. I don't want to make it about me, but the reason I asked to stay on in that role and to do it was because, first, I had the experience base that had come with all of those instruments as we executed the first year of the mission, and I still had all the contacts with the different PIs and the rest of that sustaining engineering support. That was part of it. The other part of it is, at that stage—again, I don't want to make this about me, but that was my ultimate instrument experience—but I had made a focus in my career to change over to more on the spacecraft side. So what I did then is, I spent that year—the rest of the spacecraft team, from a daily standpoint, all moved off onto their other jobs, and I started to pick up each of their functions a little bit for—we call it sustaining engineering. So I stayed there to learn more about the spacecraft, because I had learned about all the interfaces to the spacecraft, because that's what my instruments had done, and this was my time to actually learn the whole rest of the spacecraft itself as I picked up some of the knowledge from the engineers as they started to move away. I spent that first year, year and a half, doing what's called sustaining engineering, which was justified by the instrument support, but my personal ambition on that was, I wanted to make a focus towards moving on to the spacecraft bus side, and that was my opportunity to learn more about that before moving off to another job where I would be leading a spacecraft.

JOHNSON: What was the next mission you worked on?

BARTELS: The next mission I stayed on for an extended period of time was OSIRIS REx, where I was the spacecraft lead. It tied really nicely. I had a short period of time where I went back to work for the weather satellites, partially because the project manager for LRO, Craig Tooley, I really admired. There was more I wanted to learn from him, and he moved off over to the weather satellites, and so I moved over to that with him for a period of time to be in Cathy's role as his deputy. Then when OSIRIS REx became available, because my love is the planetary missions, I moved back to OSIRIS REx and stayed there for eight years.

JOHNSON: Unfortunately, Craig Tooley passed away. I interviewed Cathy, and I did ask her some questions about his management style and that sort of thing, just to try to capture some of that. Is there anything you would like to add—since you've worked for him on more than one project, anything that you'd like to include?

BARTELS: Yes, I definitely would, because he's the engine that drove this mission. Anyone who worked the mission would tell you that. He was maybe the most remarkable leader I ever worked for. Brilliant manager, also a brilliant engineer. The thing that I really learned from him was, as brilliant as he was at the technical details of both management and engineering, he had a very empathic leadership style before that was in vogue, actually. The industry has changed now to more of how we are taught to lead. Up till working with Craig, I was used to much more hierarchical leadership that comes more from a military-type style background. But he was unbelievably empathic. People, whether in individual settings, small groups, or large groups, always left a meeting with Craig knowing that they had really been heard, not just listened to but really heard, and that what they'd said had been listened to and not just rejected out of hand.

He was a very charismatic person. He tended to draw people to him that stayed. I mentioned that team that he started with that he pulled over mostly intact. It's because people would pass up promotion opportunities just to stay part of that team working with him and the spirit that he created. He created a real spirit of fun, and enjoyment, and joy about the work that, again, knowing how much pressure we were under, never allowed it to become a drag or a death march. He always found ways to try to keep it light and to enjoy the work, and to find little ways to celebrate along the way. Maybe sometimes the team celebrated a little too much. There will be stories we don't tell you that happened about the mission there, too. I learned so much from just watching him.

The most important thing I learned from him—and these are my words, not anything he ever said, but it's just the way he exhibited it—that these missions that you think are about spacecraft or about the data that come from spacecraft are really the stories of the people who built them. The spacecraft—and again, these are my words, not his—the spacecraft that you build stands as the testament to what you've achieved as a team, but it's actually a byproduct of that team formation and how the team works together. All like different musicians playing in a symphony, each part of them playing their individual parts to come through. He never said words like that, but he just lived them. The example that he showed, it's a difficult one to emulate, because he was so personally charismatic that if you attempt to be his style, it's not authentic to yourself. But some of those central core messages about honest, true empathy, and recognizing that the people are the mission and the hardware is the result of those people working together, are lessons that sound easy and trivial, but it was not.

I hadn't experienced that before, and I haven't always experienced it since. He had a real management style that would really go over well today, because teams expect a different style of leadership than they would have seen in the '80s or '90s or 2000s, and he was very much ahead of the curve, I think, in that style of people-focused leadership that was very remarkable to see. He built allegiances to people and they built to him, that if he asked them to join his project, they wouldn't even give it a second thought. They would leave what they were doing to come work with him again, just for those experiences. It's why I followed him to the weather satellites for a while, even though I wanted to stay in the planetary world, because I still wanted to learn more of his style, because I was not as naturally empathic, nor am I yet, as he just was by nature.

He was a very remarkable person. We've named one of the control centers here after him, and the people who worked with him still get together and talk about him over drinks. Time moves on, and one of my real fears here is that the stories of both Jim Watzin, who was the same—many of those same traits. From the spec side, those two were very much of a type. I know people retire, people move on, and their stories get forgotten. It would be amazing if you could interview Craig, because Craig would be able to give you perspectives that people like me and Cathy can only give you indirectly.

JOHNSON: Yes. It's good to hear your impressions, though, of someone like that, because those are lessons that you can take to every position you hold. Other people can understand that, like you said, it's more popular now, but yes, during that time period, it definitely wasn't the way most managers were, unfortunately.

BARTELS: I still think about him almost every day when I'm in a situation where I think, "How would Craig handle this situation?" You know? Yes.

JOHNSON: Yes. It's good to have those role models.

BARTELS: I'm going to get emotional if we don't, so forgive me.

JOHNSON: Well, I won't make you do that.

BARTELS: It was a sad time at the end. Let's just put it that way.

JOHNSON: I can imagine. I'm sure it was a big loss.

BARTELS: Yes.

JOHNSON: For a lot of reasons.

BARTELS: Yes, for a lot of reasons.

JOHNSON: Thinking back over LRO in that time period and getting to work with that team, is there anything that you're most proud of?

BARTELS: You know, actually, I'm trying to figure out how to say this without sounding corny. The way that team worked together, it helped that many of them knew each other even before they came to that mission, but I'm most proud to have been part of a team that was that cohesive, and unified, and synergistic, in terms of how they worked. Maybe I'm romanticizing it too much, but it really had a family, almost, feel to it, that people were each other's brothers and sisters in a way that military people tell me sometimes military folks view their coworkers. But it's hard to create that feeling sometimes on other missions. I don't know that I'm proud of it because I didn't have anything to do with it, but just to be part of a team that was so unified on achieving a goal and were willing to help each other achieve it.

Sometimes people will say, "Well, as long as my part works, the other part's their problem." People would consciously make the plans to help not just do what they do, but help the other side of the interface, and help them out, too. People would volunteer to take a weekend shift, let somebody else go off and do something with their kids, or something. There was a remarkable feeling of teamwork, and presence, and culture that started from Watzin and Tooley.

Personally, seeing the first light data sets from every instrument team was—I'm sorry. First lights is the term we use in the industry for the first time you turn them on and get data, if you're unfamiliar. But seeing the first light data come from each of those teams, and seeing how happy each of those teams were, and to see the sigh of relief on the principal investigator for each instrument's face as they got their first data sets down, that made it all definitely worthwhile.

JOHNSON: I can imagine. Well, I won't keep you any longer, unless there's something you want to talk about that we haven't talked about. We've gone a couple hours.

BARTELS: Well, I guess the one thing, if we ever did a follow-up, I feel self-conscious that this has been awfully egocentric about me working with the instruments. We should talk more about the instrument teams themselves, because they were the interesting part of the mission. So if we get a chance to do a follow-up, I'd actually like to talk more to give each of the instrument teams some more visibility than we were able to do here.

JOHNSON: Okay. That's great. No, that's fine. Yes, it would be hard to talk about each one of them and everything else in a couple hours. We can do that. But I appreciate you talking today about everything.

BARTELS: Okay.

[End of interview]