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INTERVIEWED BY REBECCA WRIGHT
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WRIGHT: Today is June 9th, 2017. This oral history session is being conducted with Dr. Lucy McFadden for the NASA Headquarters Science Mission Directorate Oral History Project at Goddard Space Flight Center in Greenbelt, Maryland. Interviewer is Rebecca Wright, assisted by Sandra Johnson.

Thank you so much for coming in today to talk with us. We appreciate it. We know that you recently retired from a long career in the field of astronomy and related aspects. Tell us how you first became interested and how that interest brought you to this career.

MCFADDEN: Thank you. It's a pleasure to be here, and thank you for this opportunity to reflect on my career. I really do feel like I got here by happenstance. However, it was also my curiosity and my personality that led me here.

I look back and some stories just pop up. Some of them are already on the Web, but those are my powerful stories of going off to college, as an excited freshman in a brand-new college. It was an experiment in my way to go to college, to go to that particular college named Hampshire College [Amherst, Massachusetts]. It was a great adventure for all of us who were there in that first class. Coming together, we were committed to learning. We were good students. We thrived on learning things. We wanted to direct our own course of study and have an impact on the world.

When I started there, I had no idea what direction I would go in. It was a new college, very small, with eager faculty to start on this adventure, and we were given a course list in a mimeographed course book. There must have been maybe 50 courses to choose from. I read each course description eagerly saying, "What do I want to do? What do I want to do?"

It was 1970, so it was essentially the late '60s. The Vietnam War protests were active, civil rights changes were underway, birth control pills were becoming available and were controversial, and [we were in] the '60s flower power and drug fiasco. Thank God I went to school, because who knows what would have happened otherwise if I hadn't decided to go to school. My parents wanted me to go in their direction to their alma mater, but I was rebel enough to want to do it my way.

I went to Hampshire College, where there were courses called, "Dimensions of Consciousness," which was basically a psychology course; Criminal Justice—that was important on how to put perspective on the civil rights activities that were going on; Film Workshop, because film was the new medium. Those were my first 3 choices; I had to put down 10 choices.

I was going through the list and running out of things that sounded interesting. Then I got down to number nine, and I read a description about optical and radio astronomy. I couldn't understand the concept of radio astronomy. I thought about the radio and had a visualization of the radio in my family kitchen. It was up on a ledge, next to the refrigerator, and we would turn it on in the morning and listen to it.

I said, "How does turning on the radio tell you something about the heavens?" I had no concept of propagation of radio waves as a senior in high school. I studied waves and vibrations in high school physics, but I hadn't really conceptualized the technical leap of radio waves being everywhere.

I signed up for this course as my ninth choice, and darn, my Dimensions of Consciousness, Criminal Justice, and Film Workshop classes were really popular, and I didn't get them. So, I got optical and radio astronomy. I said, "Okay, well, here I go on an adventure," studying something I knew nothing about. I put it down just because I was curious and I couldn't really understand the course description. That was the beginning in college.

I took the course. We used telescopes in the backyard of my astronomer's [professor's] home. They were these tiny little three-and-a-half-inch telescopes. They were built by Questar [Corporation], which are exquisite optic telescopes. We were in Massachusetts in cold nights toward the end of the semester and in January too. Cold nights, skies were clear and crisp, and I did a study observing different types of stars in the sky. They were different colors, they were gorgeous.

Then I was motivated to understand the physics of what made the colors different. That was my beginning of my astronomy. As I look back, it's actually amazing that it was my first semester in college and I'm still doing that, because most people change their careers. That was the beginning.

Throughout the course of my college career, we had new faculty members added, and the next year, we had an ex-astronaut. He taught a course called, "Moons and Planets," using a textbook that one of our colleagues had written, and I got interested in the solar system. He [the new professor] was also a coinvestigator on the Mariner 10 mission, which flew past the planet Mercury. He was looking for some students to work with him in the spring of 1973 as an internship opportunity to do some data analysis, to work with the data being returned from the planet Mercury. So I said, "Sure, why not?"

He took two students from Hampshire College and we went out to Pasadena [California] for the spring semester. That was when I was introduced to the whole world of NASA, and my first mission experience. I was this little undergraduate who knew nothing, working with all these big titans in the room, while [sitting] in their meetings and their planning on how they would get the data. I would sit there and look at it and analyze it and they would write papers.

I was in the room with Bruce [C.] Murray, who later became the head of JPL [Jet Propulsion Laboratory, Pasadena, California]. At the time, he was the head of the camera investigation team on Mariner 10 for Mercury. So, there was Bruce Murray and people who mapped the early planets.

My boss, the person I reported to, was a guy named Mert [Merton E.] Davies, big tall man who worked at the RAND Corporation. My job for him was to take the pictures that they had converted into paper prints—they had put a grid marking on them—and I had to determine the position of craters on the surface of Mercury in terms of x- and y-positions on each piece of paper.

I used an Agfa loupe [magnification device] and counted the marcations to locate the center of all these craters. Mert Davies took my x- and y-coordinates and used a computer to develop the map and determine the coordinate system on Mercury. He said, "Lucy, you're doing planetary cartography," and I felt very proud.

I think today that explains why my left eye is slightly different than my right eye, because I spent three months looking through a magnifying glass and writing info down. As I'm telling the story I can sort of feel the eye fatigue in my left eye with that Agfa loupe looking at the crater.

WRIGHT: Didn't have a lot of options? That was your only way of measuring, right?

MCFADDEN: Right. Yes. I think today they do it by screen, but you still need somebody there positioning the center of the crater and clicking and marking those positions, yes.

WRIGHT: Amazing work. You went on to MIT [Massachusetts Institute of Technology, Cambridge, Massachusetts] for graduate work, is that correct? Tell us about the transition from Hampshire College to MIT, which is pretty competitive, I understand, just to get in.

MCFADDEN: Thanks for asking that question too, because that's a fun story. Among these planetary titans on the Mariner 10 team was a man named Tom [Thomas B.] McCord. He had been a student of Bruce Murray's at Caltech [California Institute of Technology, Pasadena] and was visiting at Hampshire College.

Brian [T.] O'Leary, my Hampshire College professor, had a grant for another project that was separate from the Mariner 10. That project was to make some telescope observations of an astronomical phenomenon where as the moons of Jupiter, orbit around Jupiter—as observed from Earth, they pass in front of each other, and so they occult each other.

If you're observing the brightness of one object as the other one passes behind it, you look at the change in the light as they merge, and you can tell whether those moons have an atmosphere or not. If there's no atmosphere, when one goes behind the other, it totally blinks out, and you're just getting the light from the one that is in front. If there's an atmosphere, the change in that brightness will change more slowly as the light is diffracted through the atmosphere and interacts with the atmosphere.

Brian O'Leary had gotten money from NASA to use an instrument that would make these observations. We'd mount it on the back of the telescope at the Observatory at Mount Holyoke [College, South Hadley, Massachusetts]. Tom McCord from MIT, came to Hampshire College to set up the instrument and teach us how to run it so we could make these observations. Here again, I was still working with Brian O'Leary, and he said, "Lucy, after your spring semester at JPL, let's observe these. Do you want to work with me on this observational project?" I said, "Sure." That became my senior thesis at Hampshire College.

Tom McCord came to set up this instrument, and I remember him explaining it to Brian O'Leary. He said, "Brian, you're going to have to isolate the electronics from radio interference around here." Here's radio now; now I've learned something about radio waves, and so I know what they are. Brian nodded his head and said, "Yes, OK." Tom said, "The best thing to use to shield things from radio interference is aluminum foil."

He picked up a box of Reynolds Wrap [aluminum foil] which he'd brought with him, and Brian looked at him quizzically and said, "So where do I put it? What do I do with [the foil]?"

I said, "You just wrap it everywhere."

That was my intuitive response, and Tom McCord said, "Yes, she's right, you just wrap it everywhere." Later we took a break and were having lunch when Tom McCord said to me, "Lucy, what are you doing after you graduate from Hampshire College?"

I said, "I think I might be going to study in Germany for a year. There's a professor at Smith [College, Northampton, Massachusetts]. She teaches at Smith for one semester, and then she's a professor at a German university for the other semester. I think I might go study with Frau [Doktor Woltraut Carola] Seitter."

He said, "Have you thought about going to graduate school at MIT?"

I said, "No." I said, "Gee, tell me about that."

He gave me that idea, and he said, "I don't think you've really had enough course work to start in our regular graduate program," because at Hampshire College, we took three courses a semester. I'd taken calculus, but I was graduating without the regular foundations in physics and math that most MIT entering graduate students have. He said, "There's a category of students called special students where you can enter and not be on a degree program right away. You come in and you'll make up some classes and then apply for the degree program." He said, "I think you should apply for that, and I can give you a research assistantship."

So I was invited to apply to MIT and didn't have to pay for it. Tom McCord accepted me and it was covered through his grants and a research assistantship. His grants paid the tuition fee and I had a research stipend that I could live on.

WRIGHT: What a gift.

MCFADDEN: I graduated from college and I gave up the idea of going to Germany, because that was far away, and I'd have to brush up on my German and take courses in German. That would have been a nice adventure, but it was easier to go to MIT.

WRIGHT: Wow, I don't think I hear that statement very often: It was easier to go to MIT.

MCFADDEN: And it was closer to my boyfriend too.

WRIGHT: That was important at the time, I'm sure.

MCFADDEN: It was, yes.

WRIGHT: Just a sidenote. How many females did you find when you got to MIT in that position?

MCFADDEN: It was like when I was in graduate school, even at Hampshire as an undergraduate. The Women's Movement was also another active movement at the time, equal opportunity for women. In fact, we were trying to get a constitutional amendment, the Equal Rights Amendment. That was also one of the social issues at the time, and one that failed.

But I really felt like I was asserting myself for my equal rights to pursue academic studies, and at MIT in Tom McCord's lab there were many women. My longtime friend and colleague Carle [McGetchin] Pieters was finishing up her PhD there. There were three or four students from Wellesley College [Wellesley, Massachusetts]; MIT had connections with Wellesley College. So there were a number. I was not alone.

I was not alone, and Tom McCord encouraged me to work with instrumentation. He was building new instruments with different detectors and pushing the technology. He had a lab and it was a lot of fun. I didn't feel like I was the only one; I was not the only lonely woman. We had a nice cohort of people and a great group to work with.

WRIGHT: It makes, I guess, a firmer ground for all to see that all different types of people are involved, and everyone has an equal footing in that door. I believe while you were there that you had an opportunity to go to Hawaii and work in your adventure in astronomy.

MCFADDEN: Right, the adventure in solar system exploration is really what it turned out to be. I entered as a [MIT] special student and took all the hard courses. But, I was a Hampshire College student, and I knew how to study. Independent study was our forte.

At Hampshire, I took physics backwards. I took quantum mechanics first, then electromagnetic theory second. I didn't have the first two years of physics, so I had to take

Newtonian mechanics and waves and vibrations. But, I didn't want to take classes with freshmen, and it was probably smart of me, because they were probably too good.

So I said, "I want to do an independent study" and went to one of the professors, Professor Anthony [P.] French, who had written a textbook on Newtonian mechanics which is usually the freshman physics course. I said, "Can I do an independent study with you? I'll read the textbook and work on the problems and we'll come in and talk about them." He said, "Sure." So I did that, but the problems were still hard. I struggled with the problems and to this day I still struggle with physics problems.

Some years ago I decided I wanted to go back and take some more math courses. This was like maybe in 2005, a decade ago. I said, "I want to strengthen my background so that I can hone my math tools." So I took an advanced calculus course at University of Maryland [College Park]. I have all this experience, I use calculus every day, it's part of my being, and I went to the lectures. I was fascinated, and it was really great, and I could see these applications, I still tried to do the homework problems, and I still couldn't. "What's wrong with me? I'm under no pressure. I'm doing this of my own volition. I still don't quite get these math problems."

At MIT I did the basics. I took some more advanced calculus, thermodynamics. I worked hard, I struggled, I didn't get great grades, but I passed the tests. I knew I was a smart person. The one course I really struggled with was partial differential equations, and I took the first test and I got like a 34 out of 100. I thought, "Oh my God, how can this be? I'm a motivated independent learner. I've studied physics, I've taken calculus. How can I screw up like this?"

I went to the teacher, to the professor. He was a well-known professor, named Alar Toomre, and he was a titan in his field of mathematics. He worked with me, and he encouraged me, and he said, "Don't give up, this happens." He said, "Ms. McFadden, the mean grade was 63, so don't feel badly." But still, I was down there in the bottom.

So I worked hard, and I went to the study. They have recitation sessions where you go to a big lecture but then you meet in smaller groups and go over it with a teaching assistant. I finally got it, and I was determined to do better. In hindsight, okay, yes, here I am, taking a math course, and I realize if you start with an F, it's really hard to get yourself out of the well of an F and bring your grade up to something passable. But I stuck it out till the end.

I can remember, I can visualize in my head Professor Toomre standing there saying to me, "You know, Lucy, you can drop the course and take it again." I said, "Oh, no, no, no, no, I don't want to do that, I'm going to improve myself." But it was the last day before dropping. He said, "Lucy, why don't you drop it and take it again? I advise you to drop it, it's not going on your record." So I said, "Okay."

I dropped the course, and then I took it again. It was so much easier the second time around. I just needed to keep at it and get the hang of it to get my mind into the mindset of solving these partial differential equations that people had solved in the eighteenth and nineteenth century. I took the course again the next year and got a B. That's all I needed.

WRIGHT: Yes, gave you that confidence with a different plan of attack, and it worked.

MCFADDEN: Right. But to get back to your question, which was about going to Hawaii, I spent three years at MIT and decided to go for a master's degree. I was a special student for a year to show that I could do the course work and make the grades, and then I had to join a degree program.

I needed to decide to go into a PhD program or a master's program. I think at the time I wanted to go into the PhD program, but I remember a conversation with another professor named Roger [G.] Burns, who said, "Well, why don't you just start with a master's? Get the master's first." So I said, "Okay," and that actually turned out to be a good thing. I did a thesis, and the thesis was on those moons of Jupiter again, but some observations that we'd made with an instrument that Tom McCord had developed. I had worked on aligning the instrument and determining its capabilities, its sensitivity.

I wrote my master's thesis, and then it turns out, Tom was negotiating for a new position to leave MIT. He had gotten a position at University of Hawaii to automate the telescope at the summit of Mauna Kea. It was an 88-inch telescope, which is huge—that's eight feet across, little bit more than eight feet across. He got funding to drive it by a computer instead of manually maneuvering it.

He invited everybody in his lab to move with him, because he had a research program, and he wanted to bring his lab with him while he did this engineering project. He invited everybody in his lab, and most of us went. We said, "Sure. Move to Hawaii?" I was in my mid twenties. I did have a boyfriend, and it was the same boyfriend I had in college, as a matter of fact, who I didn't have to leave by going to MIT.

Then going to Hawaii, I said, "Yes, I'll go. My boyfriend can come with me if he wants, or—I'm going to Hawaii." I remember him saying no, he wasn't going to follow me to Hawaii. I said, "Okay, well, I'll see you." He did come to visit me once, but he was determined not to follow a woman, so we went our own ways. So then I had that Hawaii adventure, which was again another opportunity for which I'm very grateful to Tom McCord for providing.

WRIGHT: I believe I read the telescope was new in 1970, so it was still at the beginning of what it was going to be able to offer, right?

MCFADDEN: Oh, absolutely. Yes, the Mauna Kea Observatory. When I was there it had two 24-inch telescopes and one 88-inch telescope, which was the main observing telescope. Then in the course of my decade there (from ’77 to ’83), in 1977 it was still pre-digital age, we used computers; they were digital but it was prior to the emergence of the digital age.

So computerizing the telescope was an upgrade. While I was there, two other telescopes were built, one the United Kingdom Infrared Telescope, and another, the Canada-France-Hawaii Telescope, then a third one, the NASA Infrared Telescope. There was a lot of building, and an active scientific community was emerging on the Big Island of Hawaii.

WRIGHT: How exciting for a newcomer to be part of all that newness that was going on.

MCFADDEN: Exactly. That’s right. I remember getting there. We got to ship. McCord moved his lab with all his equipment, so they shipped stuff by boat. We got to send a few personal items with it out there, and there were about six or seven of us. There were two graduate students going.

There were two other women going who had been research and lab assistants. Mike [Michael J.] Gaffey went, so there were six of us who went out there and we had a little community. We moved into this small institute called the [University of Hawaii] Institute for Astronomy, for which I’m returning to Hawaii at the end of this month to celebrate its fiftieth anniversary. They’re having a symposium for its fiftieth anniversary, so it’s going to be old home week, as well as seeing what has happened at the institute since I left. That’ll be a really fun event.

But we got to Hawaii. When the container with all the lab equipment came, that was a big kerfuffle that interrupted the whole day-to-day activities of the Institute for Astronomy. So we were a big force, and we were all young, excited to be there, and it was Hawaii.

In Hawaii, they dress casually. I went there as—I shudder to think. I wore these little short shorts to work every day. It was like beach attire. I'm thinking back saying, "My gosh, where was my sense of professionalism?" I was basically dressed as if I was going to go running. And I did. I rode my bicycle to work, but I cringe to think about what I wore and how unprofessional it was. It was a casual place, and there was no dress code, so we had a good time. We were very productive, and we did a lot of groundbreaking science in those early days.

WRIGHT: I'm going to have to assume you didn't have a big budget to spend a lot of money on professional clothes. You were probably living very frugally and at work all the time. I'm sure that's part of it when you look back on those things.

MCFADDEN: That's right.

WRIGHT: But you did complete your dissertation there. If I'm correct, it was focused on near-Earth asteroids. Talk about the first time you were looking in those telescopes in Hawaii. How different were they from those cold nights in Massachusetts?

MCFADDEN: That's right. Well, they weren't much different from those cold nights in Massachusetts; that gave me good training. The Institute for Astronomy is in Honolulu on the island of Oahu. The telescopes in Hawaii are on Mauna Kea on the Big Island of Hawaii. So back then, when we went observing, we would fly from Honolulu to the Big Island to Hilo, and they have living facilities for people at 9,000 feet at a place called Hale Pohaku. The telescope is at 14,000 feet.

At 14,000 feet there's half the amount of oxygen in the atmosphere that there is at sea level. So whereas you go to Hilo and you land, it's a nice tropical paradise. It's warm, there are nice winds off the ocean, warm breeze, very humid, but because of the breeze it's just pleasant, you're in the tropics. Hilo, you think Mai Tais and sitting on the beach and having a good time, but when you get up to 14,000 feet and when the Sun goes down it gets cold at night. The telescope is huge. To get to where you put your eye at the eyepiece, or to get up to the television camera that's at the back of the telescope that records the images that we're looking at, you have to rise up on a big pneumatic platform that goes up to the telescope eyepiece.

The observatory dome is open, and so you're at ambient temperature. You're at 14,000 feet at night, and you're wearing a parka, and you're wearing down-bootees to keep your feet warm. You are basically dressed for skiing. You're wearing long underwear to stay warm, because you are out in the cold, and you're not moving around very much. The telescope is moving around, pointing at different places in the sky. I was running the equipment, hitting the start button to start the data collection cycle. Again these were the early days of computerization.

Now my colleagues [here] get up to observe in Hawaii in the middle of our night, which is sunset in Hawaii. They observe from home at a computer terminal, and they don't have to go outside. Although, it is a big problem if their telescope isn't working right and they are sitting in Silver Spring [Maryland] and their telescope in Hawaii or Tucson [Arizona] isn't working right. I literally had that conversation with a colleague down the hall this morning. She was frustrated because there's something out of alignment and she's not there to tweak it.

Back in the late 1970s, I was up on the platform, awake all night, and setting the telescope, moving it. There's a paddle, you push buttons, and little motors run, and it moves the telescope around an azimuth, moves it to the right, or it moves it up and down in declination. You have to send it over to find the object that you're looking for, looking through an eyepiece. That's old-fashioned observing, and it was fun, but it was long nights and cold.

I do remember one night when Tom McCord—bless his heart, what a slave driver he was. It gets cold up there, and you're observing, and you get hungry at night so you have night lunch. Usually you break and go downstairs where there's a kitchen and have night lunch. This one night was so important that Tom McCord said, "No, Lucy, stay up there." He said, "You're doing a great job. These observations are great. Stay up there."

He was in the control room where it was warm. I was up there guiding the telescope because the drives on the telescope weren't quite tight enough and the Earth is rotating, so the object is moving in your field of view, but I had to tweak it and keep it centered in the right place so we could collect all the light.

He said, "Lucy, you're doing a great job. Stay up there. We need you up there." He says, "I'll throw your sandwich up to you and you can eat it on the platform." He says, "I'll even heat it for you in the microwave." So I had a warmed egg salad sandwich up on the platform that Tom McCord threw up to me from below so that we could keep getting our data. It was also funny because it was the early days of microwave ovens. I had never eaten a warmed egg salad sandwich, but he thought he was being nice to me. So Hawaii was a big adventure.

But now let me get back to your other question of near-Earth asteroids. You asked what that was like. How did I choose near-Earth asteroids? I was studying the satellites of Jupiter. There was a mission. NASA plans these missions, but we rely on getting money from Congress to fund them. There was a planned mission called Jupiter Orbiter Probe, and I was going to do my thesis in work supporting of that mission, but that mission didn't get funded. So I realized, "Well, wait a minute, the timing is not right. I'm not going to do any more work on the satellites of Jupiter; I'm going to find something else to study."

McCord had pioneered this technique of observing the reflected sunlight off of planets and moons in the solar system, and then passing that reflected sunlight through a prism and seeing what the spectrum looks like. There are characteristics of rocks. Some rocks are red, most rocks are gray or black, but their colors reflect the different mineral composition. McCord had pioneered this technique from measuring the reflected spectrum off of the moons and planets, and they're different. When light passes through a prism, there are certain colors of light that are missing that tell us what the predominant material is on the surface, and that tells us about the history of the rocks, of the moons and planets.

So I said, "What hasn't been studied? What needs to be studied in the solar system?" McCord did the Moon. He demonstrated with the returned lunar rocks that his technique was actually accurate and correct, because rocks returned from the Moon had the same mineral composition that he had predicted from measuring the reflected light. He was on a roll. He observed Mercury and all the planets. Mars is particularly red; it's got iron oxide on the surface. Satellites of Jupiter, Saturn. He was basically going through the solar system. He had observed the largest asteroids in the asteroid belt; those are the fragments. The planet that failed to form has left a belt of smaller debris between Mars and Jupiter.

I said, "Wait a minute." I don't know if I said it or Tom said it. But he said, "There are these asteroids that are on orbits that leave the main belt. Somehow they've been knocked out of the main belt. They're in orbits that cross other planets, and they come close to the Earth, so they're near-Earth asteroids. But they are members of the asteroid belt."

I said, "Oh, let's look at those and compare them to what we know about the main belt asteroids and what's their relationship to the rocks that have landed on Earth—the meteorites that bring us debris from the solar system, nature's sample return from the asteroid belt." So I said, "Yes, I'll do that. Nobody's done that before. I'll look at the near-Earth asteroids." That was my observing project; that was my thesis project. I set about learning everything I could find about the near-Earth asteroids and their dynamics, what people thought, how they formed, how they got knocked out of the main asteroid belt.

Then I also had the chance to study the meteorites, the ground truth rocks that we have and look at their reflectance signature in the laboratory. That was the neat thing about this technique. We could set up an artificial Sun in the laboratory and shine it onto different types of rocks, and then get the measured spectrum, which was our spectral library that we compared with what we observed at the telescope.

Another one of my thesis advisers was Mike Gaffey; his thesis was doing a survey of the different types of meteorites and what their spectral reflectance signature is. I used his database of meteorite spectral reflectance and I observed these new near-Earth asteroids, as many as I could observe, in a time to make enough of a statement about what we thought the near-Earth asteroid population was like and how they got there.

That was my dissertation. I observed 17 objects. It was fun because they moved faster. They were near Earth, the Earth is rotating, they spun by the Earth, and it was a challenge observationally to find them. We didn't know their orbits well. I had to point the telescope and wait for them to come into the field of view and observe them.

I succeeded. I had good weather. The gods were with me; that's also very important. I had a successful thesis dissertation. It was a lot of fun.

WRIGHT: And at some point you had to leave Hawaii, and ended up actually coming here to Goddard to do your postdoc.

MCFADDEN: Yes, that was my first postdoc.

WRIGHT: Was that transition something you were seeking?

MCFADDEN: Yes. I defended my dissertation, then I met another guy in Hawaii. He was in medical school and doing a PhD. He finished medical school after his PhD, just as I was finishing my PhD. We decided that we'd get married. He wanted to leave Hawaii and go get a residency. We said, "Okay, let's go to the mainland. I'm going to look for places where I might work." This was a great adventure. He was going to look for places where he wanted to do his medical residency, so we took a road trip around the country together visiting various places where we might both be able to work. I'm trying to think where we went. I wrote to my professional colleagues at various institutions, including the University of Chicago.

I did come here. There was a guy named Bob [Robert] Murphy, who had published on the satellites of Jupiter. He worked at Goddard, so I came to meet him, and my husband went to interview at Johns Hopkins University [Baltimore, Maryland]. We also looked in Chicago, Los Angeles; I think those were the main other places. But here in this area, there were opportunities for both of us.

Bob offered me a postdoc position, but it was in terrestrial remote sensing, studying the Earth using the same technique, looking down on the Earth, and looking at sunlight reflected off the Earth of different types of ground cover. I was in the Earth Applications Branch, it was Code 923. I was assigned to work with John Barker, who was working with the Landsat [Program satellite] images. John Barker was collecting a lot of data on Landsat, and he was always fiddling with his data, as in calibrating it, trying to maximize the signal from the noise, and making sure he really had what we really wanted to look at. But he never got beyond that.

So I was tasked to "get some science out of John Barker's results. Publish something. He's sitting there calibrating his data and never doing anything else." I tried for a year and a half, and it was really hard. In hindsight, why couldn't I come up with anything? I wasn't sure what the questions were. What do we need to know about the Earth from a satellite orbiting the Earth, looking down on different ground cover? What are the issues? The issues are leaf cover, drought. It was before climate change had been identified as an issue threatening to our survival on this planet. The questions weren't adequately defined.

I was interested in the physics of the light interacting with different leaf types and what you can learn from that. So I was in a situation where I had all this data, and asking, what can it tell me? I looked at the data. It all had this absorption of chlorophyll. Leaves are green, and that's because all the blue light and the red light are absorbed and it just leaves the green light. I was trying to understand the physics of this shift. Sometimes it shifts if there's drought, if there's not enough water in there. Clearly at different times of the year the colors change and so the spectrum is going to be different, so that was cool, there was a nice physical change.

But what's the question? How do we put this to use? I know that the seasons change. I know why the seasons change. What use is that information? Farmers may need it to monitor their corn growth, but I didn't have anybody asking me to monitor their fields and correlate it with their production rate.

After about a year and a half I had another opportunity. I can't remember how I met Mike [Michael F.] A'Hearn at University of Maryland, but he offered me another postdoc to study Halley's comet. Here was an opportunity for me to get back into the solar system. With my first postdoc I said, "We know too much about the Earth. My technique isn't that useful, because it's so easy to get ground truth." We'd go on these little expeditions to the Eastern Shore and we'd send our reflectance spectrometer up in a balloon to look down at the ground cover, and we got the data. But so what? What's it telling us?

I was frustrated and eager to get back to planetary science. Of course, in Earth science now and with climate change as a critical issue needing our attention, those methods and approaches are invaluable in understanding the long term changes to the environment. I was there just at the beginning, and I didn't have the insight and others did—thankfully everybody didn't abandon that approach, because otherwise we would miss out on understanding long term climate change and its effects on our ground cover and surface conditions. But, I had this opportunity to work with Mike A'Hearn as a postdoc at University of Maryland on Halley's comet. Halley's comet—it comes around once every 70 years, once in a lifetime, so again an opportunity came to me and I said, "Sure, I welcome the opportunity."

I went to the University of Maryland, and it was great, because then I didn't have to travel down here from Baltimore. We were living in Baltimore because of my husband's residency program; he had odd hours, so we lived closer to where he worked. Taking the postdoc at the university, I didn't have to drive down to Goddard. I could take the train to College Park and go to the University of Maryland, and I had the chance to study Halley's comet, so that was going to be fun. That was another change that was a big adventure.

WRIGHT: This project certainly had an ending that you didn't imagine would happen.

MCFADDEN: Right.

WRIGHT: Talk about that project and how you began in a different way of associating with NASA and human spaceflight, and how it didn't have the ending you were hoping for.

MCFADDEN: That's right. Mike A'Hearn was working with people here at Goddard to put an ultraviolet telescope on the Space Shuttle. NASA was looking for projects and trying to find something that could be done, and again I wasn't involved in all the hard work of getting this project funded to build an ultraviolet telescope at [Johns] Hopkins and get it to fly on the Space Shuttle. That was with Ted [Theodore R.] Gull. He's still here, he's a great candidate to interview. This ultraviolet telescope was going onto the Space Shuttle and we were preparing for it. It was in about January 1986 I think.

WRIGHT: That's when the flight was scheduled.

MCFADDEN: Yes. I was in my office. I was pregnant with my first child. Few people knew that I was pregnant. I was sitting in my office at University of Maryland and my sister called me and she said, "Lucy, the Space Shuttle crashed." I said, "No, that can't be." I said, "I don't believe you." I always challenge this particular sister. She always insists that she's right and she knows everything. I said, "No, this can't be. Well, I've got to go find out."

I went down the hall and talked to Mike A'Hearn and clearly word was just getting in. I still remember the feeling. I had this feeling in the pit of my stomach, and it was at the same time that I realized I had a human life growing in me, and that I was part of—something horrible had happened, and I said, "Oh my gosh." I don't know. It was a transformative thing. Here I am about to raise a family and this horrible thing had happened. It was just a moment for all of us who were part of NASA; we were just in disbelief.

Our project, the Hopkins Ultraviolet Telescope, was scheduled on the next flight, which was scheduled for the month after that. So here we were, dealing with the tragedy and going home and watching everything on TV as everyone did. Then eventually we realized we can't do our flight, our project is going to change.

I think what happened was we figured out we still have to observe Halley's comet, because nothing's changing the path of Halley's comet. What are we going to do? We aren't going to have this ultraviolet telescope in space to use to observe. So we replanned. I remember Ted Gull continued giving us funding, and we replanned to use the International Ultraviolet Explorer [IUE] telescope, which was an orbiting telescope that was managed and run out of Goddard. We replanned and observed Halley's comet with the IUE, and learned some new things about comets that we didn't know. That was a very satisfying and successful observing campaign that was really fun. We learned then from that that comets don't outgas uniformly.

Through another telescope spacecraft mission that was able to image Comet Halley from space, they were able to see the nucleus, the solid nucleus of the comet, and to see that it had jets in certain regions. We observed those jets also as the comet rotated. We observed changes and we saw the jets come like a beacon pointing toward us when we were observing. It got brighter and then it rotated away from us and it got fainter. We determined, as did other telescope astronomical assets determine, that comets have a nucleus, and that they are active only in local regions that are rotating around. We don't really understand why they're just outgassing these jets in different places on the surface. So that was a big change in our understanding of comets.

WRIGHT: I guess for you it was as if a whole new book opened up with that information, because you actually had the chance to observe it.

MCFADDEN: Yes. It was also fun because it was different physics too. The phenomenon that we were observing, it wasn't reflected sunlight off of a solid surface. This is ice that's heating up from the heat of the Sun, and it's in temperature and pressure conditions where it's not stable. The water breaks up into hydrogen and OH [hydroxide] molecules, then with incident sunlight it fluoresces and gives off light. That and a couple of other species give off this light at different discrete positions in the electromagnetic spectrum. It was fun for me to learn another type of physics, experience it, and that expanded my perspective and my experience as a scientist. That was really fun.

WRIGHT: That must be rewarding to be able to find a whole new way of doing things?

MCFADDEN: Yes. Exactly.

WRIGHT: Did you stay on at the University of Maryland?

MCFADDEN: No, I had a sojourn out on the west coast, because my husband finished his residency. He wanted to go into private practice and maybe do some research at the same time, but he definitely wanted to do private practice. We got into our car again and drove around looking for places for him to do his residency and a place where I could also work. So I started writing and phoning. This was 1987, '88, so there was e-mail, but I think I was still writing letters and calling people. We drove around.

There was a place he liked and a group that he wanted to practice with in San Diego [California], and I went to the California Space Institute at University of California San Diego and talked to the person there who studied the chemistry of lunar rocks. His name was Jim [James R.] Arnold. I showed up and I said, "I'm looking for a postdoc. Do you have anything that you need me to do?"

He said, "Oh yes." He said, "Yes, we need a scientist here. I'm starting an automation and robotics program, and I have some funding." He was always doing things that were a little bit different, trying to develop new techniques using automation and robotics to do distance, remote science. He had a computer programmer, he had a mechanical engineer, he had a colleague who was the visionary, the mindset of this. He said, "We need a scientist. Let's beta-test these techniques and do some science with these automatic intelligent systems." It was things like how do we send a robot to Mars and program it to pick up the right rocks without being there; use automation instead of the great expense and risk of sending a human astronaut there. Let's develop that.

That was fun too, but again what projects could I do? I still had some NASA funding for planetary science. I moved on from doing near-Earth asteroids, but I moved into another subset of the asteroid belt that I wanted to study, so I was doing some telescopic work. It was half my own funding from my own research grants and half this automation and robotics with a team which was really fun and something interesting to do. I did that for a couple years, and my husband got started in his practice. I had my second child out in San Diego.

We were in San Diego doing automation and robotics research, but again I didn't feel that I was making a big contribution. I had some ideas about how I could make automation and robotics advance our understanding of the asteroids, because that's what I was working on. Again I had freedom to develop a project using these new techniques of artificial intelligence and automatically reducing data.

This was before the day of databases. Databases were just starting. I do remember trying to put together all that we knew about the asteroids from our observations and to build an early database, but it was really flawed. In fact, I had started that at Goddard. Somebody tried to use the database, but I hadn't archived it properly, and it wasn't a clean database. One of my colleagues used it and ended up being embarrassed.

When I got out to San Diego, I wanted to use these new artificial intelligence approaches and automation, machine intelligence to still try and build a database that was useful and that would help us visualize the asteroids and the evolution of the asteroid belt. Again I didn't quite have the tools; they were still early on in the developing phase. I'd still wanted to do this, to do a video with what we knew about the asteroids from our data. But the database was sparsely populated, and so I couldn't make it useful to really address any of the critical scientific questions about asteroids, so the automation and robotics stuff came to a dead end for me. Then I had some personal issues. My marriage fell apart.

I was in San Diego in a department that didn't have a lot of planetary science as I knew it, and I had to make a move professionally because I couldn't stay in San Diego, didn't want to stay in San Diego. It was not the right thing for me and my family. Again I got on the phone and contacted my colleagues using my network. When I talked to Mike A'Hearn at University of Maryland, who I'd stayed in contact with because of our collaborations on comets, he said to me, "Lucy, why don't you apply to the National Science Foundation for a visiting professorship for women and come back to University of Maryland?"

I said, "Oh, what a great idea, Mike." I called the program officer and asked about applying for it. I told her that I had a personal situation and my family and I needed to leave the San Diego area. So she said, "Write a proposal. Submit your proposal. I'll take your proposal when you have it." She had it reviewed, and I was awarded a visiting professorship at University of Maryland.

WRIGHT: What a great opportunity.

MCFADDEN: It was a tremendous opportunity to come back to the East coast and work with a group of planetary scientists. Again, science had moved on in the process. I returned in 1991 or 1992. I was back in Maryland. I was on the east coast. My family was from the east coast. I was happy to be back here.

WRIGHT: Good ground base operation to go again, wasn't it?

MCFADDEN: Exactly. A lot of planetary scientists are in the area at Goddard and at Hopkins. It's interesting too. The project that Mike A'Hearn wanted me to pursue is still something that's related to the work I'm doing today. Yes, it was neat. He said he'd made some observations with the IUE, the International Ultraviolet Explorer, which had been decommissioned, or it was about to be decommissioned.

He'd made some observations of the largest asteroid, named Ceres. He and Paul [D.] Feldman observed Ceres, and I'm not sure what possessed them to do this, but they saw a signature of fluorescence of the OH molecule, which is very common in comets, but asteroid 1-Ceres is the biggest; it's 1,000 kilometers in diameter, it's the biggest asteroid in the main asteroid belt, the first one discovered. It's a piece of rock, it's not a comet.

He said, "What is this signal?" It was very close to the noise level. The signal to noise of this signal was not very high. He said, "We're going to use the Hubble Space Telescope and go back and make these observations again and see if we can get better signal to noise with a bigger telescope." Actually that's a difficult thing to do if you're observing something that's diffuse. Even if you have a bigger telescope and you are still at the Earth, you are not necessarily going to get enough signal because this diffuse stuff spreads out.

I was tasked with planning these observations to use Hubble, or Mike planned it and I was going to make the observations and go reduce the data. Today that's really significant because those observations were significant. We have a spacecraft in orbit today around the dwarf planet Ceres, and we know that there's a significant amount of water incorporated into this 1,000-kilometer-diameter dwarf planet. There's water in the interior, there's water ice on a few places on the surface, but that water ice is not stable at the temperature and pressures of Ceres.

It was Mike A'Hearn with his IUE observations observing the sublimation of water ice on the surface from Ceres; he published his results. With Hubble we tried to reproduce the results, but they made the wrong observations. They didn't offset in the right place. Then we went back to look at it again with subsequent observations and we didn't see any signal from this alleged dissociation of water from them.

That was the science project that brought me back to University of Maryland, but again it didn't pan out in terms of having great scientific results. We were left trying to extract signal from the noise. We ended up not publishing anything on that. That project didn't go anywhere.

So there were a number of starts and stops, but then it was 1993, and [Carolyn and Eugene] Gene Shoemaker and [David] Levy discovered this comet, Comet Shoemaker-Levy 9. They discovered this comet that turned out to be a multiple comet. It was in fragments, and its trajectory was headed on a collision course with Jupiter.

Once we realized that they'd discovered this comet was a multiple comet—fragments that were all out in a line, in a row, spread out. The metaphor was it "spread out like a string of pearls," and the world realized, oh my gosh, it's going to collide with Jupiter, and it's going to happen in the next—how many months? It was within the next year it was going to collide with Jupiter, and we said, "Oh my gosh, here's an opportunity to observe the inside of a comet and see what's going to happen to it when it interacts with Jupiter."

So we started a worldwide observing campaign. Mike A'Hearn and I had the good fortune to lead the coordination of that worldwide observing campaign, and that was really exciting. We held a couple of workshops. We brought in people from all over the country, all over the world to University of Maryland, and said, "Okay, this is something that's going to happen. We've never seen this before. What do we do? What telescope assets do we have around the world to optimize our knowledge of this phenomenon that's going to happen?"

We had two workshops, and people planned what they were going to do. NASA Headquarters funded it. Our colleague Jürgen [H.] Rahe [Director for Solar System Exploration of NASA's Office of Space Science] funded it, and people went out and observed it. Mike A'Hearn and I went out to Flagstaff, Arizona, I think, or maybe it was Tucson. We went out to Arizona and observed before it hit, took images of the different fragments.

Our planning was in the fall of 1993, then in July of '94 it started to happen. I remarried in March of '94 and was going on my honeymoon to Alaska in the end of June and early July. The fragments of Shoemaker-Levy 9 were hitting Jupiter just after the Fourth of July. It got huge press coverage, because it was a phenomenon that nobody had ever experienced in the solar system. It was the process of accretion. The press liked it. It was the summertime; slow news time in the summer. We could visualize it. We then had telescopes and we had digital images. There was press coverage of the event, and I ended up being one of the spokespersons for this whole phenomenon. I'd done my observing beforehand. Goddard hosted press briefings every day for the week during which all these 27 fragments were going to collide with Jupiter. Hubble Telescope was observing it. The Infrared Telescope in Hawaii was observing it, Canada, France, all around the world.

People would call. Gene Shoemaker and his wife were also involved in these press conferences; we have videos of all the press conferences in the archives. It was so much fun to talk about it. The press wrote about it for five days, it was quite exciting. That was just the phenomenon of it.

Actually one of my retirement plans is to review the literature, because if you ask me what did we learn from that phenomenon, what did we learn about comets? Well, gravitational tides can pull them apart, so they're not necessarily strong. But what did we learn about Jupiter from the interaction of the comet interacting with the upper atmosphere of Jupiter? I can't answer that question, so I'd love to go back and look at the literature and do a summary of what did we learn from Shoemaker-Levy 9. But that was one of the early highlights of my career.

WRIGHT: The whole global connection where so many people were interested in it—your network just kept getting wider and tighter at the same time.

MCFADDEN: And we had e-mail; that was early. E-mail connection, interconnected computers and the Internet really started in astronomy in 1987 for Supernova 1987A; 1991 was early coordination where the Internet really helped us, because we could communicate with people around the clock and we didn't have to do it on the phone. We could talk to multiple people and look at our e-mails at the same time. Again the technology was with us and the timing of the heavens, that comet happened to be at the right place at the right time.

WRIGHT: It is nice when a plan comes together when you didn't know there was going to be a plan.

MCFADDEN: That was very exciting.

WRIGHT: That is exciting. I'm sure you were already working on something else as well.

MCFADDEN: So now I'm trying to reflect. What was going on then?

I have to write proposals to fund my research. We're constantly writing proposals to these various NASA programs. You have to have a plan, you have to justify it and put it in the context of the decadal survey, which is what are our objectives and what do we hope to learn in the next decade, usually a decade and a half.

So I was writing proposals, but I was invited to participate in the Near-Earth Asteroid Rendezvous [NEAR] mission. That was a robotic spacecraft mission going to the asteroid Eros. I'm trying to think. How did I get onto that team? Did I write a proposal or was I invited on that team? I can't remember, but I was pulled in to be a part of Joe [Joseph] Veverka's team. He was a PI [principal investigator] from Cornell [University, Ithaca, New York], very experienced, had been on a number of missions, and he understood cameras. We had a camera with filters on it and a near-infrared spectrometer. That was my first opportunity for a real robotic spacecraft to be on the team of a mission.

I know Andy [Andrew] Cheng had something to do with that too because I remember him calling me when I was still in San Diego, and he was writing up a white paper and proposing this mission. He asked me something about near-Earth asteroids, and I think I was asked to join the team because my dissertation focused on the mineralogy of near-Earth asteroids and they needed my expertise.

That mission was managed out of the Applied Physics Lab [APL, Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland]. And, here I am—in the right part of the country, didn't have to move, all I had to do was drive up to APL a couple times a week. I kept going with University of Maryland with various projects. I'll have to check my pub [publication] list to see what I was doing then.

But the NEAR mission was a lot of fun too. You have a bunch of eager scientists; there were about 10 of us on the team with a good leader. Joe Veverka was a great leader, he was experienced. He gave us all tasks to do. We knew what our roles and responsibilities were. I have to admit I wasn't quite sure; I was young and a little bit insecure. I wanted to do everything, and I wasn't sure what I really could do, so I did feel internal frustration again.

What's my role? I participated in testing the instrument before it flew on to the mission. I had a hiatus in my funding, because I wrote some proposals to NASA to the observing program, Planetary Astronomy Program, and the Planetary Geology Program, and it didn't get funded. There was a time when I only had the NEAR Program funding me, which was half of my salary.

I tried to get more money from NEAR so they'd fund all of my salary, but they wouldn't do it, so I had to work part-time, because I didn't have my other funding to cover my full salary. My kids were in school. Luckily my husband had a job and we could still afford for me to do it. At this time, I was part-time, a stay-at-home mom, and got more involved with the kids' school. I went in and helped teach science in the schools.

I got involved in a nonprofit after-school program called Explore-It-All Science Center [Glen Echo, Maryland]. I was the vice president of that start-up nonprofit organization. I did that for a couple of years while I worked part-time on the NEAR mission, so I found something to do. It didn't pay me but it gave me new experience and I had more time to be with my kids. I didn't have to kill myself to prepare my lectures and do my research and get home with the kids. In the end it was a good time for me to sit back and give more attention to my kids.

WRIGHT: Reassemble your brain some too.

MCFADDEN: Yes. We had fun. It was a good time, but I wanted to get back to the NEAR mission because that had fun twists and turns to it as well. The team was a lot of fun. I met a lot of new people.

I do have one story that I want to tell about the NEAR mission. We were getting ready for the flyby to fly by and go into orbit around our target asteroid, 433 Eros. It was Christmastime, and something went wrong. The spacecraft went into safe mode just before it was supposed to go into orbit. This was 1997; we were supposed to go into orbit in early 1998, I think. The spacecraft went into safe mode. All the team got called in. It was December 23rd. I remember the image of everybody leaving APL, going home. We got called in in the afternoon, and it was like fish swimming upstream on a holiday weekend. We had to figure out what to do.

Luckily, one of the space navigators—the people that navigate in space who figure out where everything is and where everything's going to go and project the trajectory of everything based on the gravitational perturbations of every single little thing they know about in the solar system—this one guy had prepared. He figured out ahead of time; he planned for a contingency if something went wrong. He was able to work another trajectory. We were not going to go into orbit this year around Eros because the spacecraft screwed up [was off target]. It can go around the Sun one more time and come back and go into orbit next year.

He said, "We're going to fly by Eros, and we'll take pictures. We'll turn on the cameras as we fly by, go around, and come back next year." We did that. That was the first "uh-oh" moment. We got through that safely.

They did the mishap investigation and figured out what had happened. They turned on a motor and the impulse of turning on the motor had forced the fuel to slosh, to move around, and disrupt the equilibrium of the spacecraft. It lost control and was going all over the place, and then it used up [almost] all its fuel trying to stabilize it. We were lucky on that.

Then a year later we went into orbit and we did everything. We got to land the spacecraft, and we were celebrating. That was unplanned when we first set out, because that would have cost a lot of money to try and build a spacecraft that would land successfully. But, they were able to demonstrate and call it an engineering experiment to land on the spacecraft, and it landed, and it was great. We've got pictures of it.

So the team was out celebrating. We took the engineer out to dinner who had designed our camera that had worked so successfully. We were up in Laurel [MD] and we were having dinner at a big long table with all these scientists. We're sitting there having dinner, and over at the bar someone goes, "Yay." We hear this uproar and everybody's excited, and we look. We ask the waitress, "What just happened?" They're watching something on TV, and we figured it must have been some basketball game, and someone had just won or something. She goes, "Oh no, they were playing beer pong, and he just got the Ping-Pong ball in his glass of beer. He threw it in and he made it in."

Our engineer said, "That's nothing, we just landed a spacecraft on an asteroid that's 100 million miles away from Earth." We outshined that guy at his beer pong. Here we are celebrating that, and we all laughed. That was funny from the NEAR mission.

WRIGHT: Did you learn a lot of lessons? As you mentioned, a bunch of eager scientists, but yet you felt a little insecure when you started. There must have been lots of things that you came away with from that mission.

MCFADDEN: I was young. Well, I wasn't that young; I was in my forties. But I got really upset when everything didn't work well, and I didn't know how to reduce the data. I was trying to get a system set up where I could process my data. I didn't know how to do that, I didn't have the skills, and I got so frustrated.

Then I got angry, and I really had some crying fits with my team member. I remember talking with Joe Veverka, the team lead, and I said, "Joe, what is it that I can do? I can't do anything for this team." I said, "I don't think I should be on this team." I was that insecure. He said, "Oh, come on, Lucy. You are part of this team. That's ridiculous."

I still felt like, "What is it that I'm contributing?" Other colleagues were processing the data and doing all this fancy image processing, and then they got to be the first authors on the paper. I was saying, "Well, wait a minute. What can I do so that I get my piece, so that I could be first author?"

All these other guys who came in, and when they started I didn't think they knew that much, and then they all left with these first author papers, and it seemed to me that they got all the credit. But really we were a team, and the team got the credit. I did contribute in our discussions, discussing the results, and deliberations. I did my part, but I still wanted to be out front, and I didn't really have the skills to be out front.

Lesson learned—I always wanted to learn things quickly, and if I didn't learn things quickly, I would give up. In hindsight, I even analyzed it. I've got to go practice my image processing techniques. I said to myself, "Lucy, it's like learning to play the piano. You have to play it every day. You have to do it every day and you'll get better."

I didn't get better fast enough for myself. I got frustrated. Well, I hired some young students to do it, so that really helped. I knew what needed to be done, so I was guiding these undergraduate students who had the tools and knew how to do the programming. I didn't have the patience for it. I wanted the answer at the end. That was realizing my personality and what my strengths were, and then getting the resources so that I could hire people who could do the actual coding and make things work. Then I would make sure that they did it right and review with them what they did, and then we'd go forward together in analyzing the results.

WRIGHT: So it set you into a new segment of your life, looking at yourself as not having to do all those pieces.

MCFADDEN: That's right. Yes, but I still beat myself up for not doing all those pieces. Why didn't I free myself from that and realize that I was growing up? I was maturing in my discipline, and I didn't have to be like a graduate student or a postdoc who has to do everything themselves. I don't know, but I still pursued new opportunities, taking on new roles.

At the beginning [of this interview,] I said I'm really surprised that I'm still doing my whole career that was started when I was an undergraduate. In reality, I've done different things within my career that have taken me in different directions: being the spokesperson for the Shoemaker-Levy 9 events; having young kids in elementary school, and having that time when I wasn't funded completely when I went off and started a nonprofit science center for science education that gave me experience in another direction of the science education and public outreach, which emerged as a new field at NASA and across the country at that time; recognizing the value of inspiring students to pursue careers in the sciences and technical fields.

On subsequent missions I ended up developing programs for Education and Public Outreach. On the next mission after the NEAR mission, the Deep Impact mission, I had responsibilities and was the lead for the Education and Public Outreach Program. So that was another chapter.

WRIGHT: It's groundbreaking in itself that you were able to pull those together.

MCFADDEN: Right. It was fun, because I did build a program. NASA in its wisdom required that money, that 5 percent of the budget be put into education and public outreach. I'd had the public outreach experience; I was an educator, because I was a research professor at University of Maryland; and I wanted to do it.

Having kids in school, I saw how important the science education was, so that was a good time for me to do that. I could still do some research, I was still doing research, but it wasn't 100 percent research. It worked well. I had a new role to play in another very exciting mission, the Deep Impact mission, which was really great.

WRIGHT: Talk about that one, because it was. It's amazing.

MCFADDEN: The Deep Impact mission. Just last week [May 29, 2017], we lost the PI [Michael A'Hearn] of the Deep Impact mission.

But the Deep Impact mission, that was the first mission that I started on from the beginning, from the proposal phase through to its completion. Remember I said that on the NEAR mission I couldn't remember how I got to be on the NEAR science team? The Discovery Program was starting. The NEAR mission was the first mission in NASA's Discovery Program, which is low-to-medium-cost missions for solar system exploration.

I was asked to participate in the proposal writing of a mission called Deep Impact. Mike A'Hearn, my colleague at University of Maryland, was leading that, and it turns out that he was part of a triumvirate, three cometary scientists, who had this plan of proposing different missions related to comets at different times. They'd been taking turns leading different proposals.

Mike A'Hearn, Mike [Michael J. S.] Belton, and Joe Veverka were the nucleus of this, and Mike A'Hearn asked me to develop an Education and Public Outreach Program. We had videoconferences from University of Maryland with the Jet Propulsion Lab building the proposal. Again I remember being frustrated and bursting into tears because I didn't know where to go, and I was so anxious about what to do; it was brand-new. Again Mike A'Hearn talked me out of it, as did all of my colleagues who've talked me through my bursting into tears and frustration throughout my career.

We ended up developing a really strong education and outreach program, and I got a big promotion that year because Mike A'Hearn told me that he felt my Education and Public Outreach Program was part of the reason that we got selected. That was the first time I'd gotten a salary increase because of the money I'd brought into University of Maryland, or my role in bringing in a significant project to University of Maryland. So Deep Impact was a lot of fun.

We had a lot of technical challenges figuring out how the spacecraft would hit the comet and figuring out how to target it. It was a pair of spacecraft that were to fly by a comet. One [of the] pair would be slightly ejected from the mother ship. One of the spacecraft would get an impulse from the mother ship, which would continue to fly by. The impactor spacecraft would be on a collision course with the comet. The comet would run into it while the flyby spacecraft took pictures of the impact and learned about the interior of the comet by looking at the debris that comes up and looking at the spectral signature of the debris that's ejected from the comet.

Boy, I sure have had a lot of exciting things in my career.

WRIGHT: You have. That's just imaginative. Then you made it all work.

MCFADDEN: I know, and it all happened, I know, so teamwork again. Meeting after meeting. Budget cuts, slowdowns, cancelations. I think I went and worked part-time again because we had a budget cut, and I said, "Okay, I'll do my part and I'll cut the EPO [Education and Public Outreach] budget." I cut my time. There were a couple of months of doing that again.

We scheduled it [the Deep Impact collision with comet Tempel 1] to happen on the Fourth of July. We were at JPL, and this was 2005. By this time, we had a big wall projector and the images were going to come back and be projected on the 18- or 20-foot tall wall. We knew when it would hit. The science team was in one room. We all had plans of what we were going to do when the images arrived, because we had to get ready for a press release. Everybody had a job. I had a research assistant back at University of Maryland who was going to put together a movie of the images. We had colleagues at Mauna Kea ready. Karen [J.] Meech had coordinated a ground-based observing campaign.

We knew when the spacecraft had hit, because we stopped getting signal from the impactor spacecraft. But we had to manage the light travel time from Comet Tempel 1 to the Earth to get the images back that this flyby had taken. It was a seven-minute travel time. All of a sudden on the screen, this image popped up with this big bright splash of light. It was like a beacon from the impact site, and it had saturated the cameras. We had prepared for and were expecting to see like a geyser come up and debris would fall back to the surface. We didn't expect the cameras to be saturated.

What we saw was so spectacular that I just stood there like a deer in headlights. Everybody else was jumping up and down, and I couldn't jump up and down. I said, "Oh my God, what's that? What do we do next?" I got on the phone and I called back to my research assistant, who's now a writer for *Science News*, and I said, "Chris, do this, do that." I was babbling instructions to him. It was Christopher Crockett, and I was babbling instructions to him. He knew what to do, and he was sitting there saying, "Yes, yes, yes." I finally realized I had to stop talking.

Then another one of my colleagues called from Hawaii, and he was at Mauna Kea, and he too was babbling. He said, "Lucy, you've done such a great job on this with the public outreach, and this is just spectacular, and this is going to be great. You really did a good job." I said, "Uh-huh, okay, Carey [M. Lisse], thank you. Okay, get back to work. What do we do now?" I don't really remember what I did. One of my colleagues had to step outside and get some fresh air. It was an amazing experience.

It happened at eleven o'clock at night and we had a press conference early the next morning, and I'd decided that I didn't want to stay up all night. We had people working on the east coast; they could work and get us stuff for the next morning. I decided to go to the hotel and get some sleep. But my colleagues Jessica [M.] Sunshine and Mike A'Hearn, they stayed there; they stayed up all night and went to the press conference the next morning. They sort of said, "Lucy, why didn't you stay?" I said, "I decided that I would be better off to get some sleep."

Then we were there at the press conference. Actually maybe before I went to sleep we had a press conference and then we said we'd come back in the morning. I remember at the first one they said we had one image to show. I was listening to the Chief Engineer reporting it. We were looking at this image, and I just started crying. It was just, "Oh my God, it actually worked." All this, culminating in one unexpected image and I just let go and cried.

I heard the engineers talking, because it was their responsibility to target this thing, and we were worried about dust particles knocking the spacecraft off course and changing it. I just started crying, and it was great. It was joyful tears that it actually worked. That was amazing.

WRIGHT: It ends up almost being like a labor of love. The fact that you gave up your pay to keep the project going. It became a passion more than just a work project at that point.

MCFADDEN: Yes. I realized I was very fortunate, that not everybody could afford to do that. I could still make my mortgage payments. I was fortunate.

WRIGHT: It was rewarding in a lot of different ways.

MCFADDEN: It was. Yes. Then the next day after the next press briefing, one of my education and outreach coordinators working for me had arranged to get Bill Haley and the Comets to come to JPL and perform, so we were dancing. The next day I was doing the jitterbug with [JPL Center Director] Charles Elachi the day after the Deep Impact spacecraft hit Comet Tempel 1.

WRIGHT: How fun.

MCFADDEN: So yes, that was fun.

WRIGHT: He probably remembers that too.

MCFADDEN: I remind him every time I see him. Yes, the adventures.

WRIGHT: But as you mentioned, you were always working on proposals. So were you putting this one off into history, and working on the next one?

MCFADDEN: Yes. I'd been invited to participate in the Dawn mission. I'd worked on the Dawn proposal from the mid 1990s, and the Dawn mission wasn't selected until 2002. We proposed a couple of times and it wasn't selected.

I was a Co-Investigator on the Dawn mission as well. I was in charge of the education and public outreach for that mission too. I had a graduate student [Jian Yang Li] who was working with Mike A'Hearn and myself who was doing photometric studies of comets and asteroids. He was doing work that was the precursor to the Dawn mission, studying asteroids Vesta and Ceres with Hubble Space Telescope to determine its photometric properties, which would allow us to set the exposure rates for our spacecraft images for Vesta and Ceres.

So again, there I was supervising. Mike A'Hearn and I were both supervising this graduate student then, a graduate student named Jian-Yang Li. I was writing proposals to use Hubble Space Telescope to observe Vesta and Ceres. I was successful in that and was funded by Hubble Space

Telescope for that work. As Deep Impact was finishing up, Dawn was ramping up, and so that was a smooth transition.

But again here, lesson for future scientists—trying to find your niche and lay claim to the work that can be done. With the Deep Impact results, what did I want to do? Again there were people in there that were quick and had tools and techniques that would allow them to find the scientifically interesting and active areas of science. I said, "Well, let me take my knowledge and go make sure we use all of our data." I was looking for images around the comet of CN emissions, the carbon-nitrogen molecule. I was trying to make a map of the distribution of CN, but there just wasn't enough signal, the data were too noisy, and the chemistry wasn't right.

I still had work that I presented at meetings, and I had a draft of a manuscript, but it's not complete. Mike A'Hearn and I couldn't really make something out of it that was really publishable—that's on my list of postretirement things, to go back and revisit, to see if there is anything that can contribute to the literature in this unpublished work. But I finally had to give up. I'd say, "Okay, I've spent enough time on this. This is what I've done." I was really annoyed because I thought I was seeing signatures of something, and it turned out to be an artifact in the camera. Because there was not very much signal, it was enhanced, and it was in the background. It was teapot-shaped, and I was saying, "Is this a halo of something? Is this something being ejected and falling back on the surface?" No. It was scattered light inside the instrument.

Again the lesson to people doing science is you really have to understand the instruments that you're working with. I didn't have the patience to get down into the nitty-gritty, but thankfully there were people that do.

WRIGHT: I'm going to sidetrack you just a little bit before we go on to your other projects and trips. Talk about how the instrumentation and how much it's changed since you first started with the technology, and how that's impacted how you've been able to accomplish what you've done.

MCFADDEN: Oh, absolutely. I think people's scientific careers are driven by the technology. That's why our engineers are so important to us. That's one of the fun things I did when I was at Goddard, work with engineers trying to improve the technology for the future.

My dissertation used techniques called photomultiplier tubes, and these were before the silicon detectors. I remember I was interviewing for a position at Hubble Space Telescope, just after my PhD, and they said, "Why didn't you use a silicon detector, CCD [charge-coupled device]?" Which is the same detector that's in our cell phones now. They said, "Why didn't you use that? Why did you use this older technology?"

I said, "Well, the CCD technology was just being developed, charge-coupled device technology was just under development, and I wanted to get scientific results. I knew the photomultiplier technology could give me the results. I was observing bright enough objects and I could get my results. I didn't want to deal with the uncertainties of a new technology." That was the answer to my question. I took the safe route to get new information for my research.

Then these CCD detectors did develop. In fact, for Deep Impact we used these same CCD detectors and it was a large format. It was 1,000 by 1,000 pixels. We had problems purchasing it for our instruments in 2000. The technology for cell phones was so much more lucrative, digital cameras and then cell phones, the manufacturers weren't producing these 1,000-by-1,000 CCD arrays with the sensitivity that we needed for low light level detection. We had a hard time getting somebody to manufacture this for such a small and limited use.

I thought that was interesting that the digital technology was driving this, and that the space program couldn't get what it needed except at a big cost. It was very expensive, because it had to be clean CCDs, and we had to know how every single little chip responded.

WRIGHT: It's interesting. I think one of the cell phones today, its big selling point is low light detection.

MCFADDEN: They are. Right.

WRIGHT: So here you are, so many years ahead, but still not having what you need.

MCFADDEN: Right. Then by the time it flies, because it takes five years to develop it, you have to test it. "Fly as you test and test as you fly" is the mantra. It just takes a year. There's no mass-producing a spacecraft, so what gets flown is not necessarily the latest technology.

In fact, it's interesting because on Deep Impact that spectacle of the comet with this big bright saturated spot like a bull's-eye on the side of the comet is a spectacular picture, but you don't see many copies of it anymore, and the reason is that we couldn't [enlarge it]. We only had 1,000 by 1,000 pixels. I go to Dulles Airport and they often have pictures from Mars and planet pictures, great solar system exploration exhibits. Where is my Deep Impact [on display]? That was really spectacular. Hitting a comet that's moving at 23,000 miles an hour and hitting it with another spacecraft is really pretty spectacular. The results, the images are spectacular, but you can't blow them up, because then you start seeing the pixels, and it doesn't look good.

It was the most spectacular thing that a NASA mission had ever accomplished, but because of the limited technology—I still question now whether someone could somehow improve the resolution [using digital reconstruction].

WRIGHT: Add that to that postretirement list you have that's long and growing.

MCFADDEN: Exactly.

WRIGHT: Because I don't want to take up all your morning, let me ask you about your adventure to Antarctica. It's very interesting for most people because that's not a place where most people get to go. Were you there a year? Or just on the project for a year?

MCFADDEN: Oh, no, no, no, no, no, no, no. Let's see. I went to Antarctica in 2007. After Deep Impact, that was a big high, and then there's a letdown. Also my kids went off to college after Deep Impact. The Dawn mission was coming. I had something coming up, but we launched the Dawn mission in 2007. So what am I going to do? I was trying to find new things to do at College Park; I had been the director of an undergraduate program there.

I was on a mission review panel and I met the scientist who runs the annual expedition to Antarctica to search for meteorites for the U.S. I was talking to him, and I started telling him the story about when I was a graduate student with Tom McCord, and I'd heard about these discoveries of these meteorites in Antarctica. This was in the early '80s and I had said to Tom McCord, "I want to go do that sometime." Tom laughed and said, "Ha, by the time you finish your dissertation, they will have found all the meteorites in Antarctica."

Here it was 2005, maybe 2006, and this guy had been going there every year, and the antarctic meteorite collection is a treasure trove. It's a national treasure, bringing us samples from the solar system back to Earth for just the cost of sending scientists out to live on the ice and ride snowmobiles for eight weeks every year in the Antarctic summer. So I looked at him and I said, "Ralph [P. Harvey], I can now go to Antarctica. My kids have gone to college and I'm in between missions. How do I go to Antarctica?"

He said, "Just send me a letter expressing your interest. Send it through the U.S. mail. Don't send me e-mail." He said, "If people are serious, they'll write a letter. They'll put it in an envelope and put a stamp on." So I did that. Then he invited me out to Case Western [Reserve University, Cleveland, Ohio] to give a talk about the Deep Impact mission.

He interviewed me and I said, "I want to go because I want to go look for a sample from asteroid Ceres, which I'm going to be studying in a couple years in the future." I got selected to go do that, and that was quite an adventure too. That was really fun. We find meteorites as a team, but the first one I found was a carbonaceous chondrite, and I was really excited. Maybe I found the meteorite from Ceres, but there are no samples on Earth from the asteroid Ceres, from the dwarf planet Ceres.

Wow. This morning [when we started] I thought I wouldn't be able to talk for two hours.

WRIGHT: We're not through yet, so hang in there. Also, you went to northern Sudan to look for meteorites there too.

MCFADDEN: Yes. That was another trip.

Then I was at a meeting one year—the Division for Planetary Sciences meeting in Puerto Rico, and they arranged to meet people who were arriving in San Juan at the airport. We took a bus out to the remote location where the meeting was being held. Everyone thinks we have meetings in exotic places, but the fact is we have meetings where someone wants to host us. We try to go to different parts of the country so that people don't have to travel from all over. We were hosted by the Arecibo Observatory, [Arecibo, Puerto Rico], which is in Puerto Rico, and it was a domestic destination. We were at a resort, where we get good rates.

We're riding in the bus, and I met some colleagues who were reporting on an asteroid that had been discovered in 2008. When they discovered it—this time it was an asteroid not a comet—it was on a collision course not with Jupiter but with the Earth, and so they launched an observing campaign to observe the asteroid. One guy was a member of a meteor association.

This was an asteroid and it was going to break up in the Earth's atmosphere due to the pressure of the Earth's atmosphere. Then, fragments were going to land and hit on Earth. They knew where it was going to collide. There was a meteorologist for KLM Airlines, and he got permission to notify the pilots who were flying south from Amsterdam to Africa to watch for the impact, because when it interacts with the atmosphere you get light emission again.

Darned if these pilots didn't see it. The pilot had his heading; he knew how to give the heading; he knew exactly where he was flying; he was prepared to look for it and say, "It's so many degrees off of my heading." They knew exactly where they found it.

This other crazy scientist—we really are crazy—he said, "Okay, I want to go out and find this meteorite." Over the Sahara Desert, it broke up over the Sahara Desert, and he's going to go out into the Sahara Desert and go look for it? That's a big place.

They'd gone out and found meteorite fragments, and they were reporting at the meeting. I was talking about my Antarctica experience. They said, "Lucy, we're doing another expedition, why don't you come with us?" I said, "Okay. I know how to look for meteorites," because I'd found meteorites on the ground. We found 700. I can't remember if it was in Sudan or Antarctica where we found 700 in our eight weeks there. So I said, "Hey, I'm experienced. You need me on your team."

I went to Sudan. I didn't know much about Sudan, except I knew that there was a war in Sudan. Then I said, "Yikes. If it lands in Sudan, this country at war, and they see something exploding in the upper atmosphere, they're going to be freaked out." Then I was concerned. But what do I do?

They'd already made contact with a professor at the University of Khartoum [Khartoum, Sudan] and they had gone out and found it. Again I did a risk analysis, because I'd been in Antarctica and safety is important. I did my health check, and I learned that we had no embassy presence. There was no ambassador to Sudan, but there were people at the Sudanese embassy. I talked to them. I asked for advice on what to wear, because I knew I was going into a Muslim country. I was really frustrated because they wouldn't give me advice, and they said, "Oh, I can't tell you what to wear," so I had to decide on my own. I decided to wear long skirts and be covered. I did buy scarves to cover my head, because when in Rome do as the Romans do, so I had scarves and covered my head, and I went on the fourth expedition.

God, it was a great experience. We were with 50 students from University of Khartoum who were physics and geology students. We had a workshop for the first couple of days where we'd been presenting the results of the previous expeditions. I'd read up on everything. These students were excited. They were part of history. The students, they were all dark-skinned, there were an equal number of men and women in the classes. The women were so excited that there was a woman scientist. There was a woman teacher there. In fact, the dean of the college was a woman, so there was pretty much parity there. I had a great time. They hosted us terrifically.

I was at University of Maryland at the time; then I'd applied for my position at Goddard, and I was waiting to hear if I was going to be offered a position. I went to Sudan, I had to do something to kill time. It was a 10-day trip or maybe a little bit longer, and it was a great experience. The campus, the physics lecture hall there, it was the same design as the physics lecture hall at University of Maryland, so it had this British influence. It was a theater style lecture hall with seats on a ramp and students sat in there. The students asked the same questions; this was what amazed me—the students asked the exact same questions as the University of Maryland students.

Their questions to me as a scientist that were very naïve were curiosity-driven. I even talked to one of the teachers. I said, "How can a student who's in physics ask me whether or not the elemental abundance of these meteorites, whether it's the same as Earth or different, whether there'd be different elements found in there as Earth?"

He said, "You know, Lucy, that particular student has not yet studied quantum mechanics, and the nucleosynthesis, the formation of the elements, tells us that all elements form. They exist everywhere in the universe, because of this nucleosynthesis process." He could explain to me why she wouldn't be asking that question next year after she takes this course.

It was really fascinating, and I loved them. They're all my friends on Facebook today. In fact, I wonder what do people think when they go to Facebook and see stuff written in Arabic. I use the translator, and the translator is not that good. I'm not sure what they are saying, and it's sort of fun. I am still friends with two of them who have gone on to study. One [Mahadia Ibrahim] is in Canada studying. It breaks my heart that she can't come into this country now because she has family here, but we'll go to Canada and visit with her.

Then another physics student from there came to the United States, and he wanted to go to graduate school in physics. He got a master's from South Africa; he came to the United States on a special visa for his political safety, but he's a physics student. He wanted to go to physics graduate school, but I don't think he got in. He's now working for a cell phone company in client relations, setting up cell phones for people. But he's here in the United States. I haven't seen him for a while, but I have to go see how he's doing.

WRIGHT: Hopefully he'll continue pursuing.

MCFADDEN: I don't know, I think he's missed his chance. He just didn't have the same background and he wasn't competitive enough, but he does know physics. He should be teaching physics to somebody else somewhere at least. [Note added in review, this student, Mohammed Elmufti was accepted into two graduate physics programs in the fall of 2017, so his persistence and love of physics has paid off.]

WRIGHT: You did come back here, in 2010, to Goddard, where you had a postdoc many many many years ago.

MCFADDEN: Right. Circled back.

WRIGHT: From what I understand you returned to lead the higher education programs. What did that entail? Why were you now very open to doing even more of that?

MCFADDEN: I didn't want to keep writing proposals. I was writing proposals, and I never could get any work done. I wasn't publishing. I didn't feel productive. It was just a constant treadmill of writing proposals, and I'd had enough of that. I investigated in starting some other programs at Maryland, education programs, but that didn't pan out. This job came to my attention by reading it in my geology newsletter. They were looking for someone to lead the higher education program, which involved running NASA's internships and NASA's postdoc program at Goddard.

I'd been teaching, I loved working with students, and I love enabling students. I'd hired a lot of students, they did research with me and they made contributions to the field of planetary science. We did science together and published papers together. A number of my research assistants had gone on to graduate school. They were undergraduate research assistants and had gone on to graduate school. I thought running NASA's intern program would be great, so I applied for it.

The same with the postdoc program. I'd get to work with undergraduate interns and postdocs. I thought what's better than that, and I know Goddard because I'd been here. I applied for that job, but it always takes a long time for anything to happen. I applied and I had to wait for months before I got an interview, and I got interviewed after I came back from Sudan. Then, I waited some more, and I was offered the position and negotiated the position. I started March 14th, 2010. That was a lot of fun.

I came in knowing what I wanted to do, it was fun, I was eager, and it was a good, challenging, very different time. I learned what it was like to be an administrator. I ran that program for a couple of years, I think three years, till 2013.

WRIGHT: You continued—or went back to, or I'll let you fill in that phrase—with your research activity as well.

MCFADDEN: Yes. Then I had an opportunity to resume research full-time, because I was also on the Dawn team. It was half-time on the Dawn team; we were getting our data. Dawn went into orbit around Vesta in 2010, and I wanted to focus on my research. The administrative stuff was hard for me, a lot of process. It was painful, I didn't like it, and I wanted to focus on the research.

So I was transferred into the Planetary Systems Laboratory at the same time, where I could focus on my research and write papers. I remember meeting with my supervisor Keith [S.] Noll, and I had to do a performance plan. I said, "Okay, I'm a co-I [Investigator] on this mission. I've got data coming in. I'll be publishing papers." He says, "That's all you have to do is just publish papers. Focus on that." But he also needed me to help with these studies we were doing for future missions.

He was involved in a number of different mission planning and development projects, and I had knowledge of the asteroids. The team of scientists and engineers who design missions in Goddard's [Integrated] Mission Design [Center] lab needed my knowledge of asteroids and instruments [imagers and spectrometers] to plan future missions. In the Mission Design Center, the engineers come to the scientists and say, "What are your science requirements? We'll build you a spacecraft that can do what you want, but you have to tell us what your science objectives are and work with us to ensure that both spacecraft and instrument payload are designed [by the engineers] that will provide the right data to answer your questions."

I had never before worked on a mission from its earliest phase, before it becomes a proposal. In my last three years at Goddard, I participated in developing the seminal stages, doing feasibility studies of missions that are going to happen in the next decade and next two decades. It was a great capstone to my career to have the opportunity to be at Goddard where I could work with the engineers, where we have this laboratory for mission planning and doing feasibility studies. I didn't have to do the calculations because all the engineers do that and know what their capabilities are and there are financial experts who cost it [though both scientists and engineers check and negotiate the processes that ultimately impact the costs]. I participated in a couple of mission studies and a big proposal effort too. That was a great way to cap off my career.

Now in my emerita status, I'm available to mentor young scientists if they want to be mentored, and our program needs to be a little bit more active and aggressive. Not aggressive, but just more active, because I'm happy to talk to people, but they don't stop by my office. So if I'm going to do that successfully it has to become a little more active.

I'm finishing up the Dawn mission that is in orbit around the dwarf planet Ceres, and I'm coauthor on papers. I finally decided last fall that I wasn't going to take the lead authorship on new papers. I found a postdoc who needed the first author publication, and I turned it over to him. I'm now working with him, getting that finished up. I'm transitioning off into enjoying this wonderful spring early summer weather that we're having this year in the Washington, DC, area.

WRIGHT: And definitely setting a whole new team of students towards a career like you have had. Who knows what the technology and the funding will bring for them?

MCFADDEN: Absolutely. I participated in interviewing a new hire just before I retired, and it was so fascinating to listen to her [talk about] the whole exoplanets [area], other planets around other stars. I asked her questions, and I had to keep the interview questions on things related to the interview, but I said, "Wow, this is really fascinating. I want to ask you about how we're using these techniques to study planets around other stars." I realized, here I am—I'm retiring so that somebody else can come in with a new perspective, using new tools, and moving our boundaries of knowledge forward. That was fun.

WRIGHT: Your excitement doesn't stop, it just shifted once again. I want to ask just a couple quick ending questions. You mentioned so many things that can be challenging, but what did you find to be the biggest challenge as you went through your career in life? Funding, technology, juggling projects? Or was it the known unknown? If you had to look back and think, what was the biggest challenges that you were able to overcome?

MCFADDEN: The ones I could overcome? I was thinking of the one that I didn't overcome of being able to do computer coding!

But no, I think challenges that I overcame—well, we overcame challenges as teams. Both of our teams. Every mission has huge technical and financial challenges as well as dealing with people—people have deaths in their family and you have to cover for them, or something else happens to somebody. There are challenges all over the place, but it's being part of a team and having a good team leader who motivates the team to do their best so that they all have a role and do what they do well, so that we move forward as a team and move our frontiers of knowledge forward.

It's making sure you're working with the right team. If you're not in the right team, take action to find another team.

WRIGHT: That works better.

MCFADDEN: Yes.

WRIGHT: When you've met these students or other team members, coinvestigators, what do you note as leadership skills, what are you looking for that you know will be a good team to be on, and as a leader yourself?

MCFADDEN: The longer you know people, the more you recognize your shared values. It's interesting, because it's really hard to identify those values. A lot of them are unspoken. I don't know; it's just a feeling of comfort. It's our shared passion for the solar system and the results that we get and the knowledge, the new things that we learn, and then over time looking back to see how our perspective has changed in time or what's the same and what's different. It's basically our passion. We have the same passion for things.

But then you have to get to know them as people and understand where they come from. Then when things happen to them, like they have kids or they get divorced or they lose a parent or family member, all of that really does help you to recognize that they are people. You get to know them and interact with them on levels in addition to our intellectual scientific pursuits. The longer you get to know people, you get to know them in different ways, and appreciate them for who they are, because they may be very different than you. That's the thing. The differences are what makes the team work better. It really is, because if we were all the same we wouldn't be able to do these complex projects.

It's fascinating. The best part, my years here at Goddard, I had the opportunity to have executive training that taught me, that gave me an opportunity to study or to be a student of these functioning groups, the psychology of functioning groups, highly functioning teams. That's been a real opportunity. That was also my last new set of knowledge where I've opened up my eyes to a new world, so that was really fun.

WRIGHT: What are you hoping that these students that you're leaving behind or those whose lives you will be touching in the next years, what are you hoping that they find that you found as you went through your career? What's the hope that you hope that they have, or the vision that they have?

MCFADDEN: Not everyone has a vision. I hope they will find something that satisfies them and take initiative to find the life and work that they find satisfying and can make a contribution to. I know that not all of the interns that come here—there's only a fraction of them that end up going into something that vaguely resembles the space program, but their experience is valuable. We are contributing to a nation that can do amazing things. They are just different things that we haven't thought of. So guaranteed, they just have to keep their eyes open to things that they don't expect, because their world is going to be so much different than what I think my world would be or what I think their world would be.

WRIGHT: You mentioned earlier about going to Hampshire College, about the value of independent study. Do you still after all these years feel like those were lessons that you learned back then that you applied over and over?

MCFADDEN: Oh, absolutely. Yes, and taking initiative, and making connections, and saying, "Let's go do this and let's go do that." It was definitely founded in my education at Hampshire College, yes. I'm on the board of trustees there now, so I'm still connected with Hampshire College.

WRIGHT: That's exciting. It's great for you to be able to give back. Before we close, I wanted to ask you about international partners, because you have done a lot of work with those. How you were able to do that? I know you have a common and a shared passion, but at the same time you have different types of barriers that you mentioned.

MCFADDEN: Yes, but that's really important too. With the Deep Impact mission, all the instruments were made in the U.S. We had some international collaborators but it was a lot simpler if it was all U.S. However, the Dawn mission works because we have two instruments, one built by our Italian colleagues and one by our German colleagues. We couldn't have afforded the mission without those contributions. We have weekly telecons where 100 people from Hawaii to Berlin are on the phone at the same time.

We get together at professional conferences that happen throughout the year. Then we have team meetings, and it's very important to get to know, to spend time with people and to work with them side by side. At these meetings we get together and we spend four or five days with them working side by side, and we also take some time to have meals together or go to a science museum, doing something that's related to science. We went to the Berlin Air Show. We tie it into seeing the technology, but it's very valuable to have that time to get to know people as people. Then when you work together on a mission for a decade they become like your scientific family. When missions are ending it's bittersweet, but we've made lifelong friends around the world.

WRIGHT: Yes, and a great, shared knowledge. Thank you for your time this morning. I appreciate it.

MCFADDEN: Thank you.

[End of interview]