DISCOVERY AND NEW FRONTIERS ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

DANTE S. LAURETTA
INTERVIEWED BY SANDRA JOHNSON
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JOHNSON: Today is August 12th, 2024. This interview with Dante Lauretta is being conducted for the Discovery and New Frontiers Oral History Project. The interviewer is Sandra Johnson. Dr. Lauretta is in Tucson, Arizona, in his office at University of Arizona, and talking to me again over Microsoft Teams for our second interview. I appreciate you joining me again today.

We were right at launch the last time we talked, but I want to go back a few years and talk about the asteroid itself. I think it was your idea to rename it to something other than its original name, 1999 RQ36.

LAURETTA: Thirty-six, yes.

JOHNSON: Talk about that decision to rename the asteroid and why you wanted to do that.

LAURETTA: When an asteroid is discovered it gets essentially a catalog number that indicates the time of its discovery. Bennu was discovered in 1999 in September, on September 11th of 1999. Its catalog number was 1999 RQ36. We used that name for about eight years. We picked the target asteroid in 2005 and we won in 2011 and in 2013 is when we changed the name of the asteroid. We are well into the program by this point.

A lot of our documents were written, and they had 1999 RQ36 listed in them as the target. We decided it's a mouthful and we're doing a lot of public engagement and communication and it's just hard for people to remember and it doesn't sound like a real place. We were in the mix. It was coming up on the preliminary design review. The challenges were really heavy. The team needed some levity and they needed some excitement and something to celebrate.

We decided the asteroid needed a name. We didn't want to call it 1999 RQ36 anymore. Asteroids are named by the discoverer. The discoverer gets to submit a proposed name to the International Astronomical Union and then the IAU approves it or not. The discoverer was the Lincoln Near-Earth Asteroid Research project, the LINEAR survey. We reached out to LINEAR, who we know and who are our colleagues and friends, and said, "Hey, 1999 RQ36 needs a name. Would you like to join us in coming up with one?" They were excited because it was a mission target and they discovered it, so it's a big deal for them, for their program.

We said, "We need a public engagement entity, somebody that can really run the program and has a large constituency that they can talk to." We had worked with the Planetary Society and had a great relationship with them. They had done a really nice job promoting our mission and showed a lot of interest in what we were up to and getting the word out to their 50,000-person membership list.

We formed a partnership between the OSIRIS-REx [Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer] mission, the LINEAR survey, and the Planetary Society, and we launched a campaign called "Name That Asteroid!" with an exclamation point at the end of it. It was to get young people [involved]. We wanted especially schoolkids from all over the world to submit potential names for the asteroid. We had over 8,000 entries into the contest. There were some really great names. I was reading through and I was like, "I can't believe there's not already asteroids named all these things because they're really good."

We worked through it as a team, had a lot of fun thinking about what it might mean to be named different things. At the end Bennu [a heron-like deity from Egyptian mythology] won. It was submitted by an eight-year-old student from North Carolina and he said that the spacecraft in flight looked like a bird, and with its solar arrays extended behind it and its robotic arm out for sampling, it looked like a heron going in to grab its prey. The name was also linked to the OSIRIS theme because Bennu and Osiris are related deities in Egyptian mythology. The combination of connecting to our name and to the engineering really made it a compelling entry and ultimately the winner of the contest.

JOHNSON: I think that's a great story just because of this eight-year-old, who by the time the samples actually returned wasn't a little child anymore. What would he have been, 18?

LAURETTA: He's in college. He came to our party in Houston in September to celebrate the sample. Him and his dad were there as our guests.

JOHNSON: Oh, that's great. That's a great little circle from getting the name, seeing it then.

When we stopped last time, we were talking about how some of the teams changed once the launch happened. Some people came on; some people went off the team. But that first year before you got to the Earth gravity assist, talk about what was going on in that first year. Did you take a vacation? Did the team relax a little after that?

LAURETTA: That's a great question. Did I take a vacation after launch in September of 2016? Certainly the holidays were quite relaxing. I was really able to celebrate with my family. I don't recall if we left town or not. I'd have to go back and look in my records for that. But mainly we were learning how to fly. We were learning how to operate as a team.

It's really different once you get that spacecraft in space and it's in the true environment that you never can really fully simulate when you're on Earth. You try as best you can with your thermal vacuum chambers and so on. But space is space and there's nothing exactly like it in any of our laboratories.

We're looking to find out—every spacecraft has its own personality—what was the personality of OSIRIS-REx? Very reliable actually. It's a great vehicle. It's very very rugged.

We started to see some outgassing which is not unheard-of. But a lot of the missions hadn't paid attention to it, and we paid a lot of attention to outgassing. It was basically water that was condensed in Florida, sucked up into all of the spongy surfaces like the sample return capsule. Especially the backshell, which is made of a soft, porous material and it grabbed a lot of water while it was in Florida. Then when it's permanently shadowed the water stays frozen as ice. But as soon as any sunlight hits it it's like a little comet. It shoots off vapor. It pushes the spacecraft. That's what we started to see, was that there was thrust on the spacecraft, and we weren't operating our thrusters. We're like, "Okay."

In most missions it would be just noise. But for us every tiny force was essential because we were trying to go into orbit around a very small asteroid. Something that had never been done before. A small force like that outgassing could literally kick us out of orbit.

We had to pay a lot of attention to it. That was something that we focused on. We got some cool images of particles shooting off of the spacecraft. We really started to say, "Yes, we're carrying some Florida water. It's been frozen. But we put the spacecraft into new angles relative to the Sun and these areas got lit up and they're outgassing." We just came up with a strategy.

We're going to rotate the spacecraft around and heat up every dark surface and try to drive as much of that water off as we can. You could see it going down every day exponentially. The thrust was getting less and less and less and less. We were baking it out. It was kind of hurry up and wait. Okay, now we know what's going on. We can just solve the problem. But that was a big challenge for us.

Then the Earth gravity assist was coming up and that was a first opportunity to get the science instruments on an extended target and really see what does the data look like when it's coming back not just from space, which for your cameras is okay, you could shoot the stars and see stars, but for your spectrometers they're just seeing really cold empty space. They're not giving you any signal.

We were really excited. It was also where we started to realize that our science–spacecraft interface needed some work. How do we communicate exactly what we want to do back to the spacecraft team? One of the reasons I was pushing hard for observations during Earth gravity assist was exactly that reason. Let's go ahead and get the team exercised.

Once we realized that we had a challenge at the interface there I said, "Let's do something before we get to the Earth." What could we do? Turns out we could look for near-Earth asteroids. We were passing through a region of space called the Earth Lagrange point where you expect a population maybe of Trojan asteroids. Trojans are famous. They're in the same orbit as Jupiter, trailing and leading around the Sun. They get trapped there because the gravity balances between Jupiter and the Sun. It's been speculated for a long time that there might also be Trojan asteroids trapped in the Lagrange points around Earth. They're really hard to see from the Earth because you're always looking right at the sunset or right at the sunrise. They're really challenging observing conditions. We're like, "We're flying right through one of the L points. Let's see if we can find asteroids."

It was a long shot and I knew it but the whole point was to get the team operating and to get observation plans over to the spacecraft to implement them, get data back. Get our pipeline, our software up and running. It was rough. That first set of observations there was a lot of miscommunication. There was a lot of which product am I sending you, which product am I receiving, do we have the right templates defined, how much of the spacecraft do we get to control as the science team versus how much is the spacecraft team, and we came up with some pretty good rules.

They said the science team can operate within a box. You can look in any corner of the box but you can't look outside of it because that puts the spacecraft in danger. We got really good at working within the resources they gave us. I think it was one of the first missions where the science team did gain control of the spacecraft. We could command slews on the spacecraft to point at specific areas of interest within the box that they gave us. They wouldn't let you do anything outside the box. If you sent a command back and said, "Slew and point at the Sun," they would be like, "No, we're not allowed to do that." There was a bunch of safety checks. We learned about how those alarms get sent back and what happens if you try to plan an observation that is out of bounds. How does it get sent back? How do you test it and reach convergence and conclusion?

For me it was kind of like boot camp. It's like okay, we got a couple years to get to the asteroid. We got the Earth gravity assist, but we want to do calibration there. We don't want to be figuring out how we command. Let's command first on a real campaign that has some real science to it but low stakes. If it doesn't work it's fine. It wasn't part of the mission success criteria. Then we did the Earth gravity assist, and then we felt like we were ready for Bennu.

JOHNSON: Talk about that Earth gravity assist and taking those pictures and getting those cameras out. I think the photo was pretty cool to see that from your spacecraft at that time.

LAURETTA: It was amazing. It was the first time the team had been all gathered in Tucson for science operations. It was a festive atmosphere. People from all over the world were coming in and they wanted to be part of it and get a feel for what life was going to be like when we were at Bennu. Our building came to life. We were having drinks after work or we were playing games together, going hiking in the mornings. Really building a team and that team spirit. That was really important.

Then yes. The day that we flew by the Earth it had been a little over a year since launch. Relatively quiet, but things were starting to get exciting. Those images came down and it was a profound moment for me, because you could see cameras that we built, that I watched get built with my eyes here in Arizona in the laboratories, were in space, and were looking back at our planet. Just to see the Earth like that. You always hear about it, but to know it was your spacecraft and your camera and your team that did that. You could just see how beautiful the planet was. It was a real Carl Sagan moment for me, and for everybody in the room.

It's such a profound experience. It's hard to explain. I wish everybody could have it because I think it would give us a much deeper appreciation for our planet and each other. The fact that we're adrift in space and you never think about it until you see it cast that way, at least for me.

JOHNSON: I think a lot of astronauts have described it that way. The blue marble or everyone on Earth in one photo, the whole population of Earth. I can see that would be quite a moment. Just to be taking it from this spacecraft that you had worked so hard to get at that point.

LAURETTA: Yes, and to see that everything worked. That was also great. We got the spectral data back a few days after. We were looking back at the Earth and Moon as we were flying away, and the spectra looked beautiful. Nice sharp features. The atmosphere is really good for spectral calibrations. We got some shots of the Moon. Saw the far side of the Moon. When I first saw the image, I was like, "That doesn't look right. Oh yes. I don't actually ever see that side of the Moon."

JOHNSON: It's not the one we get to see from here.

LAURETTA: Right. It was like oh, cool. It was part of the nearside and part of the farside was the best shot that we got.

JOHNSON: That first view that you had of Bennu. I think I read that you were in Japan at the time for one of their missions to an asteroid.

LAURETTA: Yes. This was in August of 2018. A little less than two years since launch. I was in Japan visiting my colleagues at JAXA [Japan Aerospace Exploration Agency] as part of the Hayabusa2 mission team, which I was a coinvestigator on. They were going through their site selection process. They were identifying regions on the asteroid surface for sampling and they also had a lander and rovers.

It was a really exciting time because they were a few months ahead of us in everything that we were going to be doing. It was not just helping them but helping us. That was a true hallmark of that collaboration. The two teams communicated very well and shared a lot of lessons learned and made each other's lives a lot easier because of that. I'm very grateful for their help and to be part of that mission.

But the first light of Bennu. It was just a single pixel that the PolyCam was spotting. It was coming down at that same time. It was a little heartbreaking not to be there with my team but I Zoomed in from a hotel in Japan. It was 2:00 in the morning where I was and the team was gathering. As soon as I saw that little point of light moving across the star field in a sequence of images I was like, "We're here, it's real."

It's funny. You've thought about this thing. You've looked at it through telescopes. You've plotted its orbit and its trajectory. But you always wonder is it going to be there when we get there? Did we fool ourselves? Did we get the orbit wrong? Did it disintegrate? Who knows what? Just the unknown. You're like, "It's real. It's really an object that's out there." Then you think, it's 500 meters across. We're seeing it from 2 million miles away on the spacecraft and from hundreds of millions of miles away on Earth. "How is this even possible?" It still boggles your mind when you think about how tiny a piece of rock it is on the grand scale of the solar system and that we were able to rendezvous with it and get within centimeters of where we wanted to be.

JOHNSON: Yes. That's incredible. Especially for someone that isn't in your field. When you read that, it's like how do you do that. I don't understand how that's even possible.

LAURETTA: Right.

JOHNSON: Talk about getting closer to Bennu, and as you were getting closer, some of the things you were seeing. I had read that you could see one of the boulders that was on the south pole. You could see that from some of the observations. But I think it was kind of surprising when you got there and you found a few more.

LAURETTA: Yes. When we had done the astronomical campaign, we spent a lot of time trying to figure out what the surface roughness was, because that's really important. To send a spacecraft down to make contact with the asteroid, you want a smooth surface. Whenever planetary missions land, like if you look at the Apollo landings or Mars landers, they're always looking for safe areas that are flat. The same was true with us.

We had convinced ourselves that that was the case, that Bennu was generally a flat featureless smooth sandy surface, using thermal data and radar data. It was a shock when we got those first resolved images. I remember it was about 100 pixels across when we first started to see the nature of Bennu.

I looked at it and I said, "This doesn't look right."

One of my colleagues was in the room and she's like, "What?"

I said, "Look. It's covered in boulders as far as I can tell. Maybe it's going to be smooth when we get up close to it but already it's looking really more challenging." Then as it got closer and closer and more and more resolved until it was filling the whole field of view of the camera, it was just a rocky, rough, rugged surface that was not anything like what we had planned for or were expecting. It was a real jaw-dropping moment.

JOHNSON: You'd done those studies. Like you said the thermal studies. Why do you think it was so off?

LAURETTA: Found that out a lot.

JOHNSON: Yes. I was reading in your book. You were talking about how boulders hold on to heat longer and sand doesn't, and those were the studies that you were doing.

LAURETTA: That's right. The basic idea is that something that's fine particles like sand heats up and cools off quickly. Something that's large particles like boulders heats up and cools off slowly. Bennu heats up and cools off quickly, like sand. It definitely does that. We confirmed that with the spacecraft encounter. It heats up and cools off really quickly. It's the boulders that are heating up and cooling off the most rapidly. It's exactly the opposite of what our theories had all predicted. We just got it completely wrong.

Part of it is because the boulders, they don't seem to be as solid as the boulders on Earth. They seem to be kind of soft and smooshy and porous. They're kind of like sand in their structure. Lots of space in between them.

It's the fact that they formed in microgravity. You got boulders that formed in microgravity and so they're very porous, they're very low-density, and they heat up and cool off very quickly. That was the reason we got the thermal data wrong.

The radar should have seen through that. The radar should have seen the average roughness. But because the surface is so low-density, and I'm speculating here, I haven't verified this with a study or a model or anything yet, I think the radar penetrated pretty deep into the subsurface like maybe a meter. Instead of measuring the roughness of the actual surface it was measuring the roughness of a layer maybe a meter deep because it's so low-porosity and low-density. The radar beam can move through the rock.

When we sampled, and also as we've studied the small craters, it does look like there's a fine-grained layer just underneath the surface. The sand is there. We probably saw it with the radar beam. But we didn't appreciate that the radar beam was going deep and that we were inferring surface characteristics when really it was subsurface that we were measuring.

Now that's speculative. I want to make sure if this is going into a record. I haven't proved any of that yet. That's just my idea right now.

JOHNSON: When did you realize that it was a rubble-pile asteroid. Was that something you knew earlier than that? Or was it when you first got there?

LAURETTA: We suspected it was a rubble pile based on its shape. The fact that it's almost spherical and it has that ridge, that bulge at the equator. That really suggests that it is behaving somewhat like a fluid and a rubble pile would be consistent with that. We thought the shape was a rubble pile. We just thought the rubble was really small.

JOHNSON: Easier to get, right?

LAURETTA: Right.

JOHNSON: Talk about some of those other things. When you first arrived and then you entered orbit December 31st, which would have been New Year's Eve, some of the things maybe that you started finding out about Bennu that were somewhat surprising. I think some of it led you to eventually name it the trickster asteroid.

LAURETTA: The trickster. Absolutely. Yes. The first was that bouldery rugged surface. Then we got to Bennu officially, we arrived in early December of 2018. August, September, October, November we were approaching. We were getting better and better images all the way. But arrival was when we started what we call the preliminary survey phase. Operating in proximity to the asteroid.

We spent about a month zipping back and forth looking at the poles, looking at the equator, building up the gravity field, so we could go into orbit. We went into orbit on New Year's Eve of 2018. There's a great picture, one of my favorite shots, of the flight dynamics team in tuxedos and evening gowns, because they're working to put the spacecraft into orbit, but then they celebrate the New Year, ring in the New Year as well. It was kind of a cool confluence of gatherings there.

Then less than a week after we get into orbit and we're having a science team meeting in Arizona, and the surface starts erupting and ejecting and shooting particles. It looks like a really energetic and dynamic event. We're worried for the safety of the spacecraft. It's kind of an emergency, all-hands-on-deck call. We're trying to troubleshoot what's going on. Is it a solar flare? Is it something weird? Is it an impact? We're like, "None of that makes sense."

We thought we were going to have to get away from Bennu because it was a hazardous environment, we were going to damage the spacecraft. We sent three different teams, what we call tiger teams, to go work all night. We said, "You guys, we're brewing coffee. We're staying up all night and we're going to figure out if it is safe to stay in orbit, because we need to make a decision now. If we decide to leave orbit the whole schedule is pushed back by months. It really delays a lot of things. We don't want to do that if we don't have to."

They come back and they say, "You know what, it's microgravity messing with our minds again. It just doesn't take a lot of energy to launch something off the surface of this asteroid." One of the team members said it's like breaking a cracker. You get those little flakes. That's about the energy that it would take to launch something into orbit around Bennu.

It was like oh yes. The spacecraft is moving really slowly. The particles are moving really slowly. If they bonk, it's going to be like a little tap. The spacecraft is designed to handle much bigger hits than that because it deals with meteoroids and high-velocity particles in space. Now it's just a cool science experiment. The emergency is over and we just need to figure out what can we do with this awesome ejection.

It turns out it happened almost every day. There was particles that were being ejected from Bennu. It's very dynamic. It's like popcorn. You watch the surface. Then most of it falls back. Some of it escapes. Some of it gets accelerated by sunlight and goes into orbit. The whole thing settles down. Then another one goes. Sometimes one particle, sometimes hundreds of particles come flying off the surface. It's what we call an active asteroid.

JOHNSON: That's interesting.

LAURETTA: It was very interesting. It turned out to be a great science experiment because we were able to use the trajectories of the particles to map the gravity field of the asteroid.

JOHNSON: I did see that you were going to make the highest-resolution map of any celestial body ever made and that's including the Earth by these revolutions and what you were doing to study the asteroid itself and find the touchdown site.

LAURETTA: That's right. All of 2019 was mapping, mapping, mapping. That's what we were doing. We mapped it from different angles of Sun relative to the spacecraft so you get different shadows, which helps you figure out the roughness of the surface as well. We used the laser altimeter to map it as you said to higher resolution than any object ever.

Now to be fair, it's only 500 meters across. It's not as big as the Earth. There's a scale issue there. But still we like to claim the highest-resolution global map of any object ever achieved in space. It was centimeters-per-pixel scale. The whole asteroid was mapped at centimeters per pixel, both with the cameras and with the laser altimeter. We have it in three dimensions with images overlaid on it. It's a beautiful dataset. I hope people still enjoy it, explore it. I know once we got the full 3D models in, I would just zoom around in virtual reality. It was just like exploring my asteroid. Going into the craters. Zipping around the boulders. It was so cool.

Then people would have to be like okay, you got to get back to work. Like I am working. I'm looking for a sample site.

JOHNSON: Yes. How many times can you say that and actually convince them, right?

LAURETTA: Right.

JOHNSON: Talk about trying to find those sample sites. I know you started out with a very large number, trying to find someplace that had that beachlike quality that you really wanted to use. But of course those boulders and everything else was causing a problem with finding that. Talk about looking for those sample sites and how you did that and how you formed the team to actually do that and actually even brought in a guitar player to help you.

LAURETTA: That's right. We were severely challenged with our sampling location because when we launched the spacecraft—and I think we talked about this last time—the guidance system was using a lidar. The guidance, navigation, and control lidar. It was just a point. It was telling you how far away from the surface you were. That was the only telemetry that the spacecraft was using for its guidance solution.

The accuracy was about 25-meter radius. I could pick a spot, and the team said, "We'll get you within 25 meters of that spot guaranteed." Then we looked and I was like, "There's nowhere that's 50 meters across that's safe. You're going to have to improve the guidance system."

That's when we switched over to the backup, natural feature tracking. We abandoned lidar. Lidar was never used at the asteroid. The guidance, navigation lidar. Different than the mapping lidar, the science lidar. There was two different lidar units on there. We never used the guidance lidar at the asteroid.

We said, "Okay, now we have to build a natural feature catalog. That means a global distribution of figures. We need to know where we're going. You look at the trajectory that you're going to fly over and then all along your path you build a catalog of features. These are threedimensional shapes with a photometric model on top of them so the spacecraft can predict an image and then acquire an image and compare its predict to its actual and use an offset to figure out how to correct its trajectory to get it into the tight location.

We trusted that they were going to solve that problem and then went off to the site selection campaign saying, "We're not going to be dealing with 50 meters. Let's see if we can do something with 10 meters." Which was a huge ask. It's like 20 percent of the original capability. I said, "You guys go solve that, okay?" They said, "We're going to give it our best, Dante. We're going to give it our best," and they did.

We started to look around at 10 meters and some things started to open up. Oh, these little craters look interesting. They've got fine particles inside of them. Maybe this flat patch over here might be good. We were just looking at pictures and trying to figure it out. I was like, "Man, when are we going to get the 3D data?" This was before we had the lidar map.

Then I got an email from—he wasn't a friend at the time but out of the blue, a famous rock star, Brian May from Queen sent me an email. He said, "Congratulations on arriving at Bennu. I'm a huge fan. Here's a stereoimage that I produced from what you released online."

I got my stereo imager out. I have these now. Brian makes these stereoviewers. I got my stereoviewer out and I looked and it was like a whole new realm opened up. I asked him, "Can you make more of these?" He said, "Sure, I'd love to."

I started sending him coordinates and him and his collaborator Claudia Manzoni started producing stereoimage after stereoimage and ultimately at least 50 different locations on the surface were under investigation as possible sample sites. Brian and Claudia made stereos of every one of them. We ended up writing a book about it because we had so many stereos. We said, "Let's put them all in a book." It's called *Bennu 3-D* and we published last year. He was thrilled.

He was absolutely thrilled. I made him an official science team member. I made him work hard, which he really appreciated. He really enjoyed being a productive contributing member of the team.

Eventually we got our act together and we said, "Okay, 50 is way too many. We can't even think about that many. We've got to narrow it down." I sat down with a couple key team members. Anjani Polit who's my system engineer and Carina [A.] Bennett who's my lead imaging engineer. The three of us just said, "Let's get this down to a tractable number." Some of them were just so obviously bad sites. I'm like, "Why are we even talking about this one? There's boulders everywhere. Get rid of it. Get rid of it. Get rid of it." If there's not a clear reason to keep it, it's gone.

We got down to 16. That was a good number. I said, "Okay. Now we can start to get more formal about it. We need quantitative metrics on each of these 16 sites so that we can really compare them." Not just because they look good, which is what we were basically doing, but we can verify that they are amenable to sampling using our engineering criteria.

The first one was deliverability. This is where the natural feature tracking was trying to keep up with us. They said, "Okay, if we do nothing here's what your likelihood of a safe contact is." It was half a percent or some terrible number. You're never going to fly with that. They said, "If we can get you down to 20 meters it'll be this. If we can get you down to 10 meters it'll be that." I said, "You got to get me down to 10 meters. It's going to open up all this real estate." But we were able to quantify the likelihood of safe contact. That was one of our numbers.

We were able to quantify the tilt at the surface, because one of the big safety constraints that you worry about is if we come down on a high tilt the spacecraft will tip over and it'll either crash into the surface or fly away into one of those giant boulders which are sitting around nearby.

These things are 10, 20, 30 meters tall. They're like buildings. Any kind of angle on your escape trajectory could mean flying into a boulder. Tilt was something that we were really struggling to try to get an understanding of, because that was the prime spacecraft safety parameter.

Then there was sampleability. Are there rocks that are small enough for the TAGSAM [Touch-And-Go Sample Acquisition Mechanism] to pick up? TAGSAM was guaranteed to pick up things less than 2 centimeters. We couldn't see things at the 2-centimeter scale. We didn't have enough imagery at that resolution [at that time] to determine did we have 2-centimeter particles. We used the fraction of the images that were unresolved—unresolved meaning you couldn't clearly see rocks there. They were smaller than your resolution. That meant like 10 centimeters or smaller at that point in time.

We started to really get a good handle on how to quantify how good these sites were. Then we put them head-to-head and matched up the numbers, and one knocked out the other, and we were down to eight. Then we did the same thing again, and we were down to four. Then we were down to two and then one.

JOHNSON: In choosing that last one, I think I read that really came down to you picking that. Right? From the last two.

LAURETTA: That's right. At the end there were two, and the team was split. There was Nightingale. We named the final four [sampling site candidates] after birds, like Bennu. All the features on Bennu are named after mythological birds, so we picked common birds for the site nicknames. The final two were Nightingale and Osprey. Osprey was the safest by a lot. The engineers really liked it. They're like, "Look, we can guarantee you'll get to the surface. You'll meet what was called minimum mission success."

When you make your deal with NASA you have your Level 1 requirements, which is what you're designing your mission to do. Then you have minimum mission success. It's like if you just get this done, we'll consider the mission a success. That's important when you're reporting to your stakeholders at Congress and the White House. Yes, the mission was a success.

Minimum success was just touch the surface of the asteroid, but that wasn't good enough for me. I said, "The requirement is to return more than 60 grams of sample. Nightingale gives us a much better chance because the particles look a lot smaller there. Even though it's not as safe, we're much more likely to get a sample, and it looks like a great sample." The science value was enormous. Lots of organics. Lots of water in the clay.

At the end, the science team and TAGSAM team wanted Nightingale, and safety and spacecraft teams wanted Osprey. They were deadlocked. Then it became my decision, and I said, "I have to just go with the science. I have to let the science go. It's going to be Nightingale."

In the end the engineers said, "We can do it. We can sample Nightingale." If they had come back and said, "You know what, you're putting the whole mission at risk," then I would have backed off. But they said, "We can do it; it's just not as safe as Osprey." I'm like, "Okay, great."

JOHNSON: You mentioned the water in the claylike rocks or surface, but you had seen that earlier on, right? You were able to determine that that was there in those early sightings?

LAURETTA: That's right, we saw that in global observations. But Nightingale looked better [than the average surface]. It looked more organic-rich and a little cooler. The temperature was lower.

JOHNSON: At that point when you decided the site, then you had to do some testing to see if you could get to that site. You were running those tests for the sampling rehearsals. I had talked to Arlin Bartels about the natural feature tracking, some of that, and I've been looking at your book. The spacecraft became truly autonomous by using that natural feature tracking and the computer programs that the people had been putting into it. Talk about that for a minute and when you realized that it was going to be okay, that this was really going to work.

LAURETTA: Yes. When last we discussed natural feature tracking, they were still trying to get us underneath that 10-meter mark. They were able to do that. They were able to show yes, we can get you within a 10-meter circle, so a 5-meter radius, which was fantastic, because it really opened up a lot of terrain. But as I was looking at the final sites, I thought, "Even within that 5-meter circle there's big boulders. There's still things that could cause damage and maybe lose the mission. It's still not 100 percent safe." I called Arlin Bartels and asked, "What are we going to do about that?"

He said, "Okay, we got to go think about this." They came back and they said natural feature tracking can do more than just update its propulsive maneuvers. During the final descent to the surface it can still calculate where it thinks it's going to touch down and determine if it's a hazardous area and then back away instead of continuing down with the contact. It was a new upgrade called the hazard map. More flight software that had to be developed after launch as a patch that we added to the vehicle. It was able to make its own determination on the final approach to Bennu on whether it was safe to continue or should it back away and sample another day.

The bad news was if it backed away [the blast from the thrusters] would have destroyed all those natural features that were in our catalog, so we wouldn't have been able to go to the same site. We would have had to go to the backup site. If we had failed at Nightingale, we would have had to sample Osprey.

JOHNSON: It would have disturbed the surface enough that everything would have been displaced—did you realize how much it was going to disturb it? We can talk about that flyaround afterwards. You saw that. But you didn't know at that time.

LAURETTA: Not at all. No. We had no idea how much surface disturbance it was going to cause. You can go back and look at the animations that we had prior to the sampling event, and it looks like a nice solid surface. The TAGSAM pushes down and the surface doesn't move. Then it blows gas and a little bit of rocks get pushed up into TAGSAM and it backs away and it's all hunky-dory.

That is not at all what happened during sampling. It was a very very soft surface. The robotic arm plunged down about 50 centimeters deep into the subsurface. We excavated a crater 8 meters across. It was a huge, huge disturbance, much more dynamic than anything we ever suspected.

JOHNSON: Talk about those practices, those times you went down and you were talking about the natural feature tracking. How nerve-racking was it knowing that you were getting so close but you weren't quite ready to go all the way in on that?

On top of all of this, which I meant to mention a little bit earlier, COVID [SARS-CoV-2 virus] happened. That actual sampling had to be put off because of that a couple of months. You were working toward that sampling in August of 2020 but you were also working under those kind of conditions that happened in March of 2020. Maybe let's go back and talk about that period and how you worked through that at that point.

LAURETTA: We selected the site in December of 2019. We had a nice event at the American Geophysical Union [Fall Meeting in San Francisco]. We were at the NASA booth and it was a big reveal. It was fun. Then we said, "Okay, 2020 is the year of TAG." Everybody's like, "It's going to be a great year." I remember even in December we were a little bit worried being at the conference because there was this virus in China that was looking like it was going to be really bad and ugly. The government response in the United States was confusing. It's like wait a minute. Is this something to worry about? Is this no big deal? It wasn't clear what it was going to be.

Then I was still traveling a lot. January, February I was on the road. People were getting sick. Finally March of 2020 came along and the COVID pandemic really hit the United States with a fury. Lots of people were getting sick and people were dying. It was a really scary time. The whole world shut down is what it felt like. We were confined to our rooms, our houses. Nobody was coming into the university. Nobody was allowed to go to NASA or to Lockheed

Martin unless there was a mission-critical event or activity they needed to be on console for. They were isolated and alone.

It changed what was going to be a great year. It still was a great year but it was also a terrible year in the sense that it seemed like the whole world was falling apart and that the team was really stressed out. We would have been stressed anyways because of what we were trying to do and the enormity of it and the challenge. But then you add the fact that people are working from home. A lot of the team members are parents of young children. People with young children were struggling the most, I think, with not being able to send them to school. Trying to keep them occupied.

Kate (my partner) and I were fine because our kids were tweens. They were in middle school and they were pretty self-sufficient. I don't know how much they learned, but they were able to take care of whatever they needed to take care of for school. We were able to focus on our work.

But it made it extremely challenging. We had our first rehearsal in April of 2020. The team was just exhausted. That's when we realized we need to slow down. We need to just give more time. People need to get used to this weirdness. Maybe by October, which is when we pushed the sampling event to, this pandemic will be over. That was way too optimistic, but that's what we were hoping. Maybe we'll just be back to normal. We were planning a big party obviously. The team had been working, some of us 16 years, to get to this point, and we wanted to celebrate. Everybody wanted to come together. We couldn't even get within six feet of each other during the sampling event itself.

JOHNSON: It was a difficult time for everybody. I've talked to different people on different missions that things were happening in different places in the missions. Then COVID hit. How do you handle that when you're a team that normally needs to be in the same room with each other, especially on these practices? You would be there on console, and have to do the social distancing, and not have as many people in there as you normally would.

JOHNSON: That's right. But NASA still wanted to do a live TV broadcast. We were doing live TV in October of 2020. We all had masks on. I had to wear a clear mask, which was really funny-looking. It was for people who needed to read lips because we were on TV and talking. We wanted people to be able to see your face. But it made my nose all flat and squished. I looked funny on camera because I had this flat nose. You could tell everybody was struggling with the social distancing, especially after the success. We wanted to hug and high-five and everybody was six feet apart reaching for each other in the control room. It was a small group of people that were allowed to be there.

JOHNSON: Which is sad after that kind of a buildup. Everybody probably wanted to be there to see it firsthand I would imagine.

LAURETTA: That's right. Absolutely.

JOHNSON: Let's talk about the sampling itself and those moments. I know there's a delay between what was happening on the asteroid and when you were knowing it was happening. Talk about that buildup to the moments when you knew it was a success and what you found out at that time and how quickly you knew that there was some other things it still had up its sleeve for you.

LAURETTA: That's right. The sampling was in the afternoon on October 20th of 2020 and we did the live TV show. I was on camera for a lot of that. A lot of my attention was on what I call the performance. When you're on TV it's a whole different situation. You're thinking about everybody you're talking to and making sure they can understand what you're saying. You're not talking in jargon. Trying to be excited as you can to convey that across.

Then it all happened. It seemed like it went well. The time delay was 18 minutes. It was 18 minutes for a signal to leave the spacecraft and reach the Earth. I remember that moment when it was 18 minutes from TAG and I was thinking it's already happened. Now it's in the past and I'm just waiting for photons to travel across the solar system to get to us and tell us how it went.

That's when I realized how big the solar system is. We were on the other side of the Sun where Mars is roughly. Its orbit. That's not even that big compared to the scale of the solar system. That's like our neighborhood. I was like, "Wow." It's hard to explain that sense of enormity. You kind of know it. You learn it's a big place. You see the Earth against the stars. But to think it's going to take 18 minutes for a signal knowing how fast light moves. That to me really struck home how big the solar system really is.

Everything went well. There was a huge media interest. I did a lot of interviews right after the fact. Then went back to my Airbnb and tucked into my bed. I couldn't sleep because the images were going to start coming down. We'd collected several dozen images during the descent from multiple cameras. I thought, "Well, I've got to see what happened." I was just lying there;

made a pot of coffee. The chat room for the science team was full of excitement. Everybody was going through the events of the day, how they think it went, how it happened.

Then the first images started coming in. We were getting about one a minute. I knew the money shot, the spacecraft touching the asteroid, was like number 70 or something. I was thinking, "It's going to be an hour before I see the picture." Watching one photo a minute is pretty tedious. It's Bennu. You love it. It's your favorite boulders rolling by. Okay, another image. Then finally I get to the one where we touch the surface. As soon as I saw that I knew we had the sample because the TAGSAM went in. You could see it pushing down into the subsurface of the asteroid. I downloaded the image right before and right after and I had them blinking back and forth. You could just see the surface disturbance. I texted it to Thomas [H.] Zurbuchen, who was the Associate Administrator for Science, and Lori [S.] Glaze, who was the Director of Planetary Science. I was like, "We got it. Look at these awesome images." As soon as they woke up in the morning, they had the shots right there in their inbox.

Then probably 10 minutes went by and I was just playing around. I said, "Well, let's see what the next ones look like." Then it's like oh. Yes. We really blew the heck out of the surface. It looked like a snowstorm. That's when we knew that we had that fine-grained layer. As soon as I saw the NavCam images—the NavCam was looking off to the side of the spacecraft—as we're backing away, I could see this huge plume of debris just moving across the asteroid surface. It all looked sandy. I thought, "There's the beach. It was there the whole time. It was just buried under the surface of the asteroid." We had to dig a little bit to find it.

That was a really exciting moment, and I knew we had a lot of sample. Everybody was thinking the TAGSAM was going to be packed full, like kilograms' worth of material is what we were expecting based on those images. Because that's what the capacity of the TAGSAM would be if we filled it. Then two days later, October 22nd of 2020, back in the control room and we're doing a photo shoot. We're using the robotic arm to put TAGSAM in a bunch of different angles in front of the SamCam so that we can document the sample that's inside. We have to make a case [that we've successfully collected a sample]. I'm supposed to call Thomas and Lori back at [NASA] Headquarters and say, "Yes, I think we have sample and here's all the evidence." Or "No, we don't, and we need to go try again." Because we could go back and sample a second time if we needed to. Honestly, I didn't think the team was going to be able to do it with COVID and how exhausted we were. If I come back and I say, "We got to go again," we might just lose it.

But the good news was there was a lot of sample. The bad news was it was leaking out of the sample collector. One of the rocks, the troublemaker, was about 3 centimeters, so just a little bit bigger than what TAGSAM was qualified for. It jammed open a Mylar flap that was like our check valve that was supposed to keep all the sample inside. Sample was just spilling out into space. It looked like everything was flaky. It looked like somebody had dumped a box of cornflakes into outer space is what I keep thinking of. I'm like, "Man, all those particles are different PhD theses that people could be studying, and we're losing science here. We have to stop. We're bleeding and we have to stop the bleeding."

All motion on the spacecraft was called to a halt. No solar arrays, no robotic arm. No thrusting. Nothing like that. Get it as quiet as we can. We could see. We didn't realize it but the star trackers, which are different cameras that look at the star field to help the spacecraft figure out where it is, you could see particles moving across the star trackers. Then as soon as we quieted everything down, they stopped. We're like, "Okay. We're no longer bleeding. Now we just have to expedite our stow, get the collector into the return capsule as quickly as possible." We spent the next week planning that expedited maneuver and got that sample safely tucked away inside the capsule.

JOHNSON: How did you determine you had enough at that point? Because I know there was other ways that you were going to try to determine how you had the amount but you couldn't do those because of the bleeding.

LAURETTA: That's right. We had planned on doing a spin maneuver to use the moment of inertia difference in the TAGSAM before and after collection to see if there was a measurable mass in there. We were going to get tens of grams' precision. It was going to be pretty confident that we had the requirement, which was 60 grams of sample.

Then we couldn't do that because spinning the thing around while it's leaking would just cause more material to fly out. That's the last thing we wanted to do. We relied on our imaging. We could see particles. The good news, we could see the big one that was jamming open the flap. I was like, "Look, there's a 3-centimeter particle right there. That's got to be a few grams at least."

Then we could see other ones stuck around that flap as well. We counted them up and there was about couple dozen visible particles at the centimeter scale. I said, "That's pretty good. Even if we just brought that back that would be okay." We had sample. We guaranteed we have sample.

We looked for sunlight passing through the TAGSAM screen and it was completely black. The interior of the TAGSAM was coated with material. No sunlight was passing through. We inferred a lot of sample. In fact we predicted 400 grams at the time, is what we thought we had. We might have actually had that much at that point because we were losing 10 grams at a time every time those particles escaped out of there. We convinced Thomas and Lori. I said, "I think we've got a strong case. We've got sample. I can see it and show it to you. It looks good. Let's stow."

They agreed, "Yes, let's get this thing stowed and get it tucked away as quickly as possible."

Then we needed to call all of the other missions because we needed Deep Space Network time on the antenna to do all the stow commanding because it's a telerobotic operation. It's go one step. Image. Verify. Wait 45 minutes. See the next one. Wait 45 minutes. See the next one. You're in this really slow painstaking process to accurately get the collector into the capture ring. We needed a lot more antenna time. We called New Horizons.[1] I think we called MAVEN [Mars Atmosphere and Volatile EvolutioN][2]. We called all of our friends and we said, "Hey, can we have your antenna time?" It was a barter and everybody was really happy to help us out because we'd done the same thing. It's common courtesy in the spaceflight business. If you're in an emergency situation and you need antenna time and the other mission is just doing routine ops, they're like, "Yes, please take our antenna time, we know you'll do the same for us." That really got us all of the assets that we needed to perform the stow operations. We had the thing stowed by October 28th.

JOHNSON: You didn't leave right away. Talk about that, what you did. Then that last flyby I think you had to convince them that you really wanted to go one more time.

[1] New Horizons was the first spacecraft to explore Pluto up close, flying by the dwarf planet and its moons in 2015. It then passed its second major science target, reaching the Kuiper Belt object Arrokoth in 2019, the most distant object ever explored up close.

[2] The MAVEN mission is the first mission devoted to understanding the Martian upper atmosphere.

LAURETTA: Yes. The plan was we were done at sampling. The science mission was over. The team could just focus on the return cruise and start thinking about sample recovery, capsule recovery. But I looked at all those images and how big the disturbance was and how shocking it was to everybody. I said, "We have to go back and image the surface. We can't leave Bennu because who knows when somebody's going to be back at this asteroid? It'll be decades at least before we see another spacecraft here. We've got to go document it. We owe it to the future. Our science requires it. We really need to understand the nature of this interaction. It'll inform countless future missions." In fact it already has helped the DART [Double Asteroid Redirection Test] team interpret their impact and understand the granular mechanics and the nature of the surface.[3] A lot of the same people that worked OSIRIS-REx worked on DART. A lot of knowledge was transferred over to that mission.

I had to convince Lockheed management because their contract said no science after sample collection. I don't even remember why but I'm sure it was a V&V [verification and validation] thing, like we don't want to have to guarantee the spacecraft is going to operate after TAG. Because we don't know what TAG is going to do to the spacecraft. But it looked great. The spacecraft was very healthy. There was no problems for example with the radiators. There were no problems with the solar arrays. The cameras had some dust on them that was clear but they still could take good pictures. It's like when your glasses are dirty you don't actually notice it until you pull them off and you look at them from far away. You just see through all the dirt. That's what we were doing with the cameras.

[3] DART was the first mission dedicated to investigating and demonstrating one method of asteroid deflection by changing an asteroid's motion in space through kinetic impact.

The spacecraft was in great condition and Lockheed said, "You're right, let's go ahead and plan a return." It took us like six months to get back. Because we were flying just away from Bennu straight away with no plans to return and the flight dynamics team had to stop the spacecraft, turn it around, and then plan a trajectory that got us to the right location so that we could image the asteroid and see what the change in the surface was. That's when we saw the 8-meter crater that we had excavated.

JOHNSON: That's pretty amazing when you think about the size. Just from the TAGSAM [32 centimeters across].

LAURETTA: That's right. It's astonishing. It's a very very weak surface. A very weak fluidlike surface is what that tells us.

JOHNSON: Yes. You started back in May of 2021, started back to Earth. Then there was a lot of work going on at JSC [Johnson Space Center, Houston, Texas] at that point also being affected by COVID, but as far as preparing for the curation of those samples. Did you have anything to do such as coordinating with them as far as what they were doing?

LAURETTA: Yes. Curation was part of our responsibility. We had to pay for the new curation facility that was being built at Johnson Space Center and the curation team was integrated into the mission at that point. Yes. Absolutely. We were working very closely with our colleagues at Johnson Space Center. Not only building the laboratory at JSC which would house the samples but also planning the recovery operations, because the curation team is in the field with us and they're setting up a temporary clean room in Utah [at the Utah Test and Training Range] in one of the hangars there. They have a lot of operational responsibilities as well.

We didn't start that right away honestly in May of 2021. We all needed a break. COVID was receding a little bit. I was actually able to go on vacation with my family. It was a driving vacation to California but still we got out of the house and went to Lake Tahoe. Had a nice outdoor vacation. It wasn't really until 2022 that we started in earnest thinking about the details of the recovery system and working with our military colleagues because we worked with the Air Force and the Army out at the Utah Test and Training Range. We worked tightly with curation.

Lockheed Martin was the recovery lead. [NASA] Goddard [Space Flight Center, Greenbelt, Maryland] still was managing the project and was interfacing with the military. The science team was heavily involved because we needed to document the location where the capsule came down so we had to plan the environmental sampling protocols.

JOHNSON: Let's talk about that. Where it was going to come down in Utah at the Dugway Proving Grounds. Like you said they were going to have to have this temporary clean room out there. You and the team were going to be out there. Talk about the buildup to that September return. Just walk us through when you got there and what was going on and especially the day of the return.

LAURETTA: Yes. We started going out to Utah in July for field rehearsals to start to understand where we were going to be operating, what facilities we had available, get to know the people that we were going to be working with out there. We did rehearsals in July and August in Utah. We were spending quite a bit of time. It's a really desolate area. You're way out. It's a couple hours outside of Salt Lake City. It's military-controlled airspace so there's nobody out there that doesn't have military business anyways.

It kind of grew on me. I love the desert. I love being out in the wilderness. The Utah desert was just a really special place. We were really tight. There wasn't a lot of us but we were really working closely together so it was that great family kind of team feeling that we were doing something really exciting and really fun and really important. We were very fortunate to be the ones that were out there.

By the time September rolled around it kind of felt like home. I'd been there so much. There's not a lot of people out there. It's like being in a small town. You knew everybody. You knew the people who ran the gym. You knew the people who ran the bar. People who ran the hotel. People who ran the hangar. People who ran the airfield. All of these great team members and colleagues that we were just becoming fast friends with were out there.

By the time September rolled around it was more focused on the TV show again. We were doing a live broadcast. I think there were more people involved in the TV show than in the capsule recovery. There was a huge contingent from NASA comms [Office of Communication]. They were really excited and fun to work with but they were also trying to get everything they could. We were really enforcing the rule of noninterference. "Look, you guys, it's great, we want to share this with the world, but you can't get in the way of the operations. Just please remember that we need to do our job, and you need to tell the story, and we need to work together to get that part done."

The audience went really large at that point because of the TV crew that was there. Live helicopters, satellite trucks, you name it, the infrastructure for broadcasting from the middle of nowhere is pretty impressive because you've got to bring everything with you. Your whole TV studio.

But it was really fun. We had meals together. It was like a mess hall. Meals got served communally. We had great birthday celebrations and played games and went to the pool. Nice swimming pool there. It was hot, very hot out in the desert even in the fall.

Then of course the day of was the big show. I woke up at 1:00 a.m., 1:30 in the morning, something like that. We had to do spacecraft commanding. It wasn't even guaranteed that we would release the capsule because we had to meet all the safety criteria. We're not allowed to drop that capsule in the middle of Salt Lake City. You got to make sure there's no people around. You're not going to cause any injury or damage any property.

We were pretty confident but you never know. You have to do the poll. The military was one of the poll members. They were the only ones outside the project and that made me a little nervous because it's like well, they could call off if there's something wrong with the range. The last thing you want is an aircraft that had some anomaly out there and they're like, "Well, this is all top secret and nothing can happen and you guys are out of luck." Because it would have been two years before we could come back and try again. We didn't want to do that. Two more years with the spacecraft would have been hard for everybody.

But we got through all of that. All the poll was "go." The commands were uplinked. The capsule was released and it was about a 4-hour flight from the time it left the spacecraft till the time it entered the top of the atmosphere. There was a little bit of a quiet period. But I couldn't go back to sleep. I was like, "You're not going to sleep for a couple hours. I got to do something."

I was teaching that semester. I was teaching astrobiology back here at the University of Arizona. I was doing remote teaching for the students, which they thought was really cool. Live from NASA. Your professor is getting ready to collect an asteroid sample. Oh, and we're going to talk about the origin of life today. I graded some student essays for a couple hours. It was great. They had an essay assignment. I thought, "Oh, this'll take my mind off what's happening." Kind of got lost in the student work.

Then it was go time. We headed down to the airfield. There was a huge crowd of VIPs. My family was there. The president of the University of Arizona. People from Lockheed Martin. Military leadership was there. It was a big, big gathering of VIPs. Big party that they were having out on the tarmac. I get in the helicopter and away I go to get ready to recover that capsule.

We land at a staging area called Wig Mountain. There we're just waiting for the range command officer to give us some indication that they've spotted the capsule. The Air Force picked it up as soon as it hit the top of the atmosphere. The infrared tracking was on it. The radar missed it actually. It was a little bit off from where we thought it was going to be. I think the atmosphere was a little underdense so it moved faster than the models had predicted. Radar was following where it was supposed to be, not where it was. We actually didn't get radar data on the capsule as it was coming in.

But the infrared picked it up. NASA had an aircraft, the WB-57 that was in the air, and it was tracking it as well. We were getting a lot of good footage from that airplane. A lot of what was on the live broadcast was from NASA's WB-57; the crew did an amazing job. It's almost unbelievable because they're cruising at like 50,000 feet and yet they're watching this capsule go past them and then down and towards the ground. It's just stunning footage that they were able to do that from a moving airplane.

Then I'm in the helicopter. We say, "Okay." It took 2 seconds for the capsule to cross California from San Francisco to the Nevada border. Just to give you a sense of how fast the thing was moving. Then it gets into Utah airspace and they've got it on their tracking systems. I'm in the helicopter. It crosses 100,000 feet and there's supposed to be a drogue parachute that deploys that stabilizes it as it goes subsonic. There's no drogue. They're not calling drogue. I think we've lost it. I'm having flashbacks to another NASA mission called Genesis which crashed.[4] Almost exactly 20 years ago in the same Utah desert. It was a NASA sample return mission. I'm like, "I can't do that. I cannot get out of this helicopter on live TV and deal with this crashed capsule. I don't know. I'm going to sit in this helicopter. I don't know what I'm going to do. I'm going to just lose it."

Then the longest 3 minutes of my life go by and this is all I'm thinking about, is I can't believe we're going to lose the mission right at the end after 20 years of work. We're going to have nothing but a pile of debris in the Utah desert to show for it.

Then like some miracle, at 60,000 feet they're calling main chute. It was even lower altitude. At 60,000 feet still no drogue and then later main chute. I was like, "What? How is that even possible? How does the main chute come out if the drogue didn't come out? " But I don't care. They said, "They got main. You're coming in. You're safely on the ground." We landed 3 minutes ahead of schedule because that drogue never did come out until right at the very end. Then the whole thing deployed at once. Drogue, main all came out within milliseconds of each other.

JOHNSON: That's crazy. I can imagine, thinking about picking those pieces up in that desert like they had to after Genesis. They were lucky just because of the angle it hit. If it had hit at a different angle so much more would have been lost. I imagine that gave you some palpitations.

[4] 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 the parachute failed to deploy. Despite a hard landing in the Utah desert, the Genesis samples were recovered.

LAURETTA: Oh my God. Yes.

JOHNSON: You were mentioning all the interest in it. Public interest in it. Then the public interest when you actually took the sample. Now again when it's coming down. NASA has a lot of missions that people don't even know about and don't even really know happen. Why do you think this one garnered so much public interest? Because it was even on the news, and you see very little on the news unless something blows up.

LAURETTA: I was on CNN that morning live. I talked about it. I think people like this mission. First of all Bennu being the most potentially hazardous asteroid gets a lot of attention. Even though it's not our primary science focus it's typically the media focus. That's what they latch on to. People get it. I've seen surveys when the American public has been asked, "What do you think the priorities for NASA should be?" Dealing with hazardous asteroids is always at or near the top of the list. It's really something people think is important and they pay a lot of attention to. DART saw the same kind of interest when it crashed [deliberately] into Dimorphos. There was a huge media response. Bigger than NASA expected. I remember their being pleasantly surprised by the media interest in that mission as well.

I think that people relate to it viscerally like, "Oh yes, this is a disaster that we're maybe able to prevent. This is a good thing to be spending our taxpayer dollars on." I think the adventure of it all, going to space and getting something and bringing it back to the Earth, that doesn't happen very often. It's kind of the classic story. You go off on a quest seeking treasure. You have all these challenges and all these obstacles and you overcome them all. The team comes together, rallies, and you bring the treasure back to the Earth. That's really what we did. It's a great story and people really resonate with it.

I think there was a lot of great visuals that went with the mission. Obviously, the rocket launch, but everybody has that. But arriving at an asteroid. All the challenges of Bennu. We got a lot of mileage out of the challenges. I think people related to it because we were struggling a bit. It wasn't easy. They're like, "Okay, now it's really interesting."

When the TAGSAM was leaking sample, I think we were in the *New York Times* every day for a week with an update of where we were with our sample. They just loved the story. It just kept going and going and going and going. That was really cool.

Of course there's a really charismatic leader that people just—[laughter].

JOHNSON: That always helps, doesn't it?

LAURETTA: You can take that out of the transcript. That's a joke.

JOHNSON: Jokes are good too. One of the things I was reading about is JAXA had a mission [Hayabusa] to an asteroid that unfortunately—they did get some samples but it wasn't completely successful. They had some problems. ESA [European Space Agency] had the Rosetta which also had some problems.[5] But as far as lessons learned did those ahead of you inform you? Were they enough ahead of you they informed you how to help OSIRIS-REx be successful? What do you think the lessons learned from OSIRIS-REx are for any future missions?

[5] ESA's Rosetta mission was the first to rendezvous with a comet, the first to follow a comet on its orbit around the Sun, and the first to deploy a lander to a comet's surface.

LAURETTA: We learned a lot from both our Japanese colleagues and from our ESA colleagues. From Hayabusa and from Rosetta. It was a really great collaboration. Hayabusa was really far ahead of us. When we were writing I think our second proposal in 2005, JAXA was operating at Itokawa and we were paying really close attention to that.

Then Rosetta was operating at comet 67P when we were in development like in the 2014 timeframe. Absolutely I sent my deputy PI [principal investigator] Ed [Edward] Beshore to Europe after that lander landed on the comet but not in the way they wanted it to. It was a success. We would call it a success. But not optimal. They only operated for a few days. Historic as it was, it was still not according to plan.

They had hardware failures that led to that. I told Ed, "Go to Europe and ask exactly that. What would they do differently? What would they wish they had thought of? What can we learn from them now?" The NavCam was the big lesson. Put a NavCam on there and give it to your navigation team wide-angle for them to do what they need to do and not worry about the science so much.

In terms of lessons learned from OSIRIS-REx, well, I'm very proud of the fact that our cost performance was outstanding. We are one of the best cost-performing missions in NASA's entire science portfolio. There's a chart that I've seen I think Nicky [Nicola] Fox shows of cost performance and the best-performing missions are all the way over on the left, and it's OSIRIS-REx with the best performance. We came in like $55 million under budget in development and were able to return that money to the Agency. That was really due. First of all I paid a lot of attention to the cost performance as the principal investigator. I made it a priority. It went through the entire culture of the team.

We were fortunate that we were at the right size budget. We talked about getting into New Frontiers early on in this interview. That was absolutely the right program for us. We were able to do this mission at low risk, which is what the Agency wanted. We front-loaded the budget so that we had a lot of reserves in what's called Phase B, preliminary design, which meant we could mitigate risks early and cost-effectively. If you're trying to solve a problem six months from launch, it's going to cost you a heck of a lot more than if you're trying to solve it four years before launch, because you can really think about all the different options. We're not in a time crunch. We don't need emergency shifts like a lot of times you put in a double shift or a second or third shift. We didn't have to do any of that. It really allowed us to buy down risk quite early.

But I think the most important thing is the team spirit and the team culture and the team identity. We were not Arizona, Goddard, Lockheed. We were OSIRIS-REx. That was what we were. We were a team. We were all invested in the success of this program. Everybody had a stake. I valued everybody's voice. I told them that. I sat down with them and chatted with them. If they were the engineers working in the cubicles at Lockheed, I would walk the halls and say, "Hey, what are you working on? Tell me about it. Don't be afraid to come forward if you have a problem." I think that freedom to bring risks to mission leadership early without any worry of retribution or anything like that. We want to hear.

Some of them said, "Yes, we're aware of it and we've accepted it." Or, "Thank you. This is something that's really important that we need to pay attention to." None of those responses had any recrimination to them. We really are glad you stepped up and spoke up. I think that was really critical.

We had a great target. I think we benefited enormously from NASA's observatories and I think the National Science Foundation supports some of them as well. Having Arecibo

[Observatory], which I miss dearly, but having Arecibo characterize the mission target was huge for us.[6] We learned so much information from the Arecibo data that I would hate to plan a new NASA asteroid mission without that level of knowledge. It would add a lot of risk to the program.

Heritage. We used a lot of heritage. Lockheed Martin. We were following Juno,[7] MAVEN, and MRO [Mars Reconnaissance Orbiter].[8] Those were the three spacecraft that were ahead of us in Lockheed's facility there. We gathered the best of all of those teams to provide input to us and make the engineering really robust. The engineering was simple and proven, like the propulsion system was monopropellant, no ion drives or any new technology. When we did have new technology we focused a lot on it, like TAGSAM especially was really the technology development for us.

JOHNSON: If you had to point to any one thing with this experience over all these years that you're most proud of, what would that be?

LAURETTA: I am most proud of how much we trained the next generation on this mission. It was important from day one. Mike [Michael J.] Drake's vision was that this was a mission about the future. I was the kid when it started. I was the young guy. I was the one that was brought on into something that was totally awesome and daunting. We've done that continuously for the past two

[6] The Arecibo Observatory's 305-meter radio telescope, completed in 1963, collapsed on December 1, 2020, after the failure of the individual support cables over several months.

[7] Since it arrived at Jupiter in 2016, the Juno spacecraft has been probing beneath the dense clouds encircling the planet – the first orbiter to peer so closely. It seeks answers to questions about the origin and evolution of Jupiter, our solar system, and giant planets across the cosmos.

[8] Mars Reconnaissance Orbiter searches for evidence that water persisted on the surface of Mars for a long period of time.

decades. We've brought in young people. We've put them in positions of importance and responsibility. Trusted and enabled them to succeed.

I think I'm also proud that the spacecraft is still in space. It dropped off its capsule. It's not done. It has an extended mission, OSIRIS-APEX [Origins, Spectral Interpretation, Resource Identification and Security–Apophis Explorer]. The principal investigator [Dani Mendoza DellaGiustina] is a young woman that I've been mentoring since 2005 when she was a freshman at the University of Arizona. She took my one-credit seminar on asteroids and got hooked and came up and said, "Is there any research I can do to learn more about asteroids and meteorites?" We got her in the lab and we got her working on meteorite samples right away.

We're like brother and sister now. We've just been close friends for such a long time. It's her mission. She's in charge. Mike knew her as a freshman. Mike would be so proud to see Dani leading the OSIRIS-APEX mission. I'm just a coinvestigator. I get to sit back and enjoy the ride and let them deal with budgets and schedules and challenges and spaceflight. I'm like, "Oh. Call me when the data is in. I'm going to have some fun."

JOHNSON: That's what you're doing now. Still working with the OSIRIS-REx samples.

LAURETTA: Yes. In fact I was just in the lab this morning and I had to get out of the lab for this phone call.

JOHNSON: Sorry we drug you away from the lab.

LAURETTA: I felt like a scientist. I was like, "Oh, this is so fun."

JOHNSON: Yes. That's good that you get to continue to do that and as a director at University of Arizona of that lab?

LAURETTA: Not director of that lab. I'm the director of the new Arizona Astrobiology Center, which is dedicated to understanding the origin of life and the distribution of life in the solar system and across the galaxy. That's really fun. Yes. I've started a new astrobiology center. It leverages all the OSIRIS-REx science and interest and moves it forward hopefully to some new missions. We are working on a comet sample return mission concept that we hope the Agency will be interested in.

JOHNSON: As a PI on a mission like this, Discovery was first proposed as a way of flying these lower-cost, high flight rate, scientifically defined missions. Then New Frontiers. All of this is informed through the Decadal Surveys and what they think needs to be studied, and to be PI-led.[9] What do you think that model does for exploration as far as from the scientific side? How do you think that affects exploration?

LAURETTA: I think it's incredibly valuable for several reasons. First of all you get a lot of new ideas by engaging the science community. People are coming up with all kinds of cool mission concepts out there. I think NASA benefits from that. When they put out an announcement of

[9] The National Research Council conducts studies that provide a science community consensus on key questions posed by NASA and other U.S. government agencies. The broadest of these studies in NASA's areas of research are decadal surveys. As the name implies, NASA and its partners ask the NRC once each decade to look out 10 or more years into the future and prioritize research areas, observations, and notional missions to make those observations.

opportunity, especially in the Discovery Program, or when the Decadal Survey call goes out, they get all these ideas from the scientific community. It kind of drives what the Agency priorities become because it's almost a democratic process where everybody gets to say, "Hey, this is what we think is important." At least to be a contender for a mission.

Then I think having a principal investigator is really important because there's one person who owns it. I'm the one responsible to NASA. I took that very seriously. My job is to make sure this mission maintains its scientific integrity and is delivered on cost and on schedule. Which is why I paid so much attention to the budget because that was the promise that I made. I think some missions are lacking that. When you don't have somebody who's so invested that's when you see growth or you see requirements getting out of control. I was really disciplined. This is a sample return mission. Yes, we could do a lot of cool things at the asteroid. But if it doesn't support sample return, I don't care. It's just not what this mission is about. Keeping that focus was really important.

JOHNSON: I appreciate you talking to me today. And I did enjoy reading your book.

LAURETTA: Thank you. I wanted it to read like an adventure story.

JOHNSON: It did. It read like an adventure story. But what made you want to write that?

LAURETTA: I've always wanted to write a book. I've written scholarly books before. As I became more and more the spokesperson for OSIRIS-REx I felt like I was a good storyteller. I worked on that skill. Now I say when I'm giving a talk it's not as much a talk as it is a performance. Because

I'm really trying to convey the emotions that we felt and the whole adventure of it all. I think the audience really responds well to that. I thought, "Well, this would be a cool book."

Then I just started writing. I took tons of notes. The story was just so obvious. I think people would enjoy it and I wanted there to be a record of my story. It's my story as much as it is OSIRIS-REx. *The Asteroid Hunter* is a memoir. It's what it meant for me, and I hope that inspires other people in the future to pursue their dreams.

JOHNSON: Yes. I think it could be very inspiring for anyone wanting especially to pursue a science field in the future in the way you did it. I appreciate you doing that and I appreciate you talking to us today.

LAURETTA: Thank you.

[End of interview]