Lindy Elkins-Tanton

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Erik M. Conway,
Interviewer

Q: My name's Erik Conway, and I am interviewing Lindy Elkins-Tanton. You're at Arizona State University, correct?

Elkins-Tanton: That's right.

Q: And you are the principal investigator for the Psyche mission.

Elkins-Tanton: That's right.

Q: Lindy, first give me kind of a brief bio sketch of yourself. Where were you born, how were you educated?

Elkins-Tanton: I was born in Ithaca, New York, and I did a bachelor's and master's at MIT in geology and geochemistry, and then I left academia for about eight years, worked in business, and then I taught at St. Mary's College in Maryland. Then when I was thirty-one, I went back for my Ph.D. at MIT. I was a postdoc at Brown faculty at MIT, director at the Carnegie Institution for Science, and now vice president, Arizona State.

Q: And your academic interest was in core and mantle formation, wasn't it?

Elkins-Tanton: It's really the generalized formation and evolution of rocky planets. I started out really mostly doing terrestrial geology and studying volcanic products and what they tell us about the interior of the Earth and then the Moon, then I worked on the magma ocean state of forming planets, and then planetesimal formation and differentiation. That's the bit that led to the mission.

Q: Right. That was my next question. How did you get interested in this solar system small bodies, leftovers from formations, and you kind of just answered that question.

Elkins-Tanton: Yeah, I have never really studied asteroids. I studied meteorites just in reading the literature and using other people's work. The research that I was doing with my colleagues was about the formation of the very first bodies in the solar system, the planetesimals, that became the rocky planets, and it's true that their remnants are stranded in the asteroid belt, but it was really their initial formation that we were interested in.

Q: So tell me how the idea for Psyche evolved out of that set of interests.

Elkins-Tanton: Ben Weiss at MIT—this is while I was still on faculty at MIT—Ben Weiss had discovered an interesting result with the Allende meteorite, and he had the physical measurements and then he asked me about it and I made the modeling of what might have happened. These papers were disruptive to the current set of beliefs about Allende at the time

and caused kind of a stir at the Lunar and Planetary Science Conference when we presented them back in 2011.

Then from JPL, Daniel Wenkert and Bruce Bills sent me an email saying, “How would you like to propose a mission to test your hypothesis?”

So Ben and Erik Asphaug and I and they started talking about what we might do in space to test this hypothesis.

Q: So Psyche is a mission to what we hope or think is a metallic asteroid. How did you go about formulating the more specific idea for the mission?

Elkins-Tanton: Initially, the thing we would have liked the best would have been to find a recently broken-up differentiated asteroid so that we could look at the different parts, the silicate outer parts and the metallic inner parts. But, and I don’t know if that’s changed since, but at the time, there really was no such family known, and also just trying to design a mission where you could kind of zoom around different parts of a broken-up asteroid is super difficult. So in the end, we decided if we could see the metallic insides, that would be a good solution, and I think it was Bruce Bills who originally said we should go to (16) Psyche. That’s the next great asteroid that hasn’t been measured, and it really would help us understand planetary formation.

So that was the process, and then we were all pretty much convinced. It was just a small group of us doing JPL left-field activities and then trying to convince JPL to put us into their competition portfolio, because at that time we had no support and JPL had not said that they wanted to be mission manager for the project, so it was very early on.

Q: So you had to interest JPL itself. That's interesting, because sometimes—well, I guess we do tend to get fixed on our own ideas sometimes.

Elkins-Tanton: What do you mean?

Q: Oh, because we generate enormous numbers of proposals every cycle, and sometimes things get left out, sometimes they're just oversights and sometimes it seems like the institution just doesn't like certain ideas.

Elkins-Tanton: Oh, I see. The "we" in your sentence is JPL.

Q: Is JPL, yeah, yeah, the institution itself.

Elkins-Tanton: Yeah. No, there's a lot of—it just really depends on who's leading 4X and who's leading the proposal group and who's leading—you know, at the time what kinds of things they think are likely to win and which things they're interested in, and sometimes the decisions are also swayed by what instruments are being flown and are they in the interest of the Lab for later development.

The thing that I was concerned about was I felt like I had to ask if JPL—so I was ending up as kind of the leader, and I was saying we should wait and not decide who's going to be the leader, but at that time, I was, and I felt like we had to invite JPL to be the mission manager because the idea had come from two scientists at JPL that we would propose this. But I was having trouble getting JPL to decide whether or not they wanted us in time for me to go to

another center if JPL said no, which, of course, is actually part of the proposal strategy on the part of JPL, but it doesn't start off the relationship on a friendly basis. [laughs]

Q: Who did you have to convince at JPL?

Elkins-Tanton: Mostly Brent Sherwood. That did end up to be a good relationship, but we had some working-out to do in the very beginning.

Q: So had Gregg Vane retired at that point?

Elkins-Tanton: No, Gregg was deeply involved also and was a great friend.

Q: One of my questions is how did you meet him, because I notice you tell one story about him in your memoir, and I'm always interested in how people get together.

Elkins-Tanton: Do you mean Gregg?

Q: Yeah.

Elkins-Tanton: When did we first meet? Gregg and I first met when I was president of the planetary section of the American Geophysical Union, and Gregg was working on getting the planetary sections of all the professional societies together to do more concerted Washington

lobbying, basically. We all thought that was a great idea, so we worked closely with him for a number of years, so that's how I first met him that way.

Q: He was very involved in setting up our competed programs organizations when those things became real.

Let's see. So you had troubles convincing JPL that they should support the mission. Who would you have considered, if not us?

Elkins-Tanton: APL.

Q: APL?

Elkins-Tanton: Yeah, absolutely.

Q: Yeah, that makes sense. They're also more in-house. How did you choose the other partners? You have a fairly complex set of partnerships now.

Elkins-Tanton: That's interesting. I never thought about whether it was more complex than other Discovery missions or not. We needed an industry partner to build the spacecraft chassis, so that's the biggest decision in the partnership decisions, and so when the time came to pick, JPL put out the RFP in the usual way, and a bunch of the usual companies came in and bid. But the interesting thing was, David Oh was our capture lead, then he went on to become our lead systems engineer and now he's one of our chief scientists on the mission. He's been on it almost

from the beginning, for ten years, and we've been working on this now for twelve years, so from early on. The usual suspects didn't come in, it seemed to us, really with their A-teams. They had their sights set on other of the proposals that were going to go into that Discovery round with a little more emphasis than they did on us, and nobody really expects the proposals to win the first time through, and I was a first time PI, and all those reasons.

But David was very interested in having what was then Space Systems/Loral—and is now Maxar—bid, because we really wanted their solar electric propulsion technology. We thought that was the only chance we had for fitting in the Discovery cost cap and that it would really serve us well, and since David had worked there, he really understood their technology.

So Maxar, or Space Systems/Loral, came in and they bid, and they brought their A-team, and, oh, my gosh, it was *very* impressive. They must have brought twenty people, and everyone was dressed and formal and serious, and they gave a great presentation. But our JPL advisors were advising us to pick one of the traditional partners because this, indeed, would become the first time that Maxar was prime on a NASA Deep Space mission. So they were not the leading vote.

So David and I and Carol Polanskey, who had just accepted the job as project scientist on the proposal, really had quite a discussion amongst us. We all kind of looked at each other and then we all said, "Yes, we all think the answer is it has to be Maxar." Like, first we were testing each other, you know, should we choose one of these other ones, but we all agreed that Maxar was absolutely our best bet for what we wanted to do. Then we had to figure out how to convince the rest of the JPL leadership that that was so.

So that was an exciting moment, but then we did choose Maxar, and they gave us a firm fixed-price contract which ended up to help us *unbelievably* with our budget. It saved us a

tremendous amount of money over the NASA cost model. Of course, there've been bumps along the way, but basically they've been a great partner and it's worked out really well, I think.

Q: It's interesting, because JPL's experience, many people have told me, with new Deep Space contractors is that they always overrun.

Elkins-Tanton: Yeah. I mean, we've had some contract mods, but it's been really minor. Our overruns have been in other areas. [laughs] Thank god it wasn't the chassis, because that's where the big dollars are. So that was the first partner.

Then thinking in terms of levels of the size of the contract and the importance of the object being built, Maxar was the biggest partnership to select, and then the next ones are the science instruments. I was very adamant from the beginning that we were not going to build up a big science team until we knew what instruments we wanted, because I think a common thing that happens is that people invite on to the science team people who make instruments, and then those people lobby hard for their instruments to be put on the spacecraft, whether or not they are really the right choice, and so we tried to choose first and invite second, instead of inviting first and then choosing. [laughs] So mostly that worked; not entirely. There were some backtracks, mostly because there is a rule about the percentage of foreign contributions that were allowed, and that kind of messed up our original plans.

Q: So who did you ultimately choose for your instruments? I think they're not listed on your website as being instrument PIs, so you went about it a different way.

Elkins-Tanton: Well, I guess we just don't call them a PI. We chose imagers that are led by Jim Bell at ASU and built in concert with Malin Space Science Systems, and so that's one of the subcontractors, and then, of course, they have subcontractors, and their subcontractors have subcontractors. [laughs] So it's not even really possible to ever count how many institutions are actually involved.

We picked UCLA for the magnetometer and later changed that, but UCLA went in the proposal. Then we picked David Lawrence and Applied Physics Lab for the gamma ray and neutron spectrometer, and although it's not an instrument, our final science investigation is the gravity science investigation just done with the Doppler radio and the spacecraft, and that's led by Maria Zuber at MIT. So those were the big selections on the instrument side.

We had a few other decisions, like were we going to try to go with Ka-band instead of X-band radio, and right at that moment, there were not good affordable Ka-band vendors that we could fit into our budget in a way that was going to make sense, and so we went with X-band, which was going to do what we needed anyway. Our philosophy all along was that absolute simplest spacecraft that we could possibly build, that would do exactly the science that we needed, and so we never had a baseline and a threshold. It was just one proposal.

Q: Absolute simplest spacecraft you could build. Sounds like an effort to reduce your risk, particularly since our previous ion propulsion spacecraft had been problematic in their construction.

Elkins-Tanton: Yeah, and, of course, there isn't any such thing as a simple spacecraft, so it's, in a sense, a silly thing to say, but it could have been way, way more complicated and difficult than it was, and we really tried to keep it as simple as we could.

Q: When did Henry Stone come aboard?

Elkins-Tanton: He came aboard for Step 2, so that was fantastic. That was really great.

Q: And so he's very helpful at that point.

Elkins-Tanton: Oh, yeah, deeply involved and totally helpful and utterly a part of the team, absolutely.

Q: Do you know who your competition was in that Discovery round?

Elkins-Tanton: We knew some of them, and, of course, we're always trying to gather intel. In the end, there were twenty-eight proposals that went in. I can't remember exactly how many we knew about in the end, but it might have been about half of them, I think, and I guess everybody knew what was going in from JPL. I think that there were enough rumors around to kind of know what that was. And for a while, I was on VERITAS. I was actually the DPI on VERITAS, but Sue felt like we couldn't have two proposals going in side by side, so I stepped off of VERITAS and stuck with Psyche.

Q: Interesting. VERITAS was proposed three times. Let's see. Tell me about the proposal process after Step 1. Tell me how you're notified that you're going into Step 2, and then what you had to do for the Step 2 proposal.

Elkins-Tanton: I just want to say a couple of words about Step 1 and how difficult it is to support a Step 1 proposal when there's absolutely no money for it. JPL has funds and they pay people to do the JPL side, and so does Maxar, they have funds and they pay people, but on the academic side, we just have to find a way to do it and find a way to fly out and find a way to—it's very expensive and really difficult. And I had the added excitement during Step 1 of having cancer and going through chemotherapy during the proposal-writing process. That was really hard. So Step 1 was a whole saga.

So then we just wait around to hear. Rumors start flying, you know. The rumor is the calls are going to come this week. The rumor is the calls might be tomorrow. Then I started getting messages on a particular day, "So-and-so got a call," "So-and-so got a call," and I'm waiting and waiting, like I know my call is coming, so I turned on my phone and was ready, and got a call with the news that we were down-selected to be part of the five to compete in Step 2, and that was really unexpected and very surprising and exciting. We were not expecting to be selected.

We tried really hard to write a Step 1 proposal that was exactly what we really wanted to build, not a marketing piece, and I would say that most of the team got that message and most of the groups really did write, "This is exactly what we would actually build. This is actually what we think it should be," and not at all a marketing piece. But we thought, you know, first time

through the proposal process, first time PI, first time prime partner, broke the NASA cost model, like there's no way we're going to get selected. So that was an exciting call to get.

Then Step 2 begins, and like I mentioned in the book, David Oh and I were so excited that we got $3 million and we were planning all these things we're going to do with this money, we can do these test beds, we can do these demos, and we can do whatever, and Gentry [Lee] especially was there, like, "No, you can't. Three million isn't anywhere enough. We're going to have to have at least 5 million to do Step 2." So that whole Step 2 process was actually incredibly fun and wildly intense and a great experience all the way through.

Q: Interesting. Do you recall any of the critiques from Step 1? Did they tell you what they thought your weaknesses were?

Elkins-Tanton: Oh, gosh, yeah. You get all that information. I don't have it in front of me, so I kind of am hesitant to try to reconstruct, because I'm sure it will be inaccurate, but I could certainly look stuff up and tell you about it if you want. I might be able to find it in my computer right now if that's of interest.

Q: No, I don't want to go into great detail. I was interested in—obviously you were elated, but I'm interested in additional responses, you know, when you had that briefing, what did you think about it.

Elkins-Tanton: Oh, yeah. Well, you know, I think one of the things that was a through-line through the whole proposal process and up to the present day and will be into the future is the

fact that we won't know really what Psyche is and we don't have any photographs of its surface, and so the question of how can you legitimately propose a set of science hypotheses and promise that they're testable when you don't really know what you're going to see, is a very, very challenging question and something that hasn't been addressed too much recently in NASA missions because so many of them are to objects that we have photographs of or that we know something about, even as an example of an outer planets moon, saying it's an icy object. We know it's a small body and we know it's made of ice. That gives you a really good starting point, even more than what we have for Psyche.

And then, of course, anything that goes to the Moon or to Mars or to Jupiter, so much is known, that you can really be targeted in your science hypotheses and very clear about what the data improvement would be. So a lot of times we had to be doing original science to recalculate, for example, how strong the magnetic field could be in its most extreme state, and if it was that strong in its most extreme state, would it accelerate particles to the point that they would endanger the instruments, questions like that that are answered for most bodies, but not for us. So that was that kind of thing, and I think that we were very elated about on the science side like how strong the magnetic field could be, and what we thought were sales points ended up being risks because it freaks out the engineers. [laughs]

Q: One of the things Bruce Banerdt told me when I interviewed him about Psyche was, he talked about the challenge of quantifying things in a way that would be convincing to the review board.

Elkins-Tanton: That's right. Yeah, we definitely had those moments for sure, and thank goodness for all the experts who were there to help us. One of the highlights was definitely the

development of brand-new space physics by Ben Weiss and Chris Russell and Maria Zuber on the spot, you know, something that ended up as a published paper afterwards [laughs], had to be calculated on the spot for the review board.

Q: So in Step 2, there's a site visit. Talk about your site visit.

Elkins-Tanton: This was another moment where David Oh and I needed to adjust our expectations, because the way it was described to us was you pick a location that's related to your mission. We picked Maxar because we assumed that choosing Maxar as prime would be one of our major weaknesses potentially, because the review board might not believe that they could do what we needed them to do, and so we thought, "We need the review board to come up to Palo Alto and walk through the clean high bay and see satellite after satellite after satellite with the same bus and the same power system that we're going to be flying." It's such an impressive sight, it's such a gigantic, clean space, and the satellites are so huge, and it's just like a technological tour de force. So we thought, "We need the review board to see this." So we picked Palo Alto.

The deal was, we were told, "You and your whole team will just move to Palo Alto for the week, so you're going to need not just your team for the week, but then at the end of the week, you need also a red team that's going to be as close a perfect replica of the rest of your team as possible. They're going to be sitting in the back room and answering questions while you're up presenting, because you can't be answering questions and presenting at the same time. You need a duplication of all of your brains back there to do the work.'

So then we had to also find those people, which was impossible, and read them into everything that we worked on so far on the mission so they were fully up to speed, which is also impossible. So that was the beginning of the intro.

Then the story was "On the first day, you'll get an encrypted email with a whole suite of questions, and each question will be designated as either answer in writing or present on the final day when the review board is there with you, or sometimes both."

And David and I thought, "Well, we can invite anyone in the world we want to be with us, and we'll have six days to answer the questions. No problem." Then we realized that these are the questions that hadn't been answered in over a thousand pages of proposal materials to date, and so these are the really hard questions.

So we all showed up on day one, and we were sure on the science side, at least, the questions would all be about the gamma ray and neutron spectrometer, since that was and is our most complicated instrument and also really, really important—well, I mean, none of the three instruments are droppable. They're all absolutely required. But that one seems particularly central in some people's assessment of the mission. So that's what we were expecting, and we had expectations on the engineering side, you know, there were going to be power system questions and xenon questions and whatever. So we kind of tried to anticipate.

We got our questions, and there were almost no questions about the gamma ray and neutron spectrometer. All the questions were about the magnetometry and the imager, and we hadn't even asked those two instrument leads, Jim Bell and Ben Weiss, to show up early, I don't think. So we had to email them and say—and call them—like, "You need to hop on a plane right now and come help prepare these answers. Bring your suit, because you're going to be presenting." [laughs] So it was a whole redo.

By then we had already developed this quite complex system of triaging the questions, assigning leads to the questions, assigning teams to the questions, assigning first readers, doing check-ins in the morning and the afternoon of each day, updating everything, keeping it all—the documentarians were very busy. It was just an incredible process and intensely stressful because of how much lay on it. There just are not very many times in the life of a scientist where people's jobs for literally decades ride upon your performance in this given week. It really did feel like the Super Bowl, like so much mattered.

Maxar had done an incredible job on their location. I was just talking with Henry Stone yesterday, and we were joking that they should have—Maxar has sold that particular building. They have kept the rest of the campus, but that particular building was sold, and we have a lot of nostalgia about that building because we spent so much time there. We were joking it should be designated like a national historic landmark because it's where Psyche was won. We printed out a banner that was the cover of our Step 2 proposal, this beautiful art by Peter Rubin, hung from the roof and covered most of the front of the building, was this gigantic banner. Cars were slowing down to look at it. We had custom-printed every kind of sign you could imagine, like "This is where you park," and we had people assigned to stand in all the places. And they repainted everything and they redecorated their whole executive lunchroom, and we had all this original art put up in the hallways, and big display monitors playing videos in the hallways, all stuff that had been made largely by Peter Rubin, to try to tell the story over and over again of what we thought Psyche was.

We figured it would be very hard to get people excited about the idea of just what in some people's minds is just yet another asteroid out of the whatever, 2 million asteroids we probably have. To explain the mission that we were trying to do, we have to have that videotape

rolling in their head of what we think the formation of Psyche was, an early planetesimal, the first million years of our solar system that's 4,568 millions of years old, just in the first one of those millions of years that it formed and melted and made a metal core and rocky exterior, and now the metal core is exposed to space and it's our only chance to see a metal core ever as a species. We're never going to see another one, if indeed that is what it is. We try and tell that story over and over again.

We answered questions all week, and then the review board showed up. That morning, we also get *another* email with encrypted questions, because they've now read our written response and are ready to have us answer questions about that. So then those questions go to the red team. Meanwhile, the review board is appearing downstairs, and Tim McCoy from Smithsonian has flown out samples of meteorites and is telling the story of Psyche through meteorite samples.

And pretty soon, everyone is in the room sitting in their chairs. Each chair had been individually oiled so it wouldn't squeak, and the blinds were set just so the Sun would never get in anyone's eyes and we had tape marks on the floor, and we'd all been professionally speaker-trained, how to see the audience and relate to them and hit our mark, you know, the whole thing. So it's a gigantic, gigantic production.

Then all day presenting, trying to guess what they think [laughs], and getting a couple of questions that were actually naïve questions, where David Oh leaned over to me and said, "Is that even right, like the idea of this question?"

I was like, "No, that's not even right."

And then Jim Bell, who's answering the question, kind of walks back and forth a little bit, trying to think how he's going to respond in a diplomatic way instead of just saying, "That is such a stupid question," which, of course, you are not going to say.

Q: Which would be deadly, yeah.

Elkins-Tanton: We even worked on things like our seating was in a "U," and the team is along the arms of the "U" leading up towards the screens, and then the review board is on the base of the "U" and then one or two more rows behind that, so every review board member, no matter where they were looking from, would see the speaker, and behind the speaker they'd either see me and David Oh or they'd see Henry and Jim Bell on the other side. So the mission leadership was always in the background of every speaker, and we were always being supportive, paying attention, nodding our head, you know, supporting, to make it clear how much of one team that we were, which I thought was just a really important message to get across, and it did help us a lot in the end.

So that was the day. Then we thought, "Now we get to rest," because it's very, very intense, very hard work, super exhausting.

And as my flight was landing in Phoenix the next day, we get an email with a whole new suite of questions from the review board, which was very, very painful. [laughs] People, you know, they need to see their family. It was Saturday. We'd been working uninterrupted for months, and this was supposed to be the weekend when we could be with our family. Suddenly we have all these questions and we have to work all weekend and Monday and send in all the answers.

I remember getting Ben Weiss on the call practically while he was still in the airport in Boston, to start planning how we were going to answer these questions. He's on the T in Boston and on the call with us, triaging questions. So that was a heck of a process. That's the Step 2 process. [laughs]

Q: You choreographed that like a ballet production, it sounds like.

Elkins-Tanton: It was huge. It is absolutely, yeah, it's like a Hollywood super production. Every single thing is choreographed, hundreds of people making it happen.

Q: And this is supposed to be NASA's *inexpensive* programs. [laughs]

Elkins-Tanton: Yeah, in the end, our budget is just over a billion dollars, the PI-managed budget, and I don't think there's any person in the world who would say that that's a small program, and yet it is a small program compared to the flagships, and that's a constant source of tension.

Q: Well, right, and the initial concept of Discovery was supposed to be relatively inexpensive, quickly done, low-risk missions, and it has evolved away from it.

Elkins-Tanton: It's really, really hard to do that, because any size of space mission that we're going to send is a ton of money, and since it's a ton of money, the risk tolerance goes way down. These are taxpayer dollars. We have to take it really seriously. So creating somewhere where risk can really be tolerated is a super difficult problem.

Q: Yeah, for a public agency, it really is. Okay. So between Step 1 and Step 2, what, if anything, did you change?

Elkins-Tanton: We changed very, very little between Step 1 and Step 2. The gold standard for looking at change in these is very often the science traceability matrix, since that takes you from the science questions through the instruments and all the measurements that are going to be made, down to the way that the orbits are designed and the mission requirements. By the time we wrote our STM for Step 1, I think I was on version 65 of it, or 62, something like that, up in the sixties, might have hit 70 even, and so we really, really worked it.

Then in the Step 2 proposal, you show in a particular font color every change from Step 1 and notate what they were, and there were very, very few of them. We really have ended up doing pretty much exactly what we proposed, and changes that happened happened after Step 2 largely because of, for example, parts changeouts or a problem that was discovered during the rebuild of something that was largely heritage, but heritage is a complicated concept. Then changing out the magnetometer provider was another change. But all of those are relatively minor changes. It was really a very, very similar proposal.

Q: You mentioned the magnetometer a couple of times now, so tell me what happened there to cause you to change it.

Elkins-Tanton: The UCLA shop, Chris Russell's team there, were struggling, and we became very concerned early on before their CDR that they were just not going to be able to deliver the

instrument that we needed. They were overworked and understaffed and really struggling a bit, so we made a hard decision to change to a different provider, and Chris was incredibly gracious about it and he knew the struggles that they were having, and he remains a very helpful and supportive member of the team, so that's, I thought, a big win.

Sometimes I think leadership hesitates to pull the trigger on these big decisions. It's so much easier to wait and see, it offends fewer people, but it raises the risk tremendously, because by the time you wait and see, then once you've waited and seen, it's too late to fix it if there's a problem, and we really didn't think that we could wait.

So then we searched. We searched the world. Actually, we searched the world first, of course [laughs], before we pulled the trigger, and we did find Danish Technical University able to deliver an instrument that does all the science that we needed on our schedule. It was *amazing* that they could do this. They actually held their CDR almost at the same time that it was going to be held anyway, and they passed with flying colors and they delivered on time, and they've been a spectacular, spectacular partner on this.

The magnetometry investigation is led by Ben Weiss at MIT, and a lot of the data analysis will be happening at MIT, so it's a partnership between Danish Technical University and MIT on that magnetometry investigation.

Q: Are you paying for it or are they contributing it, since, as you say, [unclear]?

Elkins-Tanton: We're paying for it. It's a contract, yeah.

Q: So not a national contribution, I guess is the term of art for that.

Elkins-Tanton: Correct.

Q: Tell me how you found out you'd been selected after Step 2.

Elkins-Tanton: Yeah, this was a day that I've written about a lot. I've blogged about it and I wrote about it in my memoir. We have a house in the hills of western Massachusetts. It's a little house in a very remote area surrounded by a big state forest, and I was up there by myself in the middle of the winter. Our grown son had gone back to where he lived, and my husband had gone off to a math conference. We knew I was going to get the call on this particular day, because I had to arrange it ahead of time because we have a landline up there, but there's no cell coverage. So nowadays, I can get calls on my cell phone because I can do them through the Internet, and now we actually have cable Internet up there, which was quite a process. Our driveway's like half a kilometer long, and it took a lot of—anyway, so now it's possible, but then, in 2017, it was a landline without a voicemail. And I'm usually outside or gone, so we had to kind of schedule. "You're going to get a call at 10:00 a.m. on such-and-such a day, and then they'll tell you that you're selected or not selected."

I'd gone through all of this soul-searching, with my husband's fantastic support, trying to just come to terms with what this would mean, because having worked full out on this for, at that time, six years, which is a long time, it's not long by proposal process, as you well know, because very often, like with VERITAS, you do it a bunch of times. That's usually the story. Usually you do not get selected first time through, but six years is still a lot of time, and I felt the weight of everybody's—you know, Maxar and all the hundreds of people who worked on the

proposals, I felt the weight of all that. I felt the responsibility. And with Maxar, I'm pretty sure this was the first time they'd gone all in to win a Deep Space proposal. It was the first time picked as prime. I don't know what else might have been in their history. But it's a very expensive prospect and it was a different game than what they were used to playing in the commercial world. So I felt a lot of responsibility, and so trying to prepare myself for the answer to be no, which is what we expected it to be, and then have to make the decision "Are we going to stand down and try again, or what do we think?" I was going through all that.

I'd reached a real state of calmness, so that I slept really well that night. I was deeply asleep when Thomas Zurbuchen called me, at a different time than we had planned [laughs]. He called me on my cell phone, which almost immediately cut out. I was sound asleep. I was in bed, answered my phone, and I knew it had to be him. I would hear, like, a word, and I would be say, "Call back on the landline! Call on the landline!" [laughs] I think he probably called me three times before he got the message to call on the landline.

So then I'm jumping out of bed and running into the other room. He could tell that he'd wakened me, because I had sleepy voice, you know, like one does first thing in the morning. You have to clear your throat a bunch of times. And he said, "I think you're going to be glad I woke you up." And so then I knew that we had been selected, which was quite a thing to hear.

Then right away, he said, "And the first thing I want you to do is re-propose your whole student collaboration plan." Because the student collaborations on these missions, you get a percentage of—it's the A-through-D proposal cost. You get a percentage of that to do student collaboration projects that are limited to being two- and four-year colleges, college students in the U.S. And the thing about them, a lot of us had proposed a CubeSat to be include in our spacecraft, and then we were told in Step 2 something that was apparently a mistake of some

sort. I've never sorted out what mistake that was, but all the Step 2 proposals were told that you had to write in a separate complete spacecraft proposal for the CubeSat, and that weaknesses against that proposal would count against your main proposal.

So, obviously, there's no way that that risk is worthwhile, so everyone immediately dropped their CubeSat, so there were no audacious student collaboration projects. Like, right away, we said, "We're going to do something really simple and really standard, like we'll build a camera, it'll be a student camera and students can operate it." You know, that's lovely. There's nothing wrong with that, but in terms of student outreach, that's something I really, really care about and I thought about a lot, and you can have a small intensive project, like building a camera, you could involve a couple of dozen students over a few years, and it's a life-changing experience for them, but where are the other thousands and thousands of students who would also like to be involved? There's no way for them to be involved.

So Cassie Bowman, who's faculty at ASU, she and I, we ended up proposing ten student collaboration ideas to try to fill out the space of how many students are involved and how intensive is that involvement. If you have a less intense involvement, you can have *way* more students involved. We tried to kind of spread out over that space, and I'm *really* proud of our student collaborations. We've just completed our sixth year since selection, and we've had over 1,500 students involved from over 58 colleges and universities just in these first six years before launch.

So, anyway, that was our conversation. He said, "Re-propose student collaboration. Then there'll be a national press event with NASA Headquarters in about six hours at 2:00 o'clock. You can't tell anybody except for the immediate team till then. You have to swear them to secrecy. Then you're going to get on a bunch of prep calls and prepare for the press event."

I was getting dressed and going downstairs, and all this is ringing in my head. We heat this little house with a woodstove. It was a very wintery, snowy day, and so I started up the woodstove and I put on some water to make coffee, and I thought, "I've got to call the university president. I have to call everybody on the team." Then I just decided I needed to just take a moment to think about what had just happened, because it definitely was going to change the rest of my life. So I turned off the water and dampened down the woodstove, and I just went for a walk up the hill into the woods, in the quiet, still New England forest and all the dark trees and the snow, and it was really—everybody talks about mindfulness and, like, living in the moment and really experiencing where you are, and that was a moment of very peak mindfulness for me. I can feel *exactly* what it felt like at that moment, looking at the trees and listening to the water dripping and hearing the crunch of the snow under my boots and the cold air, and just taking in the fact that this was a pivotal moment.

So then I went back to the house and got on the phone. [laughs] I called my husband and my son and my brother, and I called the university president. It was early in the morning on the East Coast. It was *really* early in Arizona, so it was super very fun to be able to call him. He didn't, unfortunately, pick up at that moment. We talked again later, but it was just fun to say—you know, it's like 5:30 in the morning in Arizona or something. [laughs]

Then I started calling the main parts of the team. [laughs] I think the best call of all was with Ben Weiss, who was then magnetometry lead and also coauthor on the original motivating paper. It was he and I and Maria Zuber who wrote that original paper back in 2011, so the people who started the whole process. I also called Maria, who was on the science team. I called Ben and I said, "Ben, we've been selected for flight!"

And I think he didn't believe me. [laughs] He yelled into my ear, "Are you fucking with me?" [laughs] I forget. "Are you shitting me?" It was something like that, some four-letter response, because he just could not believe that it could be true, and he thought for a second I was just like pulling his leg. [laughs] So that was a real pleasure to call people and say that.

Then we had the press event. Then it was just interviews, like hours and hours and hours of interviews, which was amazing that everybody wanted to have a little coverage of the new Discovery selections. So that was the selection day.

Q: After selection, you have to build a much larger team, so talk about that process.

Elkins-Tanton: Yeah. So we already had our science team completely built, and my philosophy all along—and I think this is my most important contribution to Discovery mission or missions in general—has been a tremendous amount of work that I've done on team culture, trying to help the teams work better. I'm really opposed to the idea that you have to break people up by disciplines. Very commonly, you have an engineering team that's led, in this case, by JPL, then you have a science team that's led by me, and then there's people who do business ops and scheduling and student collabs, who kind of like float around the outside. But, of course, the truth is that I actually lead the *whole* team. It's my ultimate responsibility, the whole thing. That's what it means to be PI-led.

So right from the beginning, I've tried very hard to integrate all these teams. So we don't, for example, have science team meetings. We have all-team meetings. We just finished one yesterday. The last two days were all-team meeting for the spring, and everyone is invited. So we have engineers and scientists and we have artists and schedulers and budgeters and everybody

comes, all the student interns and the whole thing, and it's incredibly enriching and helpful. One of the things that it does is it normalizes the idea that you can ask serious questions that are not posing, you know, that it's okay not to know the answer to something, because nobody knows the answer to everything, and if you're all in one discipline, it's hard to ask a naïve question because you're expected to know everything about that discipline, but when you have all the disciplines together, everyone can ask questions and it makes it so much more relaxing.

So right from the beginning, I was saying to everybody in our planning meetings, "This has to be the kind of team where the person with the authentic knowledge is the one who's allowed to speak up, where every voice is heard." If you have the kind of team where there's pressure to seem expert all the time or where only the leaders are allowed to talk or where there's any kind of bullying, then you silence the most junior people, and it's the most junior people who are actually holding the soldering iron a lot of times or typing in the code, and they're the ones who have to be able to say, "We have a problem," because you've got to know early in order to be able to fix it before you launch. [laughs]

So we really worked very hard on that, like having very civil conserations in our meetings where everybody can speak, and avoiding the use of passive aggression or aggressive aggression. [laughs] And I always talk about how you walk into a meeting room and certain people sit automatically at the head or the tail of the conference room table, or they sit along the edges of the conference room table because they expect to be treated like leaders and have their voices heard, and other people self-select to sit along the wall because they are *not* expecting to speak, and it should just never be that way. Everybody, no matter where they sit, has to be able to speak.

So one nice thing was that as JPL was getting people together on the team, even though JPL has a personnel shortage and did at that time, and there are big, big missions that are taking everybody, we actually got super high-quality people and a really diverse group who wanted to join the team, which is really, really lovely. So that has helped us tremendously, that team-building process. Then, of course, at places like APL or at Danish Technical University or Mailin, they choose their own people. That's not us choosing them at all.

Then as an outside PI at JPL, I was trying to be at least a part of all the major decisions, and it wasn't always easy to get in the room, frankly, at that time at JPL, so it was a bit of a struggle, but I think I prevailed over time and became a more trusted and more integrated member of all the decisions.

Q: I know from GRAIL, for example, they had essentially a weekly leadership phone con between Maria [Zuber] and Dave Lehman, the project manager and Maria's deputy. Did you do something similar to try to stay involved in the decision-making?

Elkins-Tanton: Oh, my gosh, *constant*, constant meetings and phone calls and going out there in person. In the very beginning, I was only out usually a week a month, but in recent years, I've been at JPL more or less every other week—

Q: Jeez.

Elkins-Tanton: —which is a heck of a travel schedule, I will tell you. So that stopped during COVID briefly, but the minute that JPL would allow me back on lab, I've been on lab every

other week, more or less, since then. So, yeah, absolutely, we have weekly calls, but we have more than weekly calls. At the moment, we have something like twenty standing weekly meetings that I'm a part of. I have leadership meetings with myself and the deputy PI, who's Ben Weiss now, and the project manager, deputy project manager, and so forth, we have that leadership meeting, but then we have JPL leadership staff meeting, which is, I don't know, twenty-five people or something like that, and then there are leadership meetings for other parts of the mission that I also participate in, along with the Risk Board, the Engineering Change Board, and the TSC (Technical, Schedule, and Cost) Board, so I'm involved in all of the kinds of leadership meetings. Very often I'm just listening, not ever trying to inject anything just for the sake of having something to say, but keeping track of process. Then I have one-on-ones also with a lot of the leadership to talk about more sensitive concerns or strategy. And also every week we meet with our mission managers in Alabama at Marshall and Headquarters all together. We have a leadership tag-up that way every single week as well.

Q: Since we're running out of time, my last question. When you're first selected and announced, you had one launch date and then you moved it forward, if I remember correctly.

Elkins-Tanton: Yeah, that's right. That's right. Am I going to get the dates right? They were fresh in my mind last year when we were recalculating. But we were all asked to propose for a certain date and then have a backup date two years later. The idea was going to be that they were going to select two missions, which they did, us and Lucy, and one would get the first date and one would get the second date. So that's what happened. We were selected, and then we were

selected for the second date, because Lucy's magic trajectory that hit all the objects they need to hit was that one date only, so they had to launch on the first date.

So then right after selection, NASA said, "I wonder if we could save a bunch of money if you could launch one year earlier so it would be one fewer year of the marching army on the ground." So we did find this beautiful, beautiful launch trajectory for 2022, which had been our hope, which, sadly, we did not hit, but we are feeling very good about our launch in 2023. It will be exactly five months from today.

Q: Yep. That's a great place to stop. We'll have to talk again about—I mean, you wind up deep immersed in the COVID problems, and we'll have to talk about that impact next time. [laughs]

Elkins-Tanton: It was *unbelievable*, unbelievable. Definitely don't recommend building spacecraft during a global pandemic.

Q: Yeah. But that'll be next time. Thank you so much for your time.

Elkins-Tanton: Thanks, Erik.

Q: You too. Thank you. Bye-bye.

Elkins-Tanton: Take care.

[End of interview]