DISCOVERY 30TH ANNIVERSARY ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

INTERVIEWEE ARLIN BARTELS
INTERVIEWED BY SANDRA JOHNSON
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JOHNSON: Today is August 18, 2023. This interview with Arlin Bartels is being conducted for the Discovery 30th Anniversary Oral History Project. The interviewer is Sandra Johnson, and Mr. Bartels is at Goddard Space Flight Center in Maryland and talking to me today over Microsoft Teams.

This is our third interview for the Discovery Project. I appreciate you talking to me again and agreeing to keep coming back and talking about all these missions you were involved with. I wanted to start today talking about the MESSENGER [Mercury Surface, Space Environment, Geochemistry, and Ranging] Mission and how you got involved with that. We talked about LRO [Lunar Reconnaissance Orbiter][1] before and the LOLA [Lunar Orbiter Laser Altimeter] instrument, so let's move into MESSENGER and talk about that time period.

BARTELS: Yes, absolutely. First, I need to make sure that I'm being clear with those. My role was more limited on MESSENGER than it was on the others because Goddard's participation in MESSENGER was in a single instrument, the laser altimeter we called MLA, the Mercury Laser Altimeter. That development actually preceded the LRO development in time. It was actually a lot of the MESSENGER MLA people who moved over then and became the LRO LOLA people, always had the LA at the end. We had the MLA for Mercury Laser Altimeter, and then the

[1] Lunar Reconnaissance Orbiter was the first U.S. mission to the Moon in over 10 years. LRO created a 3D map of the Moon as part of a program to identify future landing sites and resources – including deposits of water ice shadowed in polar craters. LRO continues to orbit the Moon.

Lunar Orbiter Laser Altimeter was LOLA. I'm assuming you've been talking to other folks about the MESSENGER Mission maybe overall so you kind of know about the overall MESSENGER Mission.

JOHNSON: I have not talked to anyone about MESSENGER yet. Any information you'd like to share, that would be great.

BARTELS: Yes, I'll give you a little background. The interesting thing is that orbital missions to Mercury have been really few. They've been very rare and far between. They've been limited mostly to—until MESSENGER, they were just flybys basically. The reason why is because the energy required to get there, from a launch vehicle to Mercury, makes it hard to slow down and capture and orbit when you're there. You're close enough to the Sun and you're going at such speed, and Mercury is so small, that up until MESSENGER and a more recent European mission called BepiColombo[2] there haven't really been any orbital Mercury missions. Up until MESSENGER, all the globes that you'd see and maps of Mercury all had big, open, blank areas in it because those were from missions that had just flown by.

The thing that enabled the MESSENGER mission that was so interesting was advances in what they call orbital mechanics analysis. That's the engineers who figure out how to do basically slingshots past other bodies in the solar system to either add momentum or subtract it. The interesting thing with going to Mercury is that you're actually trying to subtract momentum. Sometimes missions that are going to the outer solar system will do what's called a gravity assist

[2] BepiColombo is an international mission comprised of two spacecraft riding together to Mercury to orbit and to study the planet from unique vantage points. The European Space Agency (ESA) provided one orbiter. The Japan Aerospace Exploration Agency (JAXA) supplied the second orbiter.

where they swing back. They leave Earth and orbit sort of near it, and then they come back and do a slingshot past Earth to send them out into the outer solar system. That's what OSIRIS-REx [Origins, Spectral Interpretation, Resource Identification, and Security – Regolith Explorer][3] did, Lucy[4] did, Jupiter missions do, Saturn missions do. With Mercury, it's exactly the opposite. You fly by Venus and do Venus. They call them gravity assists but it's actually to slow you down. And so rather than using these slingshots past Venus to speed you up, you sort of catch the backside instead and it helps slow it down. The advances in the computational physics to allow us to figure out how to do that is what made an orbital mission to Mercury feasible.

That's what was proposed in the 1998 Discovery round, and it was selected then for turn on in '99. That mission, the lead institution is the [Johns Hopkins University] Applied Physics Lab [APL] up in Columbia, Maryland, and a really tremendous set of engineers that devised a fantastic spacecraft. It's able to survive the thermal environment of Mercury. Most important is once you solve the problem of how do you slow down enough that you can actually capture and to orbit and have a stable orbit, comes the realization that you're still going into and out of shadow with extreme temperature variations. The orbit we had on MESSENGER was one that I believe is a 12- or 13-hour orbit, but it was highly, what they call, eccentric. It wasn't a nice circle. It was more of an oblong oval with Mercury at one of the ends of that oval. So we would swing fast, and then you would slingshot in and do a fast pass nearby, and then come back out again. That was the main orbital pattern that they had through that mission.

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[3] OSIRIS-REx is the first U.S. mission to collect a sample from an asteroid. It returned to Earth on Sept. 24, 2023, to drop off material from asteroid Bennu. The spacecraft didn't land, but continued on to a new mission, OSIRIS-APEX, to explore asteroid Apophis.

[4] Lucy will explore a record-breaking number of asteroids, flying by three asteroids in the solar system's main asteroid belt, and by eight Trojan asteroids that share an orbit around the Sun with Jupiter.

What it meant is because of heat loading from the Mercury surface, you had to be able to design a spacecraft—the folks at Applied Physics Lab did—that would be able to withstand just being that close to the Sun to begin with because Mercury, of course, is the closest to the Sun of all the planets. There was a very special heatshield that they built. You can almost think of it like a knight's shield in a way, but a huge heatshield that was always protecting the spacecraft from the Sun. But then that portion that we shielded was still getting this hot-cold, hot-cold cycle from the planet. The analogy we always had, it was like running through a kitchen with the oven door open and running in a circle in the kitchen. You'd run in front of the oven and you'd get hot, and then you'd have the rest of the running around the kitchen to cool down before you came in front of the hot stove again. And so there were some real technical challenges there that the team from Applied Physics Lab had to confront. They really did a tremendous job.

I'll try not to speak for the areas that I wasn't directly responsible for. They should have the right to speak for themselves. But the portion that we built for them was a laser altimeter. Just like the laser altimeter on the LRO mission, its job was to do very precise mapping of the terrain and surface of Mercury to create basically the topographical maps of the missions and the grid for the map that all of the other images and things could be put to. It was a really tremendous job. That was a build of ours that was part of a long series of planetary laser altimeters that we've been doing with Goddard going back to the '70s, actually. Sometimes we build them ourselves, sometimes we subcontract them out.

There's been a group here for a while that does that sort of planetary geodesy is what it's called. In particular, we had a really extraordinary PI [principal investigator] and deputy PI. The PI's name is David [E.] Smith, who's really a legend in this field. He almost, some would say, invented this field of planetary lidars. The deputy PI is a woman from MIT [Massachusetts Institute of Technology, Cambridge] named Maria [T.] Zuber, who is really a legend in the industry, and within Discovery world was also the PI of the Discovery GRAIL [Gravity Recovery And Interior Laboratory][5] mission to the Moon. It was a very dynamic PI team that we had. The group that built the MLA [Mercury] Laser Altimeter was different at the end than it started for a significant reason. I mentioned that here at Goddard we have a long history of doing planetary lidars, and one of those planets that we do is Earth. We tend to build really large, high-power systems for Earth lidars because they have to penetrate the atmosphere, or sometimes the vegetation canopy for the ones you see now that are doing relief work on the Amazon. We tend to build those very large Earth observing lidars and then much more smaller, nimble ones for the planetary missions. They have to be smaller because the power, you can feed them less and you try to miniaturize everything for deep space compared to a big Earth platform.

When MESSENGER MLA was awarded, the intention was that it would be built after the group was done, that had been doing this work for so many years, was building a very large Earth observing lidar called GLAS [Geoscience Laser Altimeter System] on the ICESat [Ice, Cloud, and land Elevation Satellite] Mission. So the idea was they would get done with that and then a large portion of the team would just roll over and start on the MLA instrument. That works great as long as everybody’s schedules pull together. What ended up happening was that very large complex GLAS instrument, and the lasers in particular that went in it, that took a lot longer to get done than people thought. And so MLA wasn’t getting done quite yet. People

[5] NASA's GRAIL mission flew twin spacecraft—Ebb and Flow—in tandem around the Moon to map variations in the lunar gravitational field. The probes generated the highest resolution gravity map of any celestial body to date. At the end of the mission, the probes were purposely crashed on the Moon.

were trying, trying to do it part-time, but they were doing it on top of the work they were doing for the GLAS instrument. There were some key critical skills, though, of certain people who had to be required on both missions. But there came a time where it was getting obvious that that ICESat GLAS instrument wasn't going to get done in time to get MLA done in time.

One of the things that makes Discovery missions and New Frontier missions special is that because we have to have the planet orbital geometry just right to do these slingshots or slowdowns, we have very specific launch windows, actually launch periods. Each day is the window. The sequence of days is the period. We typically have fairly narrow launch periods that if we miss those, even if there is another chance it sometimes is much later. This is true for Mars missions as well. That's why when there's a delay in a mission, like the Psyche[6] Discovery mission recently had, it has such reverberations through the launch schedule and through the budget because the opportunities are fairly spread apart. Because of that, MESSENGER had to—that 2003 original launch opportunity was the only one that was the baseline. It turned out later, fortuitously, they found a 2004 backup window as well. But the point was that there came a point where David and Maria realized that—they were involved also in that GLAS instrument but they weren't in charge of it—their instrument wasn't going to get done in time to catch a ride on MESSENGER.

And so at the Center, what they did is they pulled together a group of some of the most critical people who worked on the GLAS instrument that were very uniquely skilled, did start to peel over to MLA. But then a whole other crew came in from the engineering directorate to basically finish off the MLA instrument, and I was part of that crew. I was the project manager

[6] The Psyche spacecraft is traveling to a unique metal-rich asteroid with the same name, orbiting the Sun between Mars and Jupiter. By August 2029 the spacecraft will begin exploring the asteroid that scientists think – because of its high metal content – may be the partial core of a planetesimal, a building block of an early planet.

[PM] that came in then that helped take this design that was starting to fall behind quite a bit schedule wise and make sure that we had to make sure it was delivered on time so the MESSENGER could launch.

It was a very clever design that the MLA team came up with. It had a single laser and a single optical path to return. Every laser pulse that's fired at the Mercury surface during its lifetime, measuring that precision timing down into the picoseconds that it takes to go—since you know the speed of light, if you know where you are roughly in relation to the planet and you know exactly how long, like a precision stopwatch, that that pulse took to go there and come back, then you can tell how far you are from the planet. You do that enough times and the very complex mathematics to pull all that dataset together, and eventually you can do a really nice map of the whole surface. That's certainly what we did with MLA.

The folks from Applied Physics Lab were very attuned to our schedule because there was a time period where they were concerned that we weren't going to show up in time. And so this became a bit of a political hot potato between the Applied Physics Lab and Goddard's center management, which is why Goddard decided to bring in a whole second crew here. Some of them had laser experience and some had less. I had some in the background. It was then kind of an all hands on deck to get it finished because we were starting so far behind. Specific action was at our critical design review—this was before I and other crews came on—that direction went to the Center that said, "You either need to staff this so that it gets done in time or else we need to stop this," and so we did.

It was a lot of overtime and extraordinary effort on some of the folks. By the time we got it into integration and test, we were going seven days a week, two shifts a day. That went on for a better part of a year. Our I&T [Integration and Test] lead would sometimes sleep in the parking lot because he didn't have time to go home and back before he came back on the next shift. It was a really, really amazing set of those folks that worked so hard for this. I definitely also want to note the lead system engineer, John [F.] Cavanaugh, who also was the system engineer for the LOLA laser altimeter. If you haven't talked with him, it would be great to get his perspective. He's a very humble person, but he's maybe the best lidar engineer east of the Mississippi. He's absolutely fantastic for this kind of work.

The challenges for MLA were more about getting behind and bringing a new crew in but having still a pretty fixed delivery date so that it could catch that ride of MESSENGER was really important. It did turn out that because we had a couple of things break our way and people like John were providing the expertise, we actually got to the—by the time we were able to deliver to the spacecraft, we were sort of the middle of the pack of instruments. We'd caught up from being so far behind that people were threatening to actually cancel that altimeter to being right in the pocket with all the rest of them. It was a really good feeling. And then working with that Applied Physics Lab team—so we were a small part as part of a big mission. From that point on, our role came back to more just supporting overall spacecraft testing that involved us and then starting to plan for the science team preparations and the rest.

Things were going pretty smoothly on MESSENGER overall. They were having some cost issues, but a lot of these small missions do that have fixed time constraints. The interesting thing that happened towards the end for us was you have to have—what you always find on these missions that have—we always call them the project development triangle of schedule, budget, and risk. On a mission like Discovery or New Frontiers, what makes them a little unique in NASA is that your schedule is set by these launch windows. Your budget is capped by the lifecycle that you've agreed to in what they call a PI-managed cost cap. And really the only dial that you have left is risk or performance of the hardware. Earth missions tend to absorb schedule slips because it's "just money." You don't have this launch period aspect you have to deal with that makes the planetary missions unique.

What had happened was, as often happens on these planetary missions as you get closer and closer to the launch readiness state—that's what they call an LRD—something has to give if some component is late or has an issue, has to be repaired or something. What MESSENGER ran into were the typical sort of slowdowns that you get from late instruments and hardware. They were always making sure they were clear about the risk assessment they had of their mission. The part that they hadn't had time to really do was the fault protection software checkouts.

That's actually something we didn't talk about on LRO, but it's actually very important for these deep space missions. LRO, because it—the Moon is still close enough by that you can send commands back and forth that only take a few seconds to reach. Something that is really characteristic of the deep space missions to other planets is that they have to be able to protect themselves because you really can't just have ground operators sending commands and receiving them to joystick spacecraft because it's so far away. The commands take too long because, again, the speed of light. The command has to reach the spacecraft, be processed by the spacecraft, and send a response back. That can be many minutes or even hours depending on how far away the spacecraft is.

What happens with all of these spacecraft with Discovery and New Frontiers, other than LRO, is they put in substantial software where the spacecraft learns to protect itself. The spacecraft has to sense if some aspect of the spacecraft is misbehaving and then figure out how to take action to fix it. Usually it's by shutting it off if it's an instrument that you can stop taking data from. But if it's a core part of the spacecraft, the spacecraft has to be able to figure out how to control, alt, delete itself very quickly and bring itself back up to full operating status. That's usually the last part of the development to get done because you have to have all the hardware in place and the software designed before you can do that testing. That's actually what has held up the Psyche Mission launch as well, the same sort of thing.

What happened was there was a period before the launch in 2003 where NASA management from the Science Mission Directorate did an assessment that MESSENGER was actually taking too many risks or too many chances on getting their flight software checkout done by the launch date. They directed the MESSENGER mission to find a later launch date that would allow them to complete all the software work. That same group of people who devised those really clever ways to slingshot past other planets in order to help get you where you need to be found another way to get to Mercury still. It involved a different set of orbital flybys, but they found another way that—because I didn't know we were talking MESSENGER today, I didn't do my homework. I think it was eight months later, maybe it was nine months later that it took us to launch. It took us a year and a half longer total to get to Mercury.

Really because this was an orbital mapping mission, the science team was concerned because it meant more than a year, a year and a half delay until they started getting data. From an engineering and management standpoint though, we had to think about, well, we weren't designed for that extra period of exposure to the space environment. Are we actually okay with this? Because it's going to take us now—we're going to be longer on the ground and also longer in space because it was a little more innate way to get to Mercury. And so we had to do an analysis towards the end to show that all of the elements could survive longer duration exposure to the space radiation environment and still operate successfully. It turned out that all of this, including our MLA, was designed so that we had enough margin that we were still going to be okay. From that point on, it was just all systems go. We were down to a very small crew by that point because in 2004, for instance, I was already starting to do early work on LRO. That small science team led with John Cavanaugh, Xiaoli Sun, Greg [Gregory A.] Newman. I can provide you some other names if you ever wanted to interview more folks on MLA.

JOHNSON: That would be great.

BARTELS: They stayed all the way through, of course, the early checkouts on the ground and through the entire mission. It's an interesting thing with the lidar. There's only so much that you can do with it after you launch and you're cruising in deep space. I think I mentioned the way it works is once you're at your target body, your planet, you fire at it and you bounce the signal off. By that time, you tell how far you were. But if you're cruising through space on your way to get there, if you're a camera you can take pictures, even if it's just the stars or of space. A lot of other instruments, you can at least turn them on and make sure they work. But if you're just cruising through empty space on your way to your destination, there's very little you can do with the laser altimeter. The team did the checkouts they could to make sure that the detector works, for instance. Then we could at least fire the laser, but there was nothing that we could actually fire against.

I only bring this up because there was one really interesting experiment that they did that was one of the first papers that came out from MLA. These detectors are so sensitive they can work over great distances. We actually did one experiment on route where we turned MESSENGER around back to Earth and shot a laser back to Earth that even from that long distance on the way to Mercury, we were still able to pick up those signals from the ground here on Earth. And so we were at least able to tell that the laser was up, running. And the way it was designed, it wasn't just consuming power. It was actually operating as expected.

That was an experiment that our team was really interested in because this was very early in the days of laser communications and using lasers instead of radio waves for high-density transmission of communication, which has now become more viable. We actually have laser communication demonstrations we're doing, and that's certainly the future of where this is all going. But this experiment from MLA was the first, to my knowledge—or certainly the farthest anyone had ever established a lasered link path for. Our science team was—even though they came up with these really amazing maps of Mercury that came from it, I think there are a couple of our science team members that are almost more proud of that first experiment than everything that followed. It was a very concentrated effort over a short period of time.

One of the real lessons learned that came out of this, I think at least within Goddard, for planetary missions is you can't let an instrument get that far behind and tell them to catch up because we probably caught a few breaks along the way that allowed us to still get caught up to the MESSENGER Mission that would've been easier to do if we had found it earlier. And if they'd waited much longer, we probably wouldn't have gotten done in time.

I know at least within the planetary community here at Goddard, there's much more attention to making sure you never get very far behind because it's a very unforgiving schedule to catch up. It's sort of like being in school. If you haven't read any of your textbooks until the end of the semester, it's hard to catch it all up and cram for the final exam. At least in the local world that I live in, it has changed some of the way we do business just to make sure that we never let instruments get behind again. That was a long preamble. There are probably a lot of things to follow up on.

JOHNSON: Yes, that's great. It's interesting because you came in as part of that team to help once it was already behind. Was there already an instrument manager working on this or did you just work with that person? How did that work? I was thinking that throwing more people into it, other than working a lot of hours, how did that help get it caught up?

BARTELS: It's a really good question. Along the way, yes, there was—the person who was the project manager was a very bright and talented person. He just was sort of new to the work, and so he then became my deputy from that point on. We worked side by side, and actually he had a very critical role from that point on. I knew that to bring on a deputy who had been in charge of the whole team could cause some friction, and so I wanted to make sure that he knew that he had still a really important role to play on the mission. We put him in charge of the whole laser, which is the whole heart of the instrument. I broke up the work with him so that I was doing the rest of the instrument, and he sort of had an instrument within an instrument to focus on.

With the rest of the team, it was interesting. I mentioned that an awful lot of the folks were working that large Earth observing mission called GLAS, but not every person who had a lidar experience was working on that one mission. Some were working on other smaller missions. And so we sort of cherry-picked, from some other missions, people who were working on other similar types of technology, maybe ones that were in operations that were getting a little slower in terms of daily work, or ones that were still on the drawing board that hadn't been started yet. In some cases, we pulled on some real experts there. That's when John Cavanaugh joined us as well. In some cases, some of the engineering that is for—this is true for almost every type of specialized science instrument. There are some portions of the technology that are highly specialized that only a handful of people in the whole industry know.

There are other aspects that you can bring in folks that have experience in building hardware but maybe not in this specific type of instrument, and they can apply their skills in a more generic sense. Things like mechanical engineering, some electrical engineering, integration and test, some optics work. Some of these are areas that you can bring in engineers on the fly and incorporate them into the team and bring that work in because it's not so specialized that they're having to learn a new language. It's just they're having to apply that work. What we did is during that period, the big one kept its team going and there was this small group that peeled away to work. I'll say roughly half the MLA team. The other half was a group of supplementary engineers who came in for surge support. Some had experience with laser altimeters, some didn't. I knew my trick was to try to get this all integrated as quickly as I can as a working team because we had a big job in front of us.

Really the nature of bringing in—we went from being half as big as we needed to be before we came on to being probably a little bit bigger than we would've needed to have been if we were all there from the start. One of the real successes of that team was they integrated in very quickly, and partially because it was such a charismatic PI team with Dave and Maria and such an interesting mission to work on. People were very good about letting their egos be aside. It didn't matter whether you had been on the project for three years or three weeks, everyone was able to know that we had a job that we had to get about doing. There was a lot of pressure and visibility at the higher level about were we going to get done in time that I really worked hard to try to shield the team from because I didn't want any of that negative energy to affect their performance. They had a hard enough job in the first place without worrying about the funding and were we going to get canceled and the rest. I tried to shield them from that and let them do the work they did because I recognized that they were such a really great team.

That's one of the reasons why when that team was done, we were so fortunate to be able to bring most of them forward to the LRO project for the LOLA altimeter because they'd forged a really strong working relationship already at that level. And so now we had sort of a new core team that had built that MLA. Some of them were old hands, some of them were new hands, but together they were already a team that could then move to the next development. That's what made the LOLA development so well done. They brought in a new project manager replacing, of course, me because I had moved on to LRO. But most of that core team, under a new project manager named Glenn [B.] Jackson, took that same MLA team and turned it into the LOLA team and kept them going.

JOHNSON: That's interesting. I was thinking about that because from what I read about MESSENGER, it was because of that elliptical orbit and you were talking about going close to the oven and going away and the shield. Did the instruments themselves—I know that there was a weight limit definitely.

BARTELS: There was, yes.

JOHNSON: Maybe talk about that for a minute. But also, other than the shield for the spacecraft, what kind of shielding and what kind of protections were in place, because Mercury's a lot closer to the Sun than we are?

BARTELS: Yes, that's a really great question. The idea of that big master shield that was around the whole part of the spacecraft that was always protecting the rest of the hardware, like I said, that took care of just the radiant flux from the Sun on a daily basis. But then we still had to have those hot and cold cycles from the planet, like you mentioned. Getting small doesn't help with that. Small is a different challenge. What we basically had to do was take that design of that big GLAS instrument and figure a way how to miniaturize it and shrink it down to something small enough that would fit on MESSENGER. Even irrespective of the temperature thermal design challenges, it was hard to—the most difficult part of the design was shrinking the laser design down small enough that it was basically a miniaturized version of that whole giant system. But it's hard to condense those sort of optics.

The kind of lasers that we flew in space 20 years ago are very different than the ones now in terms of how complicated the amount of optics and all of the piece parts that go into them. It was a very precision set of optics that had to be done in a very certain way and actually tuned by hand. Sometimes you would tune it the wrong way, and you would actually damage hardware and have to start all over again. We ran through that a couple of times too because it's an infrared laser. It's one that you can't see, and so you're doing it all indirectly. But the miniaturization was a real challenge, partially just fitting all the packaging in to get all the Tetris pieces to sort of fit together. On top of that, when you compress everything, you also have a harder time rejecting heat. Even when you find a way to package it to make it smaller, now you're more concentrated and that power has a harder time getting away. That complicates your thermal environment to begin with. Now we're doing this at Mercury where we have these hot and cold cycles. Solving the thermal design was a real, real trick.

The main way that we got around that actually was by building the main deck out of a very good material to use in high temperature applications—we're using it on the Venus mission as well—called beryllium. Beryllium has an advantage of being able to really absorb—it's called, heat capacity but the point, as you can see, it can absorb a lot of heat influx without distorting or getting out of shape. It's used a lot in applications where you have really wide temperature swings. It's a very exotic material we don't use very often. The James Webb Space Telescope mirrors are also made of beryllium for a different reason. But it happens to be lighter than most materials we use, even lighter than titanium, and very good at absorbing heat. So we made the laser body, the optics, and the whole instrument deck out of beryllium which was then plated gold for thermal reasons. It's a beautiful little instrument. If you haven't seen pictures of it, I'll find you pictures sometime. It's a beautiful little gold-plated instrument.

And then the electronics were done from magnesium as well, which is also very tolerant to temperature swings and is very light. The miniaturization was both making it smaller and lighter. Then we dealt with the thermal issue by making things out of beryllium, and things still would change over the temperature cycles from hot to cold. But the important part is we built it so that the components would all be tolerant of the temperature ranges it would see, and building it out of beryllium meant that it didn't deform or twist out of shape or get its pointing messed up when it would go through these hot and cold cycles.

The beryllium was a really interesting part of it too because that's what had gotten the team in its biggest schedule issue. Beryllium is actually sort of difficult to machine. It's fairly rare, very expensive. The machining is difficult because—this may be an awkward analogy, and those who know real beryllium probably won't like this analogy. But it's almost like really densely packed sand more than it is a typical metal matrix, and so it can be brittle if it's handled improperly and it can be difficult to machine. The company that did the machining for us did have some problems, damaged at least one of them so that it wasn't usable and had to start over again. That's what caused some of the schedule delay.

It's also a hazardous material to handle with your fingers unless it's coated, and so that's why we took this beryllium and—I mentioned it was gold plated for thermal reasons. It was also gold plated—so actually gold over nickel over beryllium—so that it was safe to handle as well. To your point though of how did we handle those thermal challenges, it was really by designing this system using materials that are very tolerant of wide temperature extremes. Beryllium is a really good example for these. That's one of the reasons we're also using it on the next Discovery mission called DAVINCI [Deep Atmosphere Venus Investigation of Noble Gases, Chemistry, and Imaging][7] for the Venus probe for all the decks that the instruments are on because we know it'll absorb the heat as we go through the Venus atmosphere without twisting the whole deck and messing up the pointing.

JOHNSON: Yes, I think I read that's why beryllium is being used on DAVINCI.

BARTELS: Yes, it's a material that you don't really see often except in space applications where ultra-lightweight, like on the James Webb Space Telescope, or thermal considerations, like on MESSENGER or DAVINCI, come into play. It's a very expensive material, difficult to machine, takes a long time to actually acquire it. When I say the packed sand it's because that's

[7] 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.

how they actually create the big chunk that they machine out of is under really high pressure compress that raw beryllium material so it's in a form that you can actually machine out.

JOHNSON: Did you stay with MESSENGER in that position until launch or had you already moved?

BARTELS: Yes, through launch and through early checkout. I joined right at the time called Critical Design Review, and then I stayed until we were post launch doing the first aliveness checks. I mentioned there was very little we could do, but until we got to that phase. And then I stayed attached to the team just to keep up with it, but I wasn't an active member of the team from that point other than as an enthusiastic fan.

JOHNSON: And I'm sure following when they finally got to actually do the work that it was designed to do.

BARTELS: Yes, absolutely. Seeing the first light images where we saw the datasets come down and then as our science team was able to take all those raw datasets and turn them into things that look like maps was really, really satisfying.

JOHNSON: I remember in the last interview we had you mentioned this, and it was APL as far as the science. Is that correct?

BARTELS: This MESSENGER was APL's mission, they led the Science Mission Operations Center from the beginning, and they do it in a centralized way there. One way that APL's a little different than the way Goddard did LRO is that the Applied Physics Lab has a centralized science center where each of the science teams work directly with them. It works well for them, and so that's also how they do the Pluto mission. That's how they generally work. LRO was a little different in that we were much more distributed as a science team. Each of the seven science teams stayed at their home institution and just used connectivity to sort of be a web, if you will.

We didn't actually transfer science to APL on MESSENGER. It was always theirs to begin with. It's just that our team, their daily work went from interfacing just within Goddard when we built the instrument. Once we delivered to the MESSENGER team and we integrated on their spacecraft, then our daily center of gravity was working with the APL folks.

JOHNSON: LRO was a high-profile mission and had a push behind it because the mission was going to the Moon. People [general public] were more aware of what was going on. Maybe just for a second compare that to working with a mission like MESSENGER, which was exciting to the science community because, as you said, it's the first time in 30 years anybody had been to Mercury. But it wasn't as high profile. Talk about working on those two different type of missions.

BARTELS: Yes, it's a very savvy question, and I do have to preface it by saying since I had very different roles, my role was much smaller on MESSENGER. I have to be careful too much about that. I do have enough visibility to the scrutiny that they were getting versus like what

LRO did that I think we can talk to this. The big difference to me is that LRO was—now, remember, it wasn't even Discovery at that time. It only became Discovery later because when it was initially funded, it was really being funded by the human exploration side. Because LRO was almost aligned to the Human Space Program because its charter was not a science charter per se, but it was really to find landing sites for the astronauts as part of the back to the Moon initiative that we had at the time in 2004 through 2008.

And so it was very much a different level of scrutiny because on something like MESSENGER or even DAVINCI and some of the other Discovery missions, there's a very passionate but somewhat smaller planetary community who's really interested in that science. Any of the people who were interested in the inner solar system, how the solar system formed, why Mercury is so different and so much denser than other planets, what that might mean for solar system formation, all of those things. Those people were intensely interested in the MESSENGER mission. Staying within that, it was mostly the Science Mission Directorate that was paying attention to MESSENGER.

LRO on the other hand was actually very highly placed in the agencies' priorities, not just the Center's priorities because it was part of the Moon initiative. It was the first mission of that entire program which was to end up, at that time, with sending astronauts to the locations that LRO identified. The level of scrutiny that LRO had in terms of its development was much, much, much greater because there were so many more stakeholders who had an investment in the outcome of the LRO data because we were not just sending that data to the science team. There's also a very passionate lunar planetary community as well, and so they were interested in the science data. But that wasn't the original charter of LRO. It was a human exploration mission whose data could also be used for science.

The analogy that sometimes we use internally on the LRO team that some folks didn't warm to as much is in the same way that with weather satellites taking daily weather over 20 years is climate. In the same way here, a lot of the datasets that we were taking, they were being turned into safety maps, for instance, for astronaut landing sites. That same data taken by those same instruments if processed from a scientific standpoint gives you the science information as well.

We had so much more visibility within the agency, or scrutiny within the agency, because our LRO datasets fed not only the passionate but small lunar science community but also the full human exploration community because they were all focusing, at that stage, towards going back to the Moon. I can say that MESSENGER appeared, from my perspective, to be operating a little bit under the radar in the same way that Lucy did and all the Discovery missions do. DAVINCI right now, of course we're very early. Within the pockets of NASA that really focus on Science Mission Directorate and the Planetary Sciences Division, all of these Discovery and New Frontier missions get a lot of scrutiny. Certainly because they're so exciting, they get a lot of EPO [Education and Public Outreach] as well. I'm just seeing so many things on OSIRIS-REx all over the news everywhere right now as people get geared up for that. There would be times where certainly the science data products from MESSENGER and from LRO, things that will come from Lucy, they'll all have their moment in the Sun. But it's a smaller number of people who are invested in the outcome of the planetary missions than anything to do with human spaceflight. LRO had more eyes looking at us, or it sure felt that way. But, again, I was down as one of the minions on MESSENGER by comparison.

JOHNSON: One of the questions I was going to ask, and I'd like to ask you now but we can talk about it more later if we have more time. As a manager as far as instrument manager and different positions you've been in in all these missions—and these are PI-led missions. But at the same time if you had to pick a PI, what would you consider to be a successful PI for one of these Discovery type missions?

BARTELS: That's a really good question because the PI always comes first. The PI comes first and it is really their mission. It is the heart of their mission. They all come with equal amounts of passion for what they're doing. For most of those PIs, it's the culmination of their life's work, or at least maybe the most important thing they'll ever do with that time. The only time that a person ever really gets to pick their PIs are when we're making proposals and there's—again, this may get me in trouble—the sort of dating services we run between the groups to match up PIs with prospective managers at the start. There though again, in a PI-managed mission, the thing that a manager needs to understand, whether they were on MESSENGER where I was an instrument manager, project manager working for David and Maria, who were the PIs of that instrument. Not Sean [C.] Solomon, who's the overall MESSENGER PI, but David and Maria were my local PIs. Or whether it's now where I'm in the overall project management position like DAVINCI. You have to respect the fact that in the end you do work for that PI. Your job is to make that PI successful. I want all of my PIs to be household names because of the work they've done on this.

The partnership that you have with a good PI is when a PI knows their limitations in terms of daily management. Because even on a PI-managed project, most of the time these are scientists and not administrators. They're not professional managers. And although they're some of the smartest people you'll ever meet in your life, everyone has limitations. The best PIs are the ones who know when they need us to step in, provide leadership, and guidance, and vision, and when they can delegate and trust their project managers and their system engineers to make the right decisions for them. The PIs are typically the smartest person in the room of any meeting they're in. They are singularly impressive people. But the ones who are harder to work for are the ones who also want to be managers and engineers as well, as opposed to the ones who are intently watching to make sure everything's going okay and maybe giving advice to the project manager or system engineer but allow them some leeway to operate themselves.

On a daily basis, I interact with the science team. I don't do their science. I give them the resources and I give them some of the requirements and some of the work that they need to get that going, but it's up to them to do that work. In the same way, if a PI feels they have to start stepping in and making day-to-day management decisions, it's usually not going to be as effective as if the PI establishes roles and responsibilities with their PM and then says, "Here are the areas that you run. Go run them, and I'm going to be watching you." The PI can change PMs if they want. The other way doesn't happen. A PM can't say, "I don't like this PI," because the PM works for the PI, and both sides never forget that.

Outside of planetary, I've spent still most of my career working on PI-managed missions. Once the PI understands that as the PM you've accepted the fact your job is to make the PI successful, the best PIs will let their PMs do what they need to do while constantly assessing if they're being effective or not though. I have certainly seen PIs make changes on project managers if they didn't feel they were getting the results that they need. They can do that, and they will do that because they have to. Because in the end in a PI-managed mission, they're the ones who are accountable to SMD [Science Mission Directorate] leadership and to Headquarters.

It doesn't often feel that way sometimes, where it feels like the Headquarters folks and all of NASA is—the topics they want to talk about if it's budget and schedule, they want to come straight to the project manager and grill the project manager. Or if there's an anomaly, like when we talk about Lucy, we'll talk about how that interaction went.

The best relationships that get forged on these missions that are most effective are the ones where the PI and PM forge a really, really good, tight bond. I've tried to make sure I've done that with every PI that I've worked with to really understand not just the personalities or their styles but what is it that they really value, what is it that they're trying to get out of the mission. A PM needs to mold themselves to the values of their PI. Because in order to become a PI and to be selected as a PI, they've been very effective in their lives and their careers to get to that point. They're probably not going to change their communication style or their values or their personalities. Early on in my career, I thought there were times I would help reshape my PIs to be easier to work with. That's not going to happen. You have to adapt to them.

One of the early lessons I would have for any PM that's working a PI-managed mission is it's not a struggle for control of the mission. You're working shoulder to shoulder with them, back to back with them. But they have 51 percent of command and you have 49. You have to remember that you're there for their mission to be successful. Some of these people have been thinking about these missions since they were in grad school, and now they're in late career before they finally win one of them. It means more to them than to anyone else. It has to. Your job is to help them fulfill their vision, and I've tried never to forget that.

It matters when it's on an instrument as well. When I was working on MESSENGER, although I would get to interact with Sean Solomon, the overall MESSENGER PI, especially when we were behind or he thought we were over budget, but on a daily basis my job was to make David and Maria successful so they could produce the datasets.

It was a thermal engineer on MESSENGER one time—a thermal engineer, it was very surprising that he mentioned this to me—that said, "Arlin, what do you think the real product of these missions is?" because we were so focused on why we couldn't get the laser built on time.

I said, "I don't know. What do you think?"

He says, "It's the science papers that are produced by these missions, and it's the learning and textbooks that get rewritten because of that data." You have to always keep that in mind because 20 years later after these missions, the papers are written by the PI team, not by the managers. The textbooks are rewritten based on the data that the science teams have found. The system engineers and the project managers, all of the engineers, always have to keep in mind that our customer is the PI and the science team that we work for. A PM or lead system engineer who can't make that distinction doesn't last long in the PI environment.

JOHNSON: That's a good description of what the purpose is. That's good to keep in mind I would imagine.

BARTELS: Yes, it is because sometimes as a manager too you end up thinking that when we build a project, what we're really building is a team and the people who are working within that team. The hardware that comes out of it is just the evidence of whether or not we have successfully created a team that worked towards a common goal. But still, having achieved that, at launch is when you basically then hand off to another entire crew. All the folks that have worked the mission, if you're lucky enough they get to come down to watch the launch, see the first checkout, realize they've survived that actual first launch. But from that point on, you hand the baton to the science team and you wish them the best with it.

JOHNSON: That's true. I think since we're so close to your time, I'm going to end it here.

[End of interview]