DISCOVERY 30TH ANNIVERSARY ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

ARLIN BARTELS
INTERVIEWED BY SANDRA JOHNSON
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JOHNSON: Today is September 8th, 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, and talking to me again over Microsoft Teams. I appreciate you continuing to give me information about the different projects you've worked on, and today we're going to talk about Lucy. Where we ended last time was the [COVID-19] pandemic and trying to push to launch at that point. I know when you launched, you launched on time and under budget.

BARTELS: We did.

JOHNSON: Which was amazing, considering everything you had to go through. Let's start there. Let's talk about that launch, and maybe the days leading up to it, and then the launch itself.

BARTELS: Yes, I've done a lot of missions and launches in my career, and this was one of the smoothest preparations for the actual launch that I can ever remember. On a lot of projects, there's sometimes one element of the system that's having trouble and is being repaired at the last second, or even being swapped out, or it deliver late, but despite all of the complications that COVID gave us, and the sort of unusual environment that we were having to work within, even as a team, to pull that off, the preparations went very smooth. There comes a time about a week before launch where basically you're done with everything you do on the spacecraft, and then you're in the hands of the launch vehicle provider from that point on. In our case, it was ULA [United Launch Alliance] for the Atlas V rocket, and from that point, the last seven days or so, you enter in what's called combined operations, where they install the spacecraft on their payload attach fitting, and then encapsulate the fairing around you, and you're all sealed in, and that's the point at which you have to say goodbye to your spacecraft. That's the last time you're ever going to see it, except as telemetry, unless for some reason you don't launch and it comes back.

That last week, again, working with the ULA folks, went very smoothly. The Lockheed [Martin] people had done that dance many times with them, and even though we were doing our processing at a different facility up in Titusville [Florida], compared to the one we had been using onsite at Kennedy [Space Center, Florida (KSC)], from that last period things went very well. The weather was great. Sometimes the weather can be kind of sketchy end of September, early October in Florida, and so we had hurricane plans in place.

One of the most important things we do at NASA is rarely do we just stop with the planning for the nominal case; we spend a lot of our time planning for the off nominal, what we call it, or your contingency plans, your anomaly plans. That's true for ground handling and processing, and it's also true for the spacecraft operation, which came in handy a little bit later, as I'm sure we'll talk to. Yes, we were proud, without being arrogant, about the fact that MAVEN [Mars Atmosphere and Volatile Evolution], OSIRIS-REx [Origins, Spectral Interpretation, Resource Identification, and Security – Regolith Explorer], and Lucy all launched on basically the first second of the first day of the opening of the launch period.[1] [2] That's a track record that the folks are very proud of and have earned by doing a lot of work to get to that point. As you mentioned, we were also under budget, as much because we had built up some reserves that, in a perfect world, would actually have been available to give to Hal [Harold F. Levison] and Cathy [Catherine B. Olkin] for Phase E operations work, but we had made the choice that we were going to invest all of that into making sure we launched on time.

We definitely were on budget, or just a shade under, but we're certainly not cocky about that. That's a lot of fortunate things combined with some good planning to make that happen, so any number of things could have knocked us off that rhythm and caused us to miss that date. If so, we would have had to have shut down and waited for an entire year for the planets to line back up correctly for us to repeat the mission, and so that would have been a large cost expense, as another of the Discovery missions found recently when it wasn't able to launch, one that's going to launch here in just a few weeks [Psyche][3]. We were very happy we were able to get that to launch.

On launch day, on console, we had people deployed in three locations. Where we do the payload processing up in Titusville is where we had most of the engineers, who are monitoring telemetry during ascent all seated together. That was both Goddard [Space Flight Center, Greenbelt, Maryland] and Lockheed folks there. Remember, instruments are not powered on during these sort of launches because they don't get powered on for several days, so it's an

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[1] The MAVEN mission will determine how much of the Martian atmosphere has been lost over time by measuring the current rate of escape to space and gathering enough information about the relevant processes to allow extrapolation backward in time.
[2] 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.
[3] 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.

interesting dynamic. Anyone who's working on the spacecraft bus, we call it, on the spacecraft portion—I'll start pulling up the visual aids—the people who work on the spacecraft bus portion, their components are typically on and powered, so they're monitoring their telemetry. People who work on the instruments and the science side typically are available then to do public affairs, or just enjoy the launches with their families.

It's a lot of adrenaline you get because our launch was at 5:30 in the morning, which means that most folks had a very sleepless night. It's hard to sleep anyway with the excitement of what's coming up, but we're on station for the launch to be prepared at roughly 2:00, 2:30 in the morning, and then staying through that day. We had the engineers, as I mentioned, there. We had most of the operations personnel, the people who actually radiate commands up to the spacecraft and receive the downlink from it. They were all stationed at Denver [Colorado], at Lockheed Martin's Waterton facility. Then we had Donya [Douglas-Bradshaw], Hal, and myself in the command center area at KSC, basically where the rocket people are. I don't know if Donya—how much of that she described to you, and those roles. She has a title, the Science Mission Director, SMD, that she's responsible for. The Principal Investigator in a PI mode mission also has the authority to call a halt.

In Donya's role—and typically the project manager at Goddard falls into this role—they are the ones who give the final consent to be launched, basically based on the feedback we get from the engineering team that says the telemetry on the pad is correct. And from the operations team saying they're ready to pick it up as well from their side and take over, basically. Because once we launch, then all the folks in Florida, their job is very passive from that point on because we don't have a way to command the spacecraft while it's on top of the rocket. In fact, although we're getting telemetry down, interleaved with the launch vehicle telemetry, we're not able to command the spacecraft until it separates from the launch vehicle, but when we do, that's the operations folks out in Denver who are doing that, not the people in Florida. The folks in Florida are sort of along for the ride after launch, just monitoring telemetry and ensuring everything is the way it should be, and we'll get to that in a little bit.

Prelaunch the roles that we had, again, Donya, as the final authority responsible for the payload, she's the one who says, "Yes, we are ready to go," so she gets polled on that, and she polls all of the people who report up to her. It's a very ornate, very precision method of communication that if you've ever watched a launch on TV, you hear all these voices chirping back and forth to each other. It can sound chaotic but it's actually very structured and very set. As a principal investigator mode mission, Hal was next to Donya on one side to give his consent as well, in case, for some reason, he was unhappy with something. Then I was to Donya's right as the Deputy SMD, so in case something happens to Donya at the end I was trained to take over, and I had actually run operations, simulations where I was in that role in place of Donya in case that had fallen to me.

The launch itself was absolutely spectacular. I believe it was at 5:34 in the morning of October 16th, and although the urge is to run outside and watch that beautiful fireball, you can actually see this picture up there [pointing to a photo] is one my wife took from where the public's allowed to view it, and so it was very beautiful as it went from the night into the early dawn sky, being lit up by the sun as it got to a certain altitude. It was just absolutely beautiful. Although people like Donya were excused to start doing some press, for instance, and Hal was, as well, and Cathy was already doing press, I was on console, just monitoring telemetry, although we hoped it would be very uneventful.

We did have a significant anomaly, which will probably be the major part of what we talk about here. It's interesting: whenever you see an anomaly like that, you don't notice everything right at first because there are hundreds, if not thousands, of pieces of telemetry that are coming at you, and we code them in ways to draw your eyes to the things that are the most important. But you're looking at so much information you don't necessarily see things right away. The first part was very normal, because for the first hour—58 minutes exactly—we were actually on top of the launch vehicle, and then at 58 minutes after launch we separate off of the launch vehicle. The launch vehicle then falls away and the spacecraft is on its own. For a mission that has a deployable solar array, that's a really critical time because every spacecraft has both a battery—well not every spacecraft, but most spacecraft have both a large battery and a solar array. This is a very unusual type of solar array, and we'll get to that in a minute, but there's a solar array of some point.

There's always a race against time—I shouldn't say race but it's always done in a very methodical, systematic way. When you launch, you're still on the battery, but the batteries are finite-sized, and you can't run the full mission forever because you start draining them right away. They're intended to be sort of a reservoir for short, temporary activities, not something you drive on all the time, any more than your car battery is used to start your car; it's not running electronics the whole time.

As we were ascending on the launch vehicle for that first 58 minutes, everything was nominal, and we detected separation, just like you'd expect, and then after separation from the launch vehicle there was a very prescribed set of procedures of what you do to activate spacecraft that maybe the most important is the solar array. There's also making sure that you're stable, that your guidance and navigation and control systems can control the spacecraft and position it exactly the way it should. There's a whole series of steps to get executed, and you're able to watch on the telemetry each of those steps happen, and everything is going well. The period of time where we undo the solar arrays on Lucy starts at six and a half minutes after we release from the spacecraft, and that whole procedure to take care of both of these, it was designed to take about 25, 30 minutes—I think it was 28 exactly—to actually unfold. This is a fairly unusual type of solar array. I don't know if this is showing up on the camera very well. [Demonstrated with model]

JOHNSON: Yes, it is.

BARTELS: One of the things you see first off is how large they are, and how they sort of define the look of the mission. The reason for that is the farther away you are from the sun, the weaker it is, and so the harder it is to generate large amounts of power, just almost like on any solar panels you've got: on a cloudy day, you don't produce as much as on a bright day. Since Lucy's mission is to go to the outer solar system, to the distance of Jupiter, you need much, much, much larger solar arrays than you would if you were just orbiting the Earth. Or like the Venus mission I lead now, we're going towards the sun to Venus, and so we have much, much smaller solar arrays.

This is a very unique kind of solar array, these UltraFlex Solar Arrays, and what makes them interesting is that most of the time you never see them like this [fully deployed] on the ground; they're always folded up. You can kind of imagine, if you will, how these pizza slices could be folded around almost like in the shape of a Chinese fan; that's usually the analogy we use with folks. They're hard mounted as two, if you will, just giant Chinese fans. It's about 20 foot, maybe a little bit more, across the arrays, to give you just a feel for the size of these. They're all uncoiled and flat.

I don't want to bore you if your other folks have talked to this already, but the manner in which it's designed to unfold is, once again, just like a Chinese fan. We call it a lanyard, but it's not a lanyard like these things that we have around our neck. By lanyard, that means actually a Kevlar strap, and it actually has a motor on it so that it basically pulls the whole thing open slowly, over a period of many minutes. So that Kevlar strap attached to this leading edge here, as it pulls around the whole position here, the whole solar array unfurls, kind of like a flower or like a fan. Then at the very end, when it's done its job, that lanyard pulls all the way into a point where it latches and locks in place, and at that point then we know everything's good and stable.

What happened for us on launch, then, is we were looking for—there's no cameras on it. There's no real telemetry that tells you how it's going, other than you know the motors are working, and at the end you get a telemetry point that tells you that you have latched in place. And so sitting there, over this period of time—this is, again, now an hour after we've launched. Most of the folks are finally starting to get some breakfast, or do interviews, or do whatever, but those of us who are still monitoring the telemetry noted that the first solar array, we got the telemetry that says it's latched in place, so we said fantastic, and the other one was coming right after it.

What was interesting for us was we noted that we have the telemetry that was telling us how much power was being produced by it, and so it looked like it was producing right about the exact right amount of power, so we thought everything was fine. But we weren't getting the telemetry point that indicated that it had actually latched and seated into position and locked in like it was supposed to. We noted that. Everyone saw that right away and noted that, and we said, well, we wonder what that means.

Because the solar array was clearly alive, the electronic circuitry was fine, it must be alive, it must be working, and so what could it mean that we weren't seeing that it had latched? Some of us jumped to the conclusion—turns out wrong—that, well, maybe it's the telemetry point itself that's wrong. The type of sensor that was used to actually detect that latching condition is one that can be kind of delicate, and we thought that must be the problem, because if this solar array hadn't deployed, we would not be producing power, and we would have other indications that it wasn't really stable or something. So it was really curious: we're producing the power, but we're not showing it's latched. What could that mean?

Whenever you have an off-nominal case like that, of course, the engineers all get together, and we prepare for this contingency. The first thing we always do is we say, is there an immediate time-critical action that we must take in order to save the mission? If so, we will typically have predefined steps that we will already take to do that, and we execute one of those here—talk about that in a bit—but if we know that things are safe and stable for that period of time, then usually the best course of action is to just slow down and be very careful and be deliberate. It's interesting. Even though this wasn't a mishap condition or anything, it was just an anomaly, certainly everyone wants to help, everyone wants to try to find the solution and be helpful.

Sometimes I've been on missions where, when we have anomalies like that, it can be a little chaotic because everyone's trying to help, and everyone's trying to talk to everyone, and if you weren't waiting and really trying to keep things deliberately calm and orderly, it can get a little out of hand. The Lucy team responded extraordinarily well. We have the voice links up to the engineering area, and to Denver, and so we were having just very—I don't want to say boring—it was just very calm discussions that we were having, and saying, "What are the steps that we could do?" And so the one thing that we knew we could do safely was exercise the command sequence again that we had just done, and that was our contingency plan: just do the same thing and try a second time. We knew we must be mostly deployed, because we're producing the power, but we just hadn't quite latched.

Why does that matter? The thing is this type of solar array does expect to be latched into place so that it's very rigid. It's not quite as rigid as this metal model would have you indicate, but it does pull taut, and is very nice and structurally tight. That's important because when you fire the engines later on to make adjustments in your trajectory, you want to make sure that this isn't flapping around loose, it's nice and tight like it's supposed to be. We knew we were safe, though, in that current position, because we weren't planning on doing any of these exercising of the motors for some time, so we ran the procedure a second time to try to get it to latch into place, and we saw that the motor that was pulling the lanyard in was still working, and it was tugging on something, but it just wasn't getting to where it could latch. Since that was really the only contingency procedure we had predefined, we convinced ourselves that because we were producing all the power, we needed to keep the mission going, and we were in a nice, stable configuration just flying out from Earth, that the right thing to do was to just slow down and stop.

And so that, we didn't realize, was the start of a process that was going to take us the next ten months, actually. It was interesting, as we pulled together an anomaly resolution team immediately to start working at this, we had the folks, of course, from Goddard mission, also from Lockheed Martin, responsible for the spacecraft because a lot of their engineers were still there in Florida. And it turned out that the solar arrays here that were produced by Northrop Grumman, we had those responsible engineers who were there, not as part of the engineering team but they were just there with their families watching the launch, and so they were expecting that they were there just to celebrate. We found them and pulled them in right away into this, too, and laid out the first sort of early stages of root cause analysis—system engineers call it a fishbone diagram—of saying what are all the things that could be wrong right now. What could have caused them, and what sort of actions should we take? Could there be any action we would take very quickly that would be safe, that maybe was outside of the things we had practiced, but that we knew was safe?

The first line that everyone agreed to was that because we were safe in this condition—we wouldn't want to be this way the whole ten years of the mission, but we were safe for now—we wouldn't take any aggressive action that we hadn't practiced and thought through, because sometimes there would be folks that might want you to just push harder and do something, but you might break it or make it worse. We knew we were okay. This is not how we want to execute the mission, but you could almost think of the deployment state at that stage as if this is a pizza and one slice was gone. It was being held tightly in place by that Kevlar strap. That lanyard was tugging on it, and holding it there, just wasn't able to pull it all the way to closed.

We didn't have a way, necessarily, of estimating how much had been deployed right at the start, but some of the clever engineers came up with a metric fairly quickly. Again, we don't have any telemetry that would say here's exactly where we are, and there's no cameras that could help us, but by looking at the amount of power that was being produced—now I'm going to treat you like you like you're the sun. The way the solar arrays work is that if they're directly incident to you—that's when they're producing their maximum power—and we were in a position where we thought the solar arrays were both being pointed directly at you, the sun, so the one that had latched nominally, we could tell exactly how much power that it was pulling. Which assumes that this is completely flat because it had been pulled and latched into place completely flat, and so all of the sun's rays were what we called it normal, or orthogonal, to the solar array. By looking at how much power we were producing here, they were able to tell how slightly creased these were, because it wasn't folded all the way around. That very tiny, slight angle of difference between being exactly flat to the sun, as opposed to being slightly off axis to it, enabled them to actually calculate what angles these were making to the sun, and from that, how much of that 365 degrees had it actually been pulled. It was very clever, how they came up with that.

They were able to tell at that stage that the solar array was mostly open. It just wasn't pulled out the full 360 all the way to where it could latch in place. That was important because that told us that as long as we were tugging on it and holding it in place with this Kevlar strap, we would be producing enough power that we could go ahead and keep the mission going. At that point, we all decided to take just a step back and say, "We need to figure out what happened that we're tugging on it and pulling on it but it didn't operate the way it did on ground or on the other solar array."

Immediately, Lockheed Martin and Northrop Grumman stood up a small tiger team out of Northrop Grumman's facilities in California, and they set out to try to replicate this on the ground. After some period of time they said, "Well, we've tried several scenarios, and we found one that we think is probably what happened. There's no way to 100 percent prove this, but we're pretty sure we understand what happens." The analogy we end up using here is that it's like if you're trying to wind a garden hose onto a reel, or fishing line into a fishing reel, sometimes it'll get caught off the side and it'll sort of wrap on itself and then pull itself tight and stop. That's a plausible scenario, that if for some reason as this deploys over, again, that basically 15, 20 minutes it gets a little slack in it or something, that Kevlar strap that's pulling it closed can sort of jump the little spool that it's on and sort of wrap around, again, just like garden hose or a fishing line. If you proceed with that assumption, it explained all the telemetry that we were seeing from the motors, how it operated when the little over-protections could and everything. It was very clever how they came up with that. No other theory that folks brainstormed could explain both the end result and the telemetry that we saw.

Then, based on that assumption that this is what happened—at some point along the way this Kevlar strap jumped its little spool that's winding it up and managed to get itself tangled—then what are the options? That began, then, a series of multi-months of testing on the ground various options that we had limited tools we could go from that point, but we said, well, we want to still try to get it to launch because we don't necessarily want to have this strap pulling on this, keeping it on place for ten years. We'd like to go ahead and get a latch, because that's how it was designed to be, and anything other than that would always call into question is it safe, is it going to be too wiggly when we try to fire the engines and it could actually damage itself. Or if not damage the entire structure, damage the entire cells themselves if they're not tight like they should be.

That team—that was Goddard, Lockheed, and Northrop Grumman—set out right away to find the engineering possibilities of what commands we could send to the spacecraft to try to get it to latch, and it was really great that those groups had all had different interests in mind, on top of just mission success, from their contracts and their corporate interests and the rest. They all put those concerns aside and just said, let's just figure this out. Sometimes, when large companies like Lockheed and Northrop Grumman work together, they have their own issues if the lawyers are getting involved, and the whole team decided let's worry about all of that later; let's just focus on this. Over that period of several months, then, slowly and deliberately, we tried different things that were tools that we could try. Looking at is there ways where we could heat something up, would that help pull it in, or cooling it off? There's a backup motor. What if we ran the first motor and the second motor both at the same time? Would we be able to pull harder without breaking anything?

So they spent several months being able to replicate the problem almost on command, which is important. You want to be able to create that condition. Once they were able to create that condition almost at will, then we looked at these different options we would have to try again. Then, my memory is it was sometime in the spring—I'd have to look up the actual date, somewhere in the April/May timeframe—we said, okay, we've learned enough now. We think we understand the root cause, at least the proximate cause, and we know what things we can do to try this. All of our testing on the ground says it's actually safe to try to pull with both motors at the same time, and maybe that'll be enough to pull it into place, but at least we know we're not going to break anything. We know we're safe to do that, and we set up very cautious ways of stepping into it. There were some folks, more on the science side, who were impatient to get through this, and so they were saying, "Oh, come on, just hit it as hard as you can until it works," and the engineers were saying, "No, we're not going to do anything to make it worse than it is. We're already safe."

And so we ran a series of these what we called redeployment attempts—they became known as RDAs—over that period of April, May, into June, July, where we attempted to pull it. And what we would find is each time we would try to do that, it will pull in a little bit more.

Again, just like a fishing line or a garden hose, if you push on it harder, you'll get it to go a little farther before it really just gets too really stuck, and each time we did it we pulled in a little more. The way we were able to tell was—I mentioned there's no telemetry that tells you if it's latched or not—but the really clever engineering team was able to deduce things indirectly.

What they found was that we have very precise measurements called IMUs, inertial measurement units, that can measure basically vibration on the spacecraft. That's not what they're there for, but you can induce it from that. So they were able to tell each time we did that that we were getting just a little bit stiffer, a little bit tighter. It wasn't latching, but every time we did that it became a little more secure and a more stiff structure, which was able, then, to help us with the main thing that we were concerned about, which was if it was too wiggly, too soft, when we would fire the main engine for trajectory adjustments, something bad would happen maybe to the structure or to the cells. Every time that this got stiffer and stiffer and stiffer as a system, it gave us more confidence that it would be safe to do those sort of maneuvers. We did a lot of flow charts and scenarios about, well, maybe we only can use small engines or small thrusts, because we don't want to give it too much power. How much is safe? That's why this took so many months because we were looking at all the scenarios to first say a kind of Hippocratic oath to the hardware, of making sure that nothing we did left us in a less safe space than we currently were.

There were very freewheeling engineering discussions between members of the team, of those who were saying, "Leave it alone. Don't do anything more, because if you do, something bad could happen." And other folks saying, "Well, no, we can safely do this and put ourselves in a better position." We all wanted to still get to the point that it was latched. We did those redeployment attempts until we got to the point that it was clear that we weren't really making any more progress on getting the solar array latched. We think that we're up to like 358 degrees, almost completely latched, but not quite.

Then we moved to focusing on testing properties of that Kevlar strap. We're saying, boy, okay, we may be in this configuration now for the next decade. How can we convince ourselves that this is safe to do that, that that Kevlar will hold tight over ten years and won't itself eventually have its own problem and snap? Because if that were to ever snap or break, the whole thing would fold back on itself and we wouldn't have enough power to execute the mission. So the most important thing is to make sure the solar array stays just the way it is.

We worked with some folks at the NASA Engineering Safety Center, the NESC, to do some testing on the Kevlar for long-term, accelerated aging, to try to put ten years of environmental impact on these Kevlar straps and make sure that they're going to be okay. This was actually going on in parallel with all the other work that we were having. The indications that came back from that testing from the NESC was that Kevlar was the right material to pick—it's very strong, very hardy—and so the engineering analysis was that it was safe to leave it in that position—we know it's more than 355. We still have engineering arguments about exactly is it 355, 359, 358, very passionate people on all sides of that question, but as a manager we know we're close. We're not there completely, but the engineers all say we're safe.

At that point, then, the team that developed the spacecraft handed over the mission to the operations team, and we disbanded this anomaly resolution team, saying there are no further activities that we can perform that would be safe to perform that are going to improve its condition. All of the analysis tells us that we'll be able to execute the balance of the mission in this configuration, so the safest thing to do at this point is to turn it over to the operations team and let them fly the mission they've been preparing for. That was a really long monologue. You must have some notes here, some questions, some go-backs.

JOHNSON: Yes, and this is my non-engineering ignorance here, but was one of the things they tested just going back, winding the solar array all the way back and starting over? I'm thinking like someone who has dealt with zippers. Sometimes you have to go all the way back for it to realign and come back up. I was just wondering if that was one of the things that was considered.

BARTELS: That's a fantastic question, and I should have mentioned that often for something that's a deployment it's designed to only go one way, for a very specific reason, which is you don't want to have a possibility that it would ever send it back when you don't want it to. It's a great question, and if it was something that we were doing on the ground, that we would be trying to handle on the ground, we would do exactly like what you're saying. But for a spacecraft where it's a one-time deployment that has to go right, we don't put a way for it to be reversed.

If you remember, I said it was actually that Kevlar strap that pulls it all the way around to get it into place. You would never want to have the ability to command it to go backwards and damage something, so it's really only designed to go one way. The motor only winds one way. Because if it was on the ground, just like you mentioned, you might say, well, if you're snarled up on the spool, why don't you just go ahead and unwind it and then wind it back up again, but the way these are designed is specifically not to allow that to happen by mistake, and so that's not available to you to do on purpose, either, because they would say that should never have to happen. But that's a very logical question.

JOHNSON: Okay, like I said, this is my non-engineer brain thinking.

BARTELS: No, that's a great question.

JOHNSON: Well, do you think the fact that there were no cameras and no telemetry to be able to exactly tell what was happening with it, is that something that is a lessons learned going forward? I know that would have been an extra step, more expense, that sort of thing, to have that, but is that something that because of what's happened on Lucy, might be considered for another type of array like that?

BARTELS: Absolutely. Absolutely. That's one of our lessons learned, actually, that goes in the formal Goddard Lessons Learned LLIS information database, and we're looking at actually implementing it as a Goddard rule, as well. We have a booklet of rules here at Goddard called our gold rules which are designed principles that should be followed for a mission, and if you don't follow them, you actually have to get permission from the full center to deviate from what's the best practice. And as one of the things that has come from this, we propose that a best practice should be to have engineering cameras that could photograph any sensitive deployment development for the future.

Cameras are so small nowadays, you could almost imagine a little GoPro camera that could have been mounted here that was face down, and that's the sort of thing that in retrospect seems like it could have been really a simple thing to do. There was no reason to think this was going to be an issue before, but that's definitely one of the things that we are taking forward as a recommendation for any large, critical deployment. It would be very complicated to actually have some sort of telemetry about the actual unfolding of the array itself with telemetry that would come from the array, but if we had it photographed, it wouldn't have prevented the issue but it would have been able to help inform our decisions and get us to them probably faster if we were able to see the amount by which it was still open.

Yes, in any case like this where there is an anomaly of some kind, one of the things we have as part of our investigation is to say what are the root causes, and then what are the recommendations that we could have for the future. I don't know if that recommendation has been officially enfolded in our Goddard rules, or the NASA database, but we did make that recommendation. We found who the other users were of these arrays, in working with Northrop Grumman. There's ones used for a space station, for instance, and other users, recommending that very thing. Since there's really no way to instrument the array itself to give you that telemetry in a convenient way, at least make sure you have a deployment camera facing each of these, so you can at least image it as you go. Yes, you're absolutely right, that's always part of any investigation like this.

JOHNSON: You know what happened, but was there something in the deployment? I'm sure they simulated opening these arrays multiple times before the launch.

BARTELS: Oh, yes.

JOHNSON: Did they know why this happened with this Kevlar strap when it hadn't happened in any of the previous uses? I understand your analogy, but I was just wondering if they knew exactly why it happened this time, or if that's just unknowable.

BARTELS: Another really great question. What is much easier to figure out than why in this case, because one of them was just fine and the other wasn't. What could have been different on the one that had the issue? On the ground, we knew that it was a very, I wouldn't say delicate, but deceptively complex setup to do this. Again, pulling something that is 20-foot across, so each of these are 10-foot, to have that large scale item deploy needs a pretty big area, too, in order to do this. The speculation is it's what we call a test like you fly difference between what you do on the ground and what happens in space.

What we would do on the ground, you can find online, and anybody who watches this interview can go off and google just images and videos that show how this looks on the ground when you test it and deploy it. One of the things that was key there is that whenever we would do that testing on the ground, it was always one completely steady pull the entire time that had basically a constant force being applied to it. We never did a herky-jerky stop and start because that's not how it was designed.

There is speculation that because these were being deployed together, that perhaps when the other solar array was itself moving, as well, that maybe it caused us to have a little slack or catch or something. This is all speculation, so I want to make sure anybody who's watching this knows that we'll have our final root cause investigation report out by the early couple of months of '24 where they'll have assessed whether this is credible or not. So I'm speculating when I probably shouldn't, but what we know is something caused there to be a little bit of slack in this unfolding, which then caused that strap which should have been rolling up on the spool to jump off the spool. And so there's only a few things that could have caused that, really, to happen.

I may have sounded like by last summer, when we handed over the operations folks, that we were done. There are still engineers who are still looking at this, from Northrop Grumman, from Lockheed, and from Goddard, about what else could have caused this so that we could prevent this from ever happening again. To your point of why, there's a good engineering case to be made that something caused this nice, smooth unfolding to have a little jump or little catch in it that would create enough slack that the Kevlar jumped over the spool, but it's very difficult to prove, so I don't think it'll ever be more than a theory, to be honest with you.

JOHNSON: Yes. It's not like you can bring it back and take a look at it.

BARTELS: No, and the thing is it's very difficult to test on the ground, as well, because it's not just that you can't bring it back, but when you're dealing with large mechanical devices, testing in gravity, one gravity on Earth, sometimes makes things easier or slightly different than they'll be in weightless environments, and so sometimes things that you might induce on the ground may not really be credible for what would be happening in space, and vice versa. That root cause investigation is still ongoing, but there's only a limited number of things I could say that could have done this. So when I say we had a test like you fly exception, if that speculative reason turns out to be the most likely theory, we were never in a place where we could operate and test both of these at the same time, because this would take a giant room and facility, and we only had enough ground support equipment on a Discovery budget to be able to do one at a time, anyway.

That's one of the things that's really important about Discovery missions that can't get lost. These are highly capable missions that we do, that go to really interesting places, but because we are constrained to these mid-sized budgets, we have to be careful that except the fact that we have technical risks in areas where we just don't have the resources to do something that a JWST [James Webb Space Telescope] or a Hubble [Space Telescope] or something can do. Where they might be able to have the budget to go off to just eliminate this small bit of uncertainty, through all the Discovery missions that are mostly class B, Bravo—DAVINCI [Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging] is a class C, Charlie, mission—we take what are called test like you fly exceptions, which means on the ground we're going to test this the best we can with the money we have, and in the manner in which it would happen in space, but we've only got the budget to do what we can.[4] And so, for instance, in a case like this, we didn't have the facilities to drive them both at the same time and unfold them in the same way. We would do one by itself, then the other by itself, and so any sort of linkage between the two that might cause trouble when you try to deploy them simultaneously, we were never able to do.

At the time, people didn't really think it was a credible scenario, that doing them at the same time is any different than doing one by themselves. I think people have a different opinion now, as we go forward. But that's one of the things that's important about the Discovery missions to bear in mind is they are higher technical risk than we permit weather satellites or type A or class A missions, like a JW, to do. We do the best we can with the budget that we have, and there's a pretty good track record that shows that we've been successful across the Discovery missions in having test programs that are sufficient to catch most of the large

[4] The DAVINCI mission will study the origin, evolution, and present state of Venus in unprecedented detail from near the top of the clouds to the planet's surface.

likelihood issues. This is one case where having a significantly larger budget—larger than New Frontiers, probably—could have created a different type of test environment on the ground that may or may not have found this issue.

It's a great question to say how do we know this will never happen again, and the people who want to know that more than anyone else are the Northrop Grumman folks who have this as a product line, because, of course, they need to be able to demonstrate to all future customers that this problem can never replicate again. I know there are still folks at Northrop Grumman who are still looking at this design to see if there anything in that whole design that could be changed that would still allow you to prevent this sort of scenario that we had here.

JOHNSON: You mentioned the simulations, just the control center simulations before the launch, and, of course, it makes me think of, here at JSC [Johnson Space Center, Houston, Texas], all the simulation they ran before every mission with the control center, and they would do it over and over and over again and try to think of every possible thing that could go wrong, and they were simulation engineers. That was their job, to try to fool the mission control people.

BARTELS: Exactly.

JOHNSON: I'm sure budget-wise it wasn't that intense, but were those the kind of things that you did in those simulations before launch? And were there those kinds of problems like you ended up having? Anything like that ever thrown at you at that point?

BARTELS: It's a really good question. Almost every scenario, or almost every piece of hardware has an engineer assigned to it as a subject matter expert, and as we go through all these command sequences almost every engineer has not only their primary plan but their backup plan in case if something goes wrong, what do we do about it. In the pre-launch operations readiness tests that we did, and the simulations we did, we exercised the scenarios that we thought were most likely to be something that could really occur. All sorts of things have been anomalies in the past, various other failure to get telemetry, or failure of something, and we had canned contingency procedures ready to go to immediately uplink and execute from Denver if those situations had happened.

In terms of the solar array unfolding, every mission always has a contingency for that, as well. They're not usually this big, solar array, but many have a solar array that deploys and latches in some way. In almost all the cases I'm familiar with it doesn't sound very satisfying, but usually the right answer is you try it a second time and a third time, just as the nominal deploy, because they design these to be as simple as possible. Our prelaunch engineers had defined what was safe to try again, which was that deployment sequence, try it again, and maybe it's enough to make it happen.

The scenarios we ran prior to launch, this was not one of the scenarios we'd envisioned, so we didn't practice this version, but we practiced a lot of other ones. There's a saying that sometimes they have in the space industry of you practice all of those because that ensures you'll never actually have that problem, and this was a case just like that. We exercised many other possible failure scenarios, none of which manifested, and the one that we had a procedure for but really no way to test on the ground—because this is such a large-scale thing to do. Remember I mentioned it wasn't really designed to be commanded backwards. They could physically fold it back up, of course, but that's a manual operation that's not super easy to do, and so that was another reason why we had a very limited number of tests on the ground of this solar array where we would actually practice that unfolding and latching. So we had a procedure in place that says that there's a problem, here's what you do. You rerun the procedure that you just ran, and hopefully that second time would be enough to make it work.

It's not a perfect answer to your question. Yes, we had a plan. It was never exercised as part of a simulation, though.

JOHNSON: You've mentioned that other people had gone on after the launch, and they went to do PR [public relations], that sort of thing. Was there a lot of that type of public relations after the anomaly? Was that a big deal at the time?

BARTELS: It was, it was.

JOHNSON: You want to talk about that?

BARTELS: Yes, it was a matter of intense interest, actually, and so NASA PAO [Public Affairs Office] got ahead of that, and set up a blog, and we had a couple of press conferences, and also opportunities for reporters to ask questions. The NASA Headquarters was very good about trying to communicate information, partially because if you don't the internet runs wild. You could find all sorts of YouTube videos saying disparaging things about the Lucy mission right away, and speculating because they really didn't know the answers, and so NASA wanted to make sure that the information was getting out complete and factual. There was a blog set up that was being updated once every week or two as we were researching it and then doing the activities.

NASA Headquarters was extremely, extremely helpful on this, because they did not push us to rush, either. We told them, "The mission is safe but we would prefer not to run it this way because it's not how it was designed. Please give us the time. We have the right people. We have the resources"—because we still had some funding—"so let us research this and try to figure it out, and we will report to you, and we will bring you in on it." Because of that, NASA Headquarters, Science Mission Directorate, and Dr. [Thomas H.] Zurbuchen, didn't feel the need to bring in a whole separate tiger team to come in and look at things and do things.

We convinced them that we were applying engineering rigor in a textbook manner. It really was. I was very proud of the system engineers. They resisted the urge to be rushed, and just did things in just literally a textbook way. Our leadership at Headquarters gave us the time to try to figure this out, while at the same time our PR folks, on the order of every couple of weeks, especially early on, would update the NASA blog to say here's the latest information, and so we got to know them very well, for sure.

Donya did a terrific job of updating all of NASA's leadership once a week, or once every ten days, with the news, and I would take that on when Donya was not available. We wanted to make sure that this was just very open, and everyone knew exactly what we were doing, and that we were applying the right engineering rigor to get to an answer if there was one. But yes, it was a concerted effort from NASA PAO to make sure that we were communicating the true state of the mission, that we weren't hiding anything, but that we also didn't get people unnecessarily alarmed. The mission was not ever in any imminent danger, and it's still not, because this is the way we're still flying today on Lucy, with the solar array being held in position tightly by this Kevlar strap in tension that's holding it there.

Yes, this was my first time ever being on a mission that had an anomaly of that magnitude. It was never declared a contingency or a mishap—certainly not a mishap. But despite that, NASA really wants to make sure that we're not accused of covering up anything. And certainly our science team—not just Hal and Cathy but the full, extended Southwest Research Institute-led science team of I think there's at least 50 folks there—they also wanted to know, because they wanted to know is their spacecraft going to be alive. The one thing they did, and it was smart, is PAO asked us to not be putting a bunch of stuff on our personal Facebook pages or Twitter feeds or anything, or anything speculative. Have one source of information, have it be the true information, and we would put it on that NASA blog. What we instructed all of our team to do if they were curious, as well, is just here's the link to the blog. Every time we have something that's worth knowing, go here and that'll be where you'll get the one piece of official information. It worked very well.

I see now how other anomalies get coordinated, and sometimes it seems like the information may be a little slow in coming, but that's because sometimes it takes a while to understand what's going on enough that you feel comfortable saying, "This is our best information as of today." That was handled very well by the Headquarters and PAO folks, but, yes, we got to know them much better than I ever intend to get to know them again.

JOHNSON: Yes, I bet. As far as going forward—and I know we've had the fly by Earth, and getting ready to do the first encounter, and do some testing there—is there any scenario that suggests that not having it completely rigid could still cause a problem?

BARTELS: Possibly. You know, this is the thing that the operations team just watches like a hawk now, and so the way they do this is every time that we fire one of the engines on Lucy to make any sort of adjustment—they call it a Delta V maneuver—to try to change the trajectory, the thing that they really watch for is the telemetry from that thing called the IMU that would tell them whether this is nice and tight or whether it's softened up a little bit, and they can tell that by the frequency at which you get a tiny, little resonance. So if you fire the spacecraft engine, and you look at the frequency response and magnitude that comes from the solar array, they know this latched one, exactly what it looks like in terms of the size of the spike and the frequency of it, and exactly what it looks like. And they can compare, then, the other solar array to say is it still doing what it was doing before.

As long as it's doing that, we know they're safe, but if, for some reason, they found that maybe that Kevlar strap is starting to stretch out over time or something, it's not quite as rigid as it was, then they've had the time to develop the contingency procedures to safely execute the rest of the mission by doing things like instead of firing the engine once, giving it the full impulse at one time, to do smaller burns more frequently, things that would excite it less. The team knows that it's safe now, but as they do the next times that they fire the engines, they'll look at the telemetry, and from that telemetry they'll deduce is everything exactly as it was before, or has something changed enough that we have to change our operations of it to protect it? Right now, there's no concern that we're not going to be able to execute the mission, and actually the first test of this will be in about two months. Did Cathy or Hal talk to you about the Dinkinesh fly-by?

JOHNSON: Yes, we talked a little bit about it, but I like to get everybody's version because each time I learn something different.

BARTELS: Let me come back here to this model, this spacecraft. I don't know, Cathy or Hal would have done a more elegant way of explaining this, but do you see this little portion up here? [Indicates the location of the instrument pointing platform on the model] This is where all the instruments are, little cameras and things, and they're on this platform that rotates. What happens then is as we fly by—so now you're the asteroid that we're flying by—as we go past it, what they do is use this pointing platform to sort of track as they go to get longer time to observe it, and to see it from different lighting angles, so that all of the instruments—the Ralph instrument, the LORRI [Long Range Reconnaissance Imager] instrument, the TESS [Transiting Exoplanet Survey Satellite] instrument—can all photograph the target. The important thing about this Dinkinesh, or Dinky, fly-by is it's going to allow them to test all the algorithms. The spacecraft will stay in its configuration, just a standard configuration, but this platform will rotate and follow and track the asteroid as it goes by, and so that will make sure that they've got all of the algorithms correct to do that when we get out to the later targets.

That's really important because a fly-by mission, like Lucy or New Horizons—they did that past Pluto—is that these fly-by missions, you only get one chance, and that's something that I think we miss sometimes. A mission that is an orbital mission, or like when OSIRIS-REx got to Bennu, we had many months to just orbit Bennu, although that was difficult to do, but just stay there and orbit and photograph the body. With a fly-by mission, you only have the time as you approach, encounter, and recede from it to do it. So if you don't have your algorithms correct for how you're going to point and steer the camera platform, and you miss it, there's no going back. You've missed it completely. This Dinkinesh, Dinky, was one that they serendipitously found. They didn't launch knowing that it was even there because it's so faint. We just got the images down this week, the first images taken with our own camera, actually to see it, and we're less than two months away from that encounter. That'll be really important.

The next time we actually tickle the engines and do anything for the mission isn't for many months after that, but one of the things they have figured out how to do is to do very small, little impulses of the engines that are enough to just excite the modes to compare the two and make sure that they're both the same mechanical configuration. I don't know exactly what cadence that the ops team does this now, but if they see anything in the telemetry that would indicate that maybe something has changed in the one solar array, then that would be the next step they would do, fire just a tiny, little burst of gas out, just enough to excite it enough to confirm that suspicion, and then, if so, then they would go to the alternate plans.

But the things like the Dinky fly-by, and the one we do later, past [Asteroid] Donaldjohanson—they probably mentioned that one, too—neither of these first two are actually part of our official mission set; they're actually targets of opportunity that the engineers want to have as much to check out the targeting and how we track the asteroids so that we have even a more likely chance of success when we get to the ones that really count.

These are really interesting little bodies, Dinkinesh and Donaldjohanson, but to the folks who studied Trojan asteroids, like Hal and Cathy, they're just main belt asteroids that are common, like all the other main belt asteroids. I'm sure Cathy and Hal have talked at length about why the Trojan asteroids that we're going by are so unique, why their composition is so unique, and the things that those will tell us about the composition, hopefully, of the solar system are ones that you won't really get from these first two, Dinkinesh and Donaldjohanson. But they're very fortunate that they're already where we're going and so we're taking advantage of that, and anything else they find they'll do that later as well.

JOHNSON: Yes. I did read that as things progressed and they're finding other little, mini satellites around some of them and that sort of thing.

BARTELS: Yes, that's it, that's it. One of these asteroids [Eurybates] actually has a tiny, little moon of its own that orbits it, and so that's interesting too, for lots of reasons, but especially if it's a different type of composition. That little one, they gave it a really clever name [Queta]. I believe it was a Mexican female track star from the '68 Olympics [Norma Enriqueta "Queta" Basilio Sotelo].

JOHNSON: It's just interesting that things have been found with Hubble and everything else as this has progressed.

BARTELS: Right. And Hal and Cathy I'm sure were way more eloquent than I can be about this, but all of the asteroids that they found ahead of time that actually are part of our core mission—Eurybates and Polymele and the rest—they were chosen because they have a very diverse set of properties that, taken together, form sort of a catalogue of the early solar system. So one of the real powers of Lucy—I'm sure Hal and Cathy mentioned this—is that by having such a broad selection of different types of asteroids that we're flying by, that'll help confirm their theories of how the solar system came to be. Of course, the hope is that these groups of Trojan asteroids that are trapped in these gravity wells in front of and behind Jupiter actually are remnants from the earliest part of the solar system.

The really magic thing that made this mission happen was when the flight dynamics mission design folks figured out a way to—Hal and Cathy basically said, "I need one of this type, one of this type, one of this type." They gave a list of candidate ones, "the same ones like this, this, and this," and so the people who designed the missions were able to find this path that would actually go out to, first, one swarm and find those types—a swarm is what they call the group of area of the solar system that happens to have a lot of these Trojan asteroids—and finds a path to safely thread through those and finds several of those. Then we come back and swing past the Earth again and shoot out to the other swarm that is in front of Jupiter. That's the ones where the PM binary [Patroclus and Menoetius] that Hal likes so much is. But it's really pretty amazing that they were able to come up with a trajectory that would find these sources.

I bring it up now because you mention what would they do if there was a problem. If we had found before we disbanded that anomaly resolution team that we weren't going to safely be able to actually run the main engines because they will just shake the spacecraft too hard for the solar array, that same team of flight dynamicists had actually said, "Okay, based on the small engines that we actually know would still be safe, what other targets could we go to? Maybe not the original ones that Hal and Cathy had wanted to go to, but could we still find a diversity of asteroids that we could get to safely that would still answer some of those same questions?" And they, remarkably, found another scenario of backup options, which wouldn't have been the full set of diversity of asteroids that Hal and Cathy were looking for but still would have allowed us to claim mission success, because we would at least have encountered more than one type. It really is amazing how they're able to come up with this.

There was always a backup plan to say that even if we can't fire the main engines, but we can operate the spacecraft, here are the other places we can go. The only scenario that we could not recover from is one where that Kevlar strap breaks and the fan folds back in on itself again and we're not producing power, because we wouldn't make enough power to run the spacecraft and the cameras at that distance. So that would mean the mission does not meet its success, but as long as we're able to still do these trajectory adjusts to get to other targets of interest, even if something happens over the next decade with the solar array that's in its current condition, Hal seems to be pretty confident that they'll still be able to execute the mission and get the science from it that they need.

JOHNSON: Because of what happened, you ended up staying another nine or ten months working where you thought you'd be handing it over to an operations team at that point.

BARTELS: Yes, yes.

JOHNSON: I don't know at what point you were moving on to DAVINCI. Were you doing both things at the same time?

BARTELS: Yes. Yes, actually, I was. Matter of fact, the DAVINCI selection was announced prior to launch, and so I was already working part-time on DAVINCI and part-time on Lucy. Because I'm a project manager and not the engineering team, I wasn't working full-time on this, so I was on the anomaly resolution team, and I was helping coordinate it and making sure that we weren't taking shortcuts and all of those things. But because I'm just a manager, the smart engineers were actually the ones who were really working on that. So I was multiplexing both jobs part-time. Now, that's not uncommon in NASA, for you to be working multiple projects. It's just a very different focus, one was already post-launch and the other was just getting started. But since they were both within the Discovery Program, both sets of PIs and the Discovery Program Office had no objection to multitasking.

Someday, when we talk DAVINCI, it was selected, but because of funding profiles was selected with a three-year slip right out of the gate, with just some kind of startup money for technical risk reduction, so I didn't have enough money to really get started on DAVINCI full bore anyway. Same thing with my lead system engineer, Mike [Michael] Sekerak, who was the deputy on Lucy, and who led most of the technical discussions on the solar array ART—anomaly resolution team—he was also multitasking both jobs as we went. It was a very patient PI, Dr. [James B.] Garvin, and our DPIs [deputy principal investigators], Drs. [Stephanie A.] Getty and [Giada Nicole] Arney, who said, "Go take care of that first."

Because we do have an ethos in NASA that anytime an earlier mission in flight is having an issue, it always takes precedence, and if you have to you delay what you're working on now. That's been true of all the missions I've worked on. If something happens even a decade after launch that they need the people who were there during development, they'll call those folks back in, and your first priority is always safety of personnel first and safety of your hardware second. And so it wasn't ideal. I was really hoping to get out of the gate with DAVINCI, and so was Mike Sekerak. But the truth is priorities are with the mission that you've just finished.

That's important for the PI as well, because if Hal had only the operations folks who were learning all of this as they went, but all of the engineers who developed it just disappeared on them, he should be upset at that. We would never do that to any of our PIs, or our missions.

So although the time demand on the anomaly resolution team was less, for me, than getting DAVINCI started, those meetings were higher priority, because if Lucy needed anything it came first, and then we had many years to work on DAVINCI after that.

JOHNSON: Yes, that makes sense.

BARTELS: I think we do, yes, yes. Did I tell you they pulled me back to OSIRIS-REx for something?

JOHNSON: No.

BARTELS: Oh, yes. Partially based on the fact that we've had this anomaly case here on OSIRIS-REx. Even though I'm no longer a member of that team, per se, I'm heading up what's called the Interim Response Team, so in case we have a mishap or contingency that happens when the OSIRIS-REx capsule comes back to Earth, then I lead the team that takes the initial steps to address that phenomena, if it doesn't come down in Area 52, like it's supposed to, but if it lands outside the controlled airspace area, or if the parachute fails to deploy, like happened on a mission about 20 years ago called Genesis.[5]

JOHNSON: Yes, Genesis, yes.

[5] The Genesis spacecraft spent more than two years collecting samples of the solar wind. The spacecraft then brought the sample canister back to Earth where it parachuted to the ground. Despite a hard landing in the Utah desert, the Genesis samples were recovered.

BARTELS: Right, that's one of yours you've been doing the history on. This is a great example of lessons learned within Discovery. Because of that Genesis impact, and the fact that they didn't already have a pre-stage team with procedures in place to take immediate action and safeguard the hardware, that was one of their lessons learned that came forward. So because of that, for OSIRIS-REx, I'm now filling that role to be redeployed with a small team that'll take charge in the event of a contingency or a mishap. Hopefully I'll just be an insurance policy that won't be needed, but that's a good example of how the Discovery missions, even across decades, feed each other from a lessons learned standpoint.

It's the interesting thing about the Discovery missions, in that—well, many interesting things—but one of them is that although each of their targets are very different, and their mission definitions are very different, they do have a lot of the same recurring technology, and there's a lot of information exchange from one to the next to the next. We try to really learn off of those previous missions. That's one of the powers of this being a program, as opposed to just being a collection of one-off projects. Every PI that you talk to really is only involved in that one mission, and that's their view into Discovery, that one mission they worked on, but from the Marshall [Space Flight Center, Huntsville, Alabama] folks, and those of us who have had the blessing to be on multiple missions through the years, we're able to draw from those scenarios. As part of me prepping for this OSIRIS-REx position, I was not only able to go talk to the people who were involved at the Genesis mission, but also the person who headed the mishap board later on Genesis, to say, "Had there been an interim response team in place, what would you have wanted them to do?" By talking to him, Mike [Michael] Ryschkewitsch from the [Johns Hopkins University] Applied Physics Lab, that helped me frame what my role should be in case something does go wrong out there.

We do tend to be a learning group from one mission to the next. Even though a lot of the science team are only there for one mission, their mission, there is sort of a thread of continuity across all of these missions that does make this an actual program and not just a collection of independent projects. Anyway, I was trying to think—that's one thing that would be interesting maybe when we're all done is we're talking always about individual projects, but there is also a larger thread about the importance of the Discovery Program as a sequence of successive missions that altogether tell a story beyond what just the individual missions themselves tell, and I don't know if we ever get to a point that we could talk about that, that would be interesting. I would think that people who want to look at this information later would be almost as interested in not just the details of the individual missions but sort of the thread that pulls all of them together into what we learn about the solar system.

JOHNSON: Yes, definitely. And when I talked to some of the Headquarters people that were overall program people, we talked about what was the purpose, what was the mission, the overall mission of Discovery, and not just the individual things that were going to be found out and the science that was being done. So, yes, it is a good subject, and I always like to hear different perspectives. That's what oral history's about, so, yes, I'd like to hear what you think about that, too.

BARTELS: Well, I'm glad they gave you that vision, because even in terms of as they go forward, the subsequent missions that they select, even though, again, selecting officials come and go, with that background there of the type of missions we've done in the past, that they choose new missions with the knowledge of everything that they've already flown. So, for instance, that's where the Venus mission I'm doing now, the two Venus missions that were selected in the last round, ourselves and Veritas, the one that's been put on hold a little bit, those filled in new holes of that overall portfolio.

JOHNSON: Yes. It's similar to where Lucy and Psyche are there to answer those questions about the asteroids.

BARTELS: That's it absolutely, different questions about the solar system. They're all questions about the solar system, but if you take each of these missions as books, make a book of each and you put them all on the shelf, that set of books tells you additional information about the solar system that no one book on its own tells you.

JOHNSON: Right. Well, I appreciate you talking to me today.

BARTELS: Of course.

JOHNSON: And I will talk to you again next week.

BARTELS: Yes, absolutely, absolutely.

[End of interview]