NASA Discovery and New Frontiers Oral History Project
Edited Oral History Transcript

David J. Lawrence
Interviewed by Sandra Johnson
Maryland – January 12, 2024

Johnson: Today is January 12th, 2024. This interview with David Lawrence is being conducted for the Discovery and New Frontiers Oral History Project. The interviewer is Sandra Johnson and Dr. Lawrence is in Maryland today and talking to me over Microsoft Teams. I appreciate you taking the time out of your busy schedule today to talk to me for the project.

The first thing I want to talk about is to have you briefly describe your education and background and where or how you first became interested in planetary science.

Lawrence: My education and background, I'm a PhD physicist and my interest in space started when I was very young. I was born in 1968 and grew up on the Apollo Program. As a kid I wanted to be an astronaut, and interestingly over the years I met many colleagues, people that wanted to be an astronaut. Most of it doesn't happen and that's okay. But I was four years old when Apollo 17 launched, and the silly thing is, and I think my parents will forgive me for saying this, it was a night launch, I wanted to see it, and they made sure I went to bed instead. I know, crazy.

When I was a kid, I wrote to NASA asking for materials, and this was a time when NASA sent a ton of information. They sent drawings of the spacecraft. They sent nice glossy photos. I had this whole collection of Apollo memorabilia that all came from NASA. It was fantastic.

One of my challenges is my eyesight is bad, so I wasn't going to be a test pilot. The advice I received was to go be a scientist. My father is a physicist. That's sort of in the blood, and so that's the direction I went. "Maybe you can be a scientist and be part of some of the missions," I was told.

Just as part of this history, one story that I think is neat, and this doesn't have to do with Discovery per se, but this happened when I was an undergrad Physics major at Texas Christian University [Fort Worth]. I grew up in Albuquerque [New Mexico] and all the summers I went home to Albuquerque and I was doing an internship at Sandia National Labs. I think the year was the twentieth anniversary of the Apollo 11 landings and I'm in this science lab doing work, thinking about being an astronaut, and I'm the kind of person to cold-call people. I knew Jack [Harrison H.] Schmitt was from New Mexico, member of Apollo 17, and I thought, "Hmm, I wonder if I could call him up and see what he has to say about what it takes to be an astronaut." I don't recall the details but he had a consulting business. I think his number was in the phone book. I called him up and he answered the phone. Amazing! I thought wow, this is incredible! Maybe I'll get 30 seconds with him. I gave my spiel and said, "I want to be an astronaut. Do you have any advice?" He says, "Sure, let's go to breakfast."

JOHNSON: Wow.

LAWRENCE: We went to breakfast in a location in Northeast Heights, Albuquerque, and we sat and chatted for about 2 hours, and he paid for breakfast.

JOHNSON: What an honor.

LAWRENCE: Yes. Since that time, I've gotten to know Jack quite well over the years. But what a thrilling thing as a young student; he was just so open and so kind. One of the pieces of advice Jack gave me is yes, go do science, go do space science, and "definitely work with NASA, not for NASA." I think part of that is there's a lot of bureaucracy associated. And when I look at my career, that's what happened. I can't say it was totally planned out that way, but he definitely encouraged me getting into science, getting your hands dirty and all that kind of stuff.

That was one of the points in my young career which is very memorable. I will get back to Jack in a bit. But then I finished my undergrad in Texas and then I ended up going to graduate school at Washington University in St. Louis [Missouri]. I was looking for schools that had space science type of programs, and Washington University in St. Louis was a great experience. One of the things they are really good at is once you get in, they make sure you finish. They do everything they can to help the grad students thrive.

I joined the high-altitude ballooning program. This is a group at WashU that did cosmic-ray research, and what they do is build really big detectors and put them on high-altitude balloons and fly them to get your data. One of the great benefits of that program was it was very hands-on; we built everything. This is a big difference from when you start doing spaceflight builds. In spaceflight builds, grad students don't touch the hardware; and the joke is that PIs [principal investigators] don't touch the hardware either. But with ballooning it's a lower level of quality assurance, and so you put things together yourself, you use aluminum tape, you put all the screws in, you do all the wiring, you make the cables, you hook up everything. That was just a great experience.

In the end the experiment that I did, there was no big discoveries. The experiment launched from Lynn Lake, Canada, I've forgotten the year, it was '93 or '94, and the flight lasted 45 minutes at float altitude because the balloon burst and came back down. It was near the end of the season and we didn't have enough time to do a reflight. However, I look back in hindsight and I realize that that balloon burst saved me a year on my grad school because there was enough data to show that the experiment worked, but not enough data to find all the problems. I was able to get out, and then looking for jobs found a postdoc at Los Alamos National Lab [New Mexico].

One other thing going back to that balloon program which I'm pleased with, it was the first flight of an experiment called TIGER which is the Trans-Iron Galactic Element Recorder. TIGER has had in the last 30 years a really great career. It's had a couple flights from Lynn Lake [Manitoba, Canada], a number of record-breaking flights from Antarctica, and now a version of the experiment has been selected to fly on the [International] Space Station. My part in it is really small. We had the first experiment. But the folks at WashU and Goddard Space Flight Center [Greenbelt, Maryland] have been involved in it. We originally had University of Minnesota involved, a guy named Jake [Cecil] Waddington was an old guard cosmic ray physicist. I'm still in contact with the folks and it's been really exciting to see how that goes.

JOHNSON: It is exciting to have that early exposure to that.

LAWRENCE: Yes. That's how I got in. When I went to do a postdoc, at the time I still wanted to be an astronaut, still wanted to stay in space science, and there were two possibilities for me. I had an offer from University of Colorado to work in atmospheric sciences and then an offer from Los Alamos National Lab. At the time it was to work on an experiment called PEPE, Plasma Experiment for Planetary Exploration. I guess that was my first dipping of the toe into planetary science. This was an experiment that was part of a NASA mission called Deep Space 1. It was a NASA program called the New Millennium Program as a technology demonstration.

I was hired on to help out with that experiment. One of the really awesome things about Los Alamos National Lab at the time is they had a very extensive history in doing spaceflight which starts all the way back in the 1960s. That started for national security purposes because, of course, Los Alamos is where nuclear weapons were first developed. It's a great history, of course note the interesting movie out about [J. Robert] Oppenheimer recently this year. So yes, Los Alamos is an amazing place, it's also quirky as all get out. It's a whole town of PhD scientists, so watch out.

They started doing work in space sciences for nuclear treaty monitoring. The basic gist for them was in the 1960s there were treaties that said you can't have nuclear explosions in space. But a big question is how can you tell? How can you tell if someone set off a nuke in space?

On the basis of that, Los Alamos over the years has developed spaceflight instrumentation to really ask that question. For example if you have a big solar storm and you get big count rates in detectors, is that from a nuclear explosion or is that from some natural event? Over the years they built up this whole infrastructure, building gamma-ray detectors, neutron detectors. These are the things that nuclear weapons produce. But also other types of instrumentation, energetic particle detectors, plasma detectors, where you need to know the space environment from which you're making your measurements. The old guard folks that really did this, they were just amazing.

Once you build up the infrastructure for doing spaceflight for national security purposes, well, now you can also do it for NASA purposes. At the time, Los Alamos built up this amazing program, which really straddled the line between national security and space science. One of their goals was to do space science so you can keep up your scientific chops as well as doing national security. One of the reasons is the following. Let's say something does happen, someone sets something off in space, and the President calls, you need to answer what is it, and you need to have the best scientists, the best tools at your disposal, to be able to answer that question. The way you do that is you do good science across the board. You do good experimentation across the board. This is the group that I joined.

They were doing this plasma instrument, and this was the deep space mission that was going to a comet. The instrument lead was a scientist named Beth [Jane Elizabeth] Nordholt. She was the one in charge and I was just coming alongside to help.

It finally got built, was flown, and gathered some good measurements. But I didn't stay with that as long. In the meantime another one of the great things at Los Alamos was when you join as a postdoc, you're not a lower-level citizen, you're just another scientist. They had many different projects going on and you could pick and choose different things, so this was where I started with the Discovery Program, and I met my mentor Bill [William C.] Feldman.

Bill Feldman, we'll just say he is the kind of scientist that I still want to grow up to emulate, he's an amazing man. We just had this last August, a Bill Feldman symposium up at Los Alamos. If you're interested, I can get you some information about that, but we had about 30 scientists in from all over the world giving talks of all the work that Bill has done over the years. He started out as a nuclear physicist, went to Los Alamos in 1968 doing space and solar physics. He got involved in planetary science doing neutron and gamma-ray spectroscopy, and just an amazing scientist that does everything from conceive the experiment, design the experiment, build it, test it in the lab, uses the oscilloscopes, gets it on the spacecraft, launches it, does the analysis and interpretation. He was one of the big movers and shakers at Los Alamos, and oh, by the way, one of the most kind people and scientists that I've ever known. In a world full of prima donnas he is the exact opposite. Amazing.

When I was there, he was in the middle of building three instruments for the Lunar Prospector mission. Lunar Prospector was the first competitively selected Discovery mission. This was a mission that was led by Alan [B.] Binder and somehow, he and Bill got hooked up and Bill was funded to build the three spectrometers: a gamma-ray spectrometer, neutron spectrometer, and alpha particle spectrometer. The amazing thing is I'm probably going to get the number wrong but I'm just going to throw it out there. He built these three instruments in 18 months for about $3 million.

JOHNSON: That's amazing.

LAWRENCE: Yes. One of the reasons he was able to pull it off was the quality assurance paperwork was almost nil. They got the money and he just did it. I think Lockheed Martin and NASA Ames [Research Center, Mountain View, California] were overseeing the mission and they covered a lot of the QA [quality assurance] for that and so that was a big deal. Even so doing that in that timeframe was extraordinarily stressful for Bill. But what was funny, I got to Los Alamos in 1996, and was working the prior mission, and when I was looking around, okay, I have some time, where can I help? I sat down and talked to Bill, and Bill, bless his heart, was doing just a ton of work, but he had no idea who was going to help analyze the data. I said, "Hey, I can do that." In a matter of weeks I got spun up. This was right before the launch of Lunar Prospector. It launched in '98, and I started helping him in maybe October of '97 ish. And I had a friend that was another postdoc, office next door, a man by the name of Sylvestre Maurice. He was at Los Alamos doing work on

Saturn magnetosphere and probably the best data analysis person I've ever known. He got roped in.

Lunar Prospector launched in January of '98, and a few days later data started coming in, and here Sylvestre and I find ourselves getting data from this mission that we didn't know how remarkable it really was, but we were learning what the whole goal of it was.

One of the main goals was to confirm if there is water at the poles of the Moon, and do that with neutron spectroscopy, and also measure global composition of the Moon using gamma-ray spectroscopy. The alpha particle detector didn't provide as striking results but one of the things it was doing was to see if there were any gas release events coming off the Moon by looking at radioactive radon. Data was coming in and here we are analyzing this data and starting to find really great results. Both of us are postdocs and we know nothing of planetary science. Really really cool.

One story that I like to tell was kind of fun and it needs a little backstory. When you're looking for water on the Moon, water is mostly hydrogen as far as the technique we're using, which is neutron spectroscopy. The indication that you have hydrogen is you're measuring these neutrons, and we call them epithermal neutrons because they're medium-energy neutrons. You see a decrease in the number of these epithermal neutrons compared to where there isn't as much hydrogen. We were getting in some of the early data from Lunar Prospector, Sylvestre was analyzing that data and the three of us [me, Sylvestre, and Bill] were huddled around the computer, and Sylvestre was plotting the data as counts versus latitude. What you would expect with water at the north or south poles is to see a decrease in the number of counts at both poles.

Sylvestre, he's a little cagey and fun, and so what he says, "I'm going to do something and let's see what Bill does." He artificially put in this really low count rate right near the poles, and said, "Hey Bill!" The real data at the time was very noisy and you really couldn't see anything. We were only a few weeks in.

Bill's reaction was so fun. We had to peel him off the ceiling because one of the great things about Bill is he gets so excited when we're doing science. Of course Sylvestre and I had to fess up that no, that really wasn't the case, and it's still just noisy data.

In the end a few weeks later, we ended up getting a result that really was excess hydrogen at the poles of the Moon, and so this was a big result. Prior to that in 1994 there was the Clementine mission with a radar that obtained what is now considered some ambiguous measurements of volatiles at the poles of the Moon. But Lunar Prospector was the first positive indication that you have excess hydrogen at the poles of the Moon. Right now that's driving NASA's exploration strategy for the Moon. As far as these measurements go, it started back with Bill. That was kind of cool.

Then I worked on the gamma-ray spectrometer, and within a few months was able to publish a paper in *Science* magazine looking at thorium abundances on the Moon. Bill had a paper on hydrogen. It's just gone on from there.

So there's a lot of fun stories. Every year there's an annual planetary science meeting in Houston [Texas] called the Lunar and Planetary Science Conference [LPSC]. Lunar Prospector launched in January. It was in March, and I'm trying to think of all the exact sequence, but we may have had some of the initial results. I think we did. There was initially a press conference about hydrogen at the Moon. Then LPSC was in March. I went down to Houston with Bill and Sylvestre and others to my first planetary science meeting.

Going back to my time in undergrad, who do I bump into at LPSC but Jack Schmitt. One of the great things about Jack is that to this day he is still a scientist at heart. He was the only scientist to fly on the Apollo missions and he showed up at this meeting and we were doing a poster session and talking about Lunar Prospector data. He was very engaged. The funny thing is I didn't expect to see him there, but of course I talked to him and I said, "Do you remember going out to breakfast?" He hardly remembered it. Isn't that funny?

JOHNSON: Such a memorable part of your life.

LAWRENCE: I know. But sometimes you talk to so many different people. But what was interesting there is he was at that meeting, and that started a continuing relationship with me and Jack that extends to this day. In 2001 I hosted a meeting in Taos, New Mexico, called New Views of the Moon, when we were learning a lot about the Moon. Much of the data was from the Discovery Program. One of the things I had learned was that the Apollo astronauts did some of their training at the Rio Grande Gorge south of Taos in New Mexico because the Rio Grande Gorge, it turns out, has almost the same dimensions as Hadley Rille where the Apollo 15 astronauts went.

One of the things I thought was, okay, it's going to be a small workshop, about 100 people, let's do a field trip and I'll give Jack a call and ask, "Would you be willing to help host a field trip to simulate how the astronauts trained for Apollo 15?" He's responded, "Yes, that sounds great."

He called up a couple of his friends, Gordon [A.] Swann from USGS [U.S. Geological Survey] and Bill [William R.] Muehlberger, who was a professor at University of Texas, and they set up a whole field trip.

But the coolest thing for us was Jack and his friends said, "We need to do a practice run, so how about a month before we do the real thing, why don't we do a test drive? And Dave, do you want to come up and join us?" I said, "Sure." Me and my wife, Amy, and at the time we had my young daughter, Molly, she was one at the time. I have six kids now, but she joined us because she was so young, so we drove up from Los Alamos to Taos. We got a hotel, but Gordon Swann at the time was driving a fifth wheel, a big trailer, and so we had a campout at his fifth wheel, and it was me, my wife, my daughter, Jack Schmitt and his wife, Gordon Swann and his wife, and Bill Muehlberger and his wife, sitting around having a campout, and they were all telling old Apollo war stories.

JOHNSON: Too bad you didn't have a recorder.

LAWRENCE: Oh, no kidding. But what a treat. The next day we went out. They drove around and said, "Here's how we did the training for the astronauts. How do you teach them how to see a rock, pick it up, and do all this stuff?" Of course we did it for the actual meeting and it was just fantastic.

They were such fun people. It was great. I could talk forever even about some of these things. But on the actual time of the meeting in September we went and did the whole thing. My wife, we had rented a van because she would help drive some of the other people down into Taos for various activities. At one point in time, for whatever reason, she ended up driving over a big rock and busted the radiator on the van. It was rental, and we had no way to get back home. Bill Muehlberger, it turned out he had driven to Taos from Austin, Texas, and so he and his wife offered to drive us home. He drove us home to Los Alamos from Taos. I don't know if you've been there, but the geology is amazing. The entire hour-and-a-half drive as we were going back, Bill Muehlberger gave us a geology class talking about the formation of all these rocks. There's these beautiful formations near Los Alamos. There's these cliffs of volcanic tuff [rock] that came from this huge volcano the Valle Grande [Valles Caldera National Preserve]. Talking about when you see those and how they form, the reason you see these vertical cleavages is it's the same way as if you have mud that ends up drying and you look on top of it and you see all these cracks form. Well, that's what they were doing on a very large scale. This was a geology lesson from a master teacher, Bill Muehlberger.

JOHNSON: What an experience.

LAWRENCE: Yes, and so by that time I was a staff member. But a young scientist. We got these papers in *Science* magazine and a number of follow-on papers. Quite frankly, at the time I realized that if nothing else happens in my career, I was going to be content with that. More stuff has happened for which I'm thankful; but just to have that connection with the prior history of people in the space program is just really neat.

JOHNSON: Yes. It sounds like it. That first experience with Lunar Prospector and all the information, and I did read that people are still writing papers from the information that's still coming from that. I was reading an article from back in '99. They actually quoted you and you said, "Before Lunar Prospector we only saw 20 percent of the Moon. Now we're mapping a whole other planet and that's really exciting." That mission allowed that.

LAWRENCE: Yes, it's an amazing mission. Again building these three instruments for $3 million and that kind of thing is never going to happen again. The science team was Bill Feldman, me, Sylvestre, another colleague, Rick [Richard C.] Elphic, another colleague Tom [Thomas H.] Prettyman joined a little bit later. But it was small. We were tight. I'd forgotten that quote, but it's true.

One of the things I was doing was looking at data from the gamma-ray spectrometer and the strongest signal was thorium abundances on the Moon. As you said there were maps of that from the Apollo Program. They had a gamma-ray spectrometer, but only got the equatorward part of the planet. It's a remarkable thing where you're mapping these data and you realize you're the first person in all of history to have seen this. The thorium on the Moon, our understanding of it drives a lot of what we think is going on on the Moon. I've likened it to—I say this a lot in talks—you can put on your glasses; you can go out and look at the Moon. With our gamma rays and neutrons, you put on your gamma-ray or neutron glasses and you see something totally different. Now the thorium map on the Moon, people look at it and can recognize it. At the time it was pretty neat to do that.

So I had mentioned that this meeting in Taos was New Views of the Moon. This was a whole initiative of trying to publish papers and information of what have we learned new on the Moon since the Apollo Program. You had the Apollo Program, there was a big desert of lunar science after Apollo ended. Clementine restarted that in '94, and then Lunar Prospector. Then it just blossomed.

New Views on the Moon was a whole initiative put together by a number of folks. Brad [Bradley L.] Jolliff from Washington University in Saint Louis and Clive [R.] Neal, they were some of the key players in doing that, and so we had this conference in Taos that I hosted. They ended up putting a book together, and at the time my mother who lives in Albuquerque is an artist, and I got chatting with her about this idea of looking up on the Moon and seeing something that you hadn't imagined, hadn't seen before. The two of us got talking and I thought wow, I wonder if you could do a painting of the Moon as you would see it over Los Alamos. From Los Alamos there are places, in fact in our house at the time, you can look out and you can see the city lights of Santa Fe, the mountains, the Sangre de Cristo [Mountains] beyond, and you can see the Moon there.

In the end she ended up doing this painting where it has the Moon and a ghost image of the thorium. That painting became the cover for the New Views of the Moon book. And she still sells reproductions of it.

Going back to when I wanted to be an astronaut, in the end, I applied twice. Never selected. This is a good thing. My wife and I, before we got married, we went to go watch the Apollo 13 movie. I loved it, it was awesome, really great. She was horrified. Why would anyone want to get in this little can with a ton of explosives under you and light the fuse? In the end this was a good thing. But I admire the astronauts that do this.

Yes, what we do is bigger than just the science because it captures our imagination. It takes us out of ourselves. Another great thing is it brings people together. One of the cool things about this whole field is you have people that are from a huge variety of backgrounds, countries, political persuasions; and when we're focusing on things that are not ourselves, we're focusing on something outside of us that's awe-inspiring and amazing, and really cool things happen.

JOHNSON: Let's talk about the team. You mentioned the people at Los Alamos when you were working with them on Lunar Prospector. But when I was reading over the different missions it seemed like the teams themselves that you worked with on the GRS [Gamma-ray spectrometer] and the neutron spectrometer both, a lot of those same people were carried over from mission to mission. Talk about forming those teams and what it takes to have a team working on a mission for NASA and those relationships. As you said when you're doing these missions you're working with NASA, you're working with the spacecraft, maybe Lockheed Martin or somebody like that, you're working with Los Alamos or APL [Johns Hopkins University Applied Physics Laboratory]. There's a lot of different types of people working for the mission itself, but then you have the instrument. Talk about those relationships within your team on the instruments but then also how that works with the larger picture, with the larger mission.

LAWRENCE: Oh, great question, a lot to say there. I'll just jump in some random place. Much of it does start with relationships. I mentioned Bill Feldman. He was my mentor, really my scientific father I would say. He just cares for the people that he works with. There's no recipe for how you bring that together, it's not something that you can go in the textbook, pull it out, and say, "Okay, here's how you form a team." It has to do with focusing on the project and the topic that you're doing, having a focus on excellence, and caring about excellence, working hard, enjoyment, enjoying people's company and presence. It's one of these things. The teams that Bill formed, they kind of just happened. But when you see a good team there's an aroma about it and people want to be a part of it.

It doesn't mean there isn't intentionality and working hard. But when Bill was doing it, people wanted to be a part of what he was working on, and he has always been very welcoming. You also get into some of these scenarios where teams can go really bad as well, and what happens there is when people get the idea of "This is my data, no one else shall enter," that's a problem, but it happens. We're human and like it or not, everyone wants to get the science paper, and yet it's bigger than that. You write a science paper and that's the 15 minutes of fame and then you're back to where you are. With Bill, you have the long game in view.

Over time from Lunar Prospector we just had this group of folks that were doing good work. There was work to do. But there's always more stuff to do, and so there this sense of, welcome, please join us. That led into Mars Odyssey.[1] Bill was a part of that mission, and some of us helped out there. Then one thing led to another and there was the NASA Lunar Reconnaissance Orbiter mission that in the end we were not a part of. We proposed to be a part of it and were not selected, but that was still a big part of our career. This is where some of the, shall I say dicey or interesting things were going on. Maybe I'll cover that later.

But getting back to teams, people move on, but we had the core people of Los Alamos that were still part of our work. Let me see. Another mission in terms of folks that are part of a broader team was the MESSENGER [Mercury Surface, Space Environment, Geochemistry, and Ranging] mission.

I was still at Los Alamos; we were wanting to push forward this technique of gamma-ray/neutron spectroscopy. It's a really amazing technique. There were a lot of tensions in that particular subfield with personalities going on and it was a challenge. But the group of folks at Los Alamos—we were still really tight.

There was a round of Discovery proposals, and at the time Bill was part of proposals for two missions to Mercury that were not selected. The one that got selected was MESSENGER and there were some of our competitors as part of that mission. The head of the gamma-ray/neutron

[1] The 2001 Mars Odyssey mission is NASA's longest-lasting spacecraft at Mars. Its mission includes making the first global map of the amount and distribution of many chemical elements and minerals that make up the Martian surface. It successfully completed its primary science mission from February 2002 through August 2004. The orbiter's extended operations continue today.

instrument on MESSENGER was Jack [Jacob I.] Trombka. Bill [William V.] Boynton and some other folks from Goddard were also part of that.

One of the things you learn in Discovery is, as a colleague of mine said recently when asked what he did for a living, “Well, I write losing proposals.” Okay, yes, that’s fine, and that happens. We lost it. But somehow, and I don’t recall all the details, Bill had gotten to know an engineer at APL named John [O.] Goldsten. When APL had proposed the MESSENGER mission they had a gamma-ray spectrometer and a neutron spectrometer. Doing these instruments had become a thing. For whatever reason, this engineer John Goldsten knew that the neutron spectrometer they proposed wasn’t going to work very well. By this time Bill had acquired the reputation that he was the master at doing neutron spectroscopy. At the time I also happened to know a person who was at Carnegie Institute of Washington, a guy named Larry [R.] Nittler. I went to grad school with him. The PI of the MESSENGER project, Sean [C.] Solomon was at Carnegie Institute and so they were at the same organization.

You had to be a little careful because you don’t want to tread on sensitive subjects but John Goldsten, and I, and others, we wanted to find a way to get a good neutron spectrometer on the MESSENGER mission without upsetting people too much. I knew Larry, he knew Jack, we knew John, and so through a series of discussions we got permission for Bill Feldman to talk to John about how to redesign the neutron spectrometer in a fashion that would work much better.

Bill was sheepish about doing that, and he would say things like, “Look, I was on the losing proposals, this is bad form.” Somehow, we got over that. Over a series of conversations that lasted weeks and then months, finally there was permission to send a little bit of funding from APL, who was running the mission, over to Los Alamos to help with this design. At the end of the day, it turned out Bill got brought on the mission as a full co-investigator. The instrument was fully redesigned. Jumping to the end, it was the redesigned instrument that ended up taking the data that was the final piece in the story of measuring water at the pole of Mercury.

Again, talking about people, a lot of it consists of these things you can't plan. But you know who people are and sometimes you can call it an old boys' network. There's areas where that's an exclusionary thing, but there's also building relationships which is bringing people together. It's having these conversations and getting to know people, getting to build trust. In fact, it was those MESSENGER-related relationships that ended up being a key reason for me leaving Los Alamos and going to Applied Physics Lab where I am right now.

At the time, Los Alamos was going through some difficult periods. There were challenges with doing space science there, and through a series of events, I received a job offer from APL that I ended up taking. It was a hard thing to leave, as I love Los Alamos. But sometimes you end up changing. Around that time, I was selected as a participating scientist for the MESSENGER mission, but continued to work with Bill Feldman, and then built new relationships working with people at APL, including John Goldsten. He is one of, if not the best electrical engineer for doing gamma-ray/neutron spectroscopy instruments. On paper he's an engineer but at heart he's a scientist. In fact a better scientist than me. And he focuses on excellence, focuses on not just checking the box and building a piece of hardware but how do you get information to do it well. It was his tenacity to see that this original neutron spectrometer was not going to work, and how to make it work well, and how do we have people around us that can make it work. It's that kind of ethos that really makes things go well.

Your question way back when, many minutes ago, about teams. I was hired on to APL. At that time, I'd published quite a number of papers. I was at the point of being able to lead projects. Yet I was still in this place of what do you do for your career? I write losing proposals.

But this is the deal: you have to keep going at it. One of the things I was hired on at APL to do was to help lead the work of doing gamma-ray/neutron spectroscopy instruments. They were doing the instruments, but for whatever reason they didn't have a scientist there that was leading that effort. They had been working with Goddard, but APL wanted a scientist on staff that could really lead that effort.

One of the things that really attracted me about APL, and it was similar to the space science group at Los Alamos, is what you try to do is you build smaller teams of people focused on excellence and doing really good work. You don't care about the boundaries between engineering and science. You focus on solving problems and getting a really dang good experiment. APL also has that ethos of how do you do good work. John Goldsten is part and parcel to that.

Over time at APL, now I've been there 15 years, and we've built up an amazing team. But it's done very slowly and carefully and strategically bringing people on. I was brought on to help out with the MESSENGER mission. It had already launched by the time I joined there. We did need some help, and so one of the first things is we hired a postdoc, and we were extremely fortunate. We hired a postdoc named Patrick [N] Peplowski and he was a nuclear physicist trained at Florida State University doing homeland security work up in Washington state. One of the ways you know you have a good person is when you talk to their graduate adviser and he says, "He was one of the few students I really didn't want to see go because he made the lab work."

He has since blossomed and now we have that kind of ethos at APL that we had at Los Alamos. He's one of the best scientists I know as far as planetary nuclear spectroscopy. He's the best in the field. And he has a similar type of ethos for caring about excellence, getting good people around you that do really good work.

As an aside, I love to read all sorts of books, and we've been working the Psyche mission, another Discovery mission, over the last many years. That was a challenging experience because working JPL, NASA Jet Propulsion Laboratory [Pasadena, California], their culture is different. It's just different. But we've done a lot of reflecting on how do you do what I'll call good projects in a good way.

There's a book called *Shop Class for Soulcraft* by an author named Matthew Crawford. He's an interesting guy. He's a philosopher that has a PhD in physics and works at a motorcycle repair shop. If anyone's interested, it's a really great book for how do you do good work with technical things, and a lot of it is you get your hands dirty, you work with hardware, you don't get overrun by processes, you have good people, learning by experience, you mentor younger people, bring them up, and enculturate them into this type of work.

During that build process I gave this book to a number of people on our team, and they resonated with it. Again it's the kind of thing you don't have a textbook that says, "Here's the checklist for how do you build a good team." If you do the checklist thing, your team is going to be at best mediocre. Carrying forward a lot of those same types of ideas, we finally broke that trend of writing losing proposals by being part of the Psyche mission, and getting selected for a Japanese mission, Martian Moons eXploration [MMX], a NASA-funded instrument, also in the Discovery line. Then based on those successes, getting selected as part of the Dragonfly mission, which is New Frontiers. All of it is a continuum from the Lunar Prospector days with Bill Feldman and building that type of instrument. I like the word aroma of how do you do good work with excitement, joy, but it's not always easy. There's been some really intense and very hard things. But looking back at it and having time to reflect, it's really cool.

JOHNSON: Yes. It's interesting. As you said, building those teams and figuring out how to win those proposals and getting the right people together, also the instrument itself has evolved, and it has to change I'm assuming from which mission you're going for. Maybe talk about that, the way it started out in Lunar Prospector and then all the way to the way it's evolved and changed for Psyche. I've read that MESSENGER and Psyche are somewhat the same type of challenges. Talk about how that instrument has evolved and what's changed on that.

LAWRENCE: Sure. Lunar Prospector, again this was designed by Bill. I'm going to leave off the alpha particle spectrometer. That's its own thing. I'll just focus gamma ray/neutron. When he designed it, his own marching orders were keep it as simple as you can to do the job that needs to be done. He designed a scintillator gamma-ray spectrometer which is not the best-performing instrument.

At the time during that proposal round I think there was a competing proposal for some lunar instruments that had more fancy detectors. Bill was hit pretty hard that the main metric for gamma-ray spectrometers is energy resolution, and that's how fine you can identify gamma-ray peaks. BGO [bismuth germanate scintillator] was not that great for energy resolution. What it had was very good efficiency, which meant it got lots of counts, which means it has great statistics. For that purpose it was absolutely right thing. It was a very simple detector building on things that he had already done before. It really proved its worth as we're still looking at data from that detector many, many years later.

The neutron detector again was very simple. It was something called helium 3 sensors and these are just cylinders that have compressed helium 3 gas in them. When neutrons come in, they get captured by the helium 3 and you get a signature that says, "Okay, I know a neutron was detected." Again, Bill knew about these kind of detectors because these were the same detectors that were used at Los Alamos for national security purposes. The materials you put around them were different but the sensor itself was the same.

For Lunar Prospector it was pretty straightforward. Jump to MESSENGER. There's always a tension between doing the things that you already know how to do and having technology development that really pushes the field forward. For MESSENGER the big innovation was going to a high purity germanium gamma-ray detector. I was not involved in that. I was more peripheral at the time but was aware of it. Interestingly, at the same time the whole neutron detector was being completely changed, the gamma-ray detector was changed even more. But it was some of the same group of people. What they proposed was a scintillator not too different from Lunar Prospector. For the MESSENGER mission, that design wasn't going to hold because for MESSENGER you were not spending as much time close to the planet. You weren't going to get as many counts. You had to have something different.

At the time the APL-Goddard team had just completed the NEAR [Near Earth Asteroid Rendezvous] mission which also had a gamma-ray spectrometer. It was a scintillator similar to Lunar Prospector but they did not get the results that they thought they were going to do, because they didn't have the statistics. John Goldsten, the same engineer who wanted a better neutron detector – he also wanted a better gamma ray detector. In the middle of this whole design, post preliminary design review, they started a new study at APL of how they might redesign the gamma-ray spectrometer for MESSENGER. They had three options: keep it the same; do a new kind of technology called cadmium-zinc-telluride, these were smaller gamma-ray detectors but had better energy-resolution performance than scintillators; or go to high purity germanium.

At Los Alamos we had Tom Prettyman who was an expert in cadmium-zinc-telluride. He led the portion of the study to see if one could use cadmium-zinc-telluride. That was a kind of detector that actually flew on the Dawn mission[2], another Discovery mission.

Then they had the idea of flying a high purity germanium detector, an idea that was being promoted by an APL scientist named Ed Rhodes, who unfortunately died a number of years ago. That had been done on the Mars Odyssey mission. So, there is this tension. You fly what you know, or you go for new technology. You need to be able to be light enough on your feet to do both the new stuff when you need to, and be wise enough to stick to the old stuff when it makes sense.

The innovation for MESSENGER was to try high purity germanium. But high purity germanium needs to be cooled to cryogenic temperatures, which is a big challenge. For Mars Odyssey they did it passively with a radiator. You're at Mars orbit, you're further away from the Sun, you can get away with it. When you get to Mercury, the planet closest to the Sun, how do you cool to 90-kelvin temperatures when you're at 0.3 AU [astronomical unit]? This was the big challenge.

They did this trade study, keep it the same, use cadmium-zinc-telluride, or high purity germanium. In the end, they decided to go with high purity germanium post PDR [preliminary design review]. Which is crazy. At the time, the APL folks ended up making connections with people they knew at Lawrence Berkeley [National] Laboratory [California]. APL worked with the Berkeley folks, got a viable solution and they built the germanium detector.

[2] The Dawn mission featured extended stays at two different extraterrestrial bodies: giant asteroid Vesta and dwarf planet Ceres.

Ed Rhodes and John Goldsten led the charge. Bill Feldman helped out in some of the reviews. I was just a hanger-on at the time. But flash forward many years, when MESSENGER finally completed its mission, the germanium detector made some amazing measurements. Measured potassium abundances, chlorine, sodium.

One of the things it determined was that Mercury had a much higher abundance of volatile elements than anyone expected. Those elements I mentioned are the type of elements that tend to be cooked off when you get hot. You would expect Mercury would have low abundances of those elements, but they were high.

The person who did the initial paper for those results was Patrick Peplowski, the person we hired as a postdoc. When the MESSENGER mission was over and they had this nice list, I think you can still see it on the MESSENGER website, top 10 discoveries of the MESSENGER mission. The top 2 were critically dependent on the results from the gamma-ray spectrometer and the neutron spectrometer. Hydrogen at the poles of Mercury and measures of volatile elements. Again, going back to Bill Feldman and a lot of that crew that he had, and determining what do you do to innovate and what do you do to keep the same?

Now back to your question. How does that evolve? That evolves into the Psyche mission that we are a part of. Since I was at APL one of the things is how do you move things forward. As good as the germanium detector was for MESSENGER, there was a lot of things that didn't work well. It got put together post PDR, and so I think in the end compromises were made on the design just because they had to move quickly.

Once that was all done, as we were thinking of how do we move it forward, this was an area where we realized targeted work needs to be done to make improvements so that if we have an opportunity to do it again, it's going to be much better.

NASA has a great program called the MatISSE [Maturation of Instruments for Solar System Exploration] Program. It's an instrument development program. It's always a challenge with technology enhancement, and over the years NASA has struggled with how to fund that, because that's seed money and it's hard to put seed money when you have all these really big needs; such and such mission is behind schedule, over budget, we need to fund those.

Sometimes they have good programs for doing tech demo. Other years it's been not great. But MatISSE was a great program, it's still ongoing. We proposed once, were not selected. Theme. What do you do for your living? Write losing proposals. Second round we did get selected.

The great part of MatISSE is they fund projects at about $1 million per year for $3 million over three years. Oh yes, by the way, the same amount of money that Bill built Lunar Prospector instruments for. Anyway we ended up getting that proposal, and at APL John Goldsten is still a part of it. We know the team now at Lawrence Livermore National Lab [Livermore, California] who helped out with MESSENGER that inherited all this. It's now led by a colleague named Morgan [T.] Burks. We got this MatISSE to say, "Okay, what are we going to do for this germanium detector to really do the lessons learned and make it better for any future missions?" Really target the things you need improvement, things that don't keep them the same. We got the MatISSE, did some really great work. It was me, Patrick, John Goldsten, and Morgan Burks were the key people. Obviously other people have come on. Then through a series of events we got to be part of the Psyche proposal process and Psyche was selected, and we're able to put all of those things into practice.

But what was interesting is we also want neutron spectrometers. What Lunar Prospector did was good – helium 3 tubes. You don't need to change it. There, if you don't need to change it, do the same thing. Psyche has helium 3 tubes very similar to Lunar Prospector. We actually made one change to target a different energy range for what we think may be a metal-rich body at the asteroid Psyche, but other than that, it is very similar to Lunar Prospector.

Another area where improvements can be made that really make sense is in the area of electronics. This is another place where John Goldsten is just a master, is taking the analog electronics that were existing in the days from Los Alamos, it's 1970s, '80s, and '90s electronics where you just have analog signals. What John was able to do, he did it partially for MESSENGER, but really fleshed it out for Psyche, is turn essentially all that analog electronics into digital electronics. Effectively what we have on Psyche is a digital oscilloscope that is fully programmable; and you can have really good flexibility and all of your functionality you can mostly deal with in flight software in a way that you never had for Lunar Prospector.

While the sensor technology, the germanium detector is evolving for MESSENGER, the neutrons are pretty much the same. We have a much greater capability of understanding the instrument and operating it with the new type of electronics that Bill in his days just couldn't do.

Now what's really neat, as of where we are in January 2024, Psyche launched October 13th of '23; November 13th of '23 we started the initial checkout operations for the Psyche gamma-ray/neutron spectrometer. We finished all of that mid-December and the instrument is absolutely amazing. The instrument works great. The germanium detector is the best that has ever flown in space. Targeting where you make your improvements and trying to be wise enough—not that we're always wise—but trying to be wise enough and have the judgment to keep things the same where they need to stay the same.

JOHNSON: With a mission like Psyche do you get to see the launches? Or where are you during the launch?

LAWRENCE: I got down to the launch. That was actually my first launch that I ever witnessed in person. I could have gone to the MESSENGER launch in '04. I was at Los Alamos at the time. I had my travel all arranged to go down to Florida with my father-in-law. Unfortunately, this was a time when Los Alamos had a lot of safety and security problems and the director of the lab at the time Pete [George] Nanos, one or two weeks prior to the launch, gave an edict that said, "I'm stopping all work so everyone can focus on security and safety, all travel is suspended." So I missed that.

But Psyche was glorious. Went down with my whole family. There was a lot of the team there, and that was just really enjoyable to be a part of that after many of the challenges with the mission and getting to the launch pad. Coming together at the end and having that launch the way it did was just glorious. It was neat to be a part of that.

For us who do instruments, when you do the launch, you're super excited. But then you know what's on that payload and think, "Oh my goodness, I hope it survives." At least for us, the folks that do the instruments, equally exciting was the time of turning the instrument on for the first time, and there we wanted our key people actually at JPL working with the operation folks who are fantastic. It's great to see the squiggly lines come up and look like they're supposed to, because there's no guarantee that's going to happen. Space is a hard business, and sometimes it doesn't work.

Right now for Psyche I'm very pleased. We're always looking over our shoulders when you have something in space because you never know what's going to happen. But yes, we are pleased.

JOHNSON: Will your instrument be turned on periodically on the way? Or does it come back on again once you get there?

LAWRENCE: The germanium will be periodic. We had it on for two weeks on its initial turn-on. Our plan is to turn it on roughly once every six months. Early in the mission planning, we got the go-ahead to keep on neutron spectrometer and a portion of the gamma-ray spectrometer on all the time unless you have a spacecraft safing event. Part of running an excellent experiment is having the instrument on as often as you can so you understand all its quirks and foibles and how it works. We're going to get to do that. Oh, by the way, we're going to get to measure cosmic rays throughout the solar system, which is its own interesting measurement. It's not groundbreaking, it's never going to be on the cover of *Science* or *Nature*. But it's good information that's useful for the community and useful for us. We're going to keep that on throughout cruise and see what we can see in the space environment as well as continue to learn the instrument.

JOHNSON: Let's talk about the proposal for Psyche just for a minute. Just to get an idea, as an instrument scientist and as the instrument lead person, during the proposal and when these teams form, do you write the instrument part of the proposal – like you said you have a history or the experience of writing losing proposals. But talk about writing this winning proposal and how that works together. You have the overall proposal, then you have the instruments, so talk about that, how that works in relation.

LAWRENCE: By the time we got to Psyche we had our small core group for gamma ray/neutron. Had a lot of experience doing this. We had written a losing proposal for Mars 2020 for a gamma-ray spectrometer. It was an excellent proposal, in the end not selected, and I think that was a blessing in disguise as it would have been a really hard mission to do. I still think they could have a gamma-ray spectrometer for a rover on Mars, but at the time we're fine with that.

We had our own group that knows the instrument but one of the things for us is it is really important that the instrument itself is not its own thing. It's part of a bigger whole. We wanted to work hard as best as we could understand all aspects of the proposal, most certainly the science. Because if you're just building an instrument, but you don't know what science you're trying to do, that's no good in my opinion, because these are not just assembly line things. You're crafting the instrument to do the best science that you can. You need to understand the planetary science aspect of it.

I'm not an expert on all things asteroids or Psyche, but you try to get up to speed as much as you can. When we were involved with JPL and Arizona State University, we did our best to be involved in everything we can about how the measurements were going to be used and where this was going. I think it was a generally good experience because having that kind of team where you're with people with different expertise. Then of course for mission proposals when you're leading an instrument you spend a lot of time doing the instrument portion of it as well. That involves everything from how do you apply the science to your measurement, your measurement requirements, but then all the nuts and bolts of how is the instrument going to come together.

What's its mass, what's its power, and making sure that fits in with how you can have a successful mission. Having experience, doing missions before, is really key in this because you gain viscerally an understanding of what are the important things, and what are the things that really just aren't.

Our goal was to be involved in all aspects of it from beginning to end; and oh, by the way, there is the budget as well. When you're leading an instrument proposal you have to care about that. Really having knowledge of what is the budget scope for an instrument, a big issue when you're in proposal world is cost modeling. How do you estimate what the cost is? There's a whole science behind cost modeling that you have to get up to speed on. All aspects of that are involved in crafting a good proposal.

JOHNSON: I've read that Psyche might be a relic core of a planetesimal. I don't know if I'm saying that word right or not.

LAWRENCE: You did great.

JOHNSON: But among the oldest bodies in our solar system. What are you expecting to find with your instruments once you get there or do you have those expectations what you think it's going to be or what you think you're going to see once you get there?

LAWRENCE: The short answer is I have no idea. Slightly longer answer. When we were doing the initial proposal, information about the asteroid was scanty, and we were having the working assumption that it might be really metal-rich, maybe as much as 90 percent iron-nickel metal. If it is, then that is just tremendously different than anything else we've seen. Much of our thought process on designing the instrument was focused on the idea that if you have a metal-rich body like that, the gamma rays, but even more so the neutrons, will respond in a very different manner than what we were used to seeing on the Moon or Mars or Mercury. In fact, for the neutron spectrometer we added a third sensor to handle some different energy neutrons. It was really targeted towards this case of if it's really 90 percent metal.

Of course when you get selected for a mission to some body where you don't know much about, everyone else starts to get excited, and they train their telescopes and other stuff to learn more.

Since that time I think it's become more ambiguous on whether the Psyche asteroid really is as metal-rich as we were initially saying or thinking. There's some conflicting information out there. Some data say, "Yes, it's still metal-rich." Other data suggests, "Not so much." We think it's still an odd body. But at this point, my short answer is I have no idea what it really is. To a certain extent that makes it really interesting.

When we get to Psyche, I think the instrument that's really going to give us the soonest indicator of how metal-rich Psyche is will be the neutron detector. So, if I had to make a prediction, the neutrons will give us our first indication if it is really super metal-rich or is it more silicate type of body that we see on the Moon and other planetary bodies. I don't know. But some of the data that's been acquired since selection indicates that it may have heterogeneities across the surface. For us that's really interesting because that's an important clue to see different things when we're looking at different places of the body. Short answer I don't know what we're going to find. But it will be interesting.

JOHNSON: I was going to say not knowing actually is more exciting it seems like because it's going to be something unexpected.

LAWRENCE: Yes.

JOHNSON: I did read that it has to be within 60 miles of the surface of Psyche to get that gamma-ray detector. That'll be at the very end of the mission, right?

LAWRENCE: Actually no. That was one of the better changes for us with the later launch date compared to the original date. For the original mission, the spacecraft was going to start out at high altitudes and go lower and lower. Because of aspects of Sun angle where different orbital things going on with the spacecraft with respect to Psyche, our primary mission is now happening right in the middle. They're going to start high. They're going to go low, really low, and operate us for longer than we were originally planning which is great. We'll get the low altitude right in the middle of the mission, which is really good.

JOHNSON: Yes. That's a nice surprise, isn't it?

LAWRENCE: Yes.

JOHNSON: Why don't we stop there? Because I'd like to get into some of the other missions, unless there's something about Psyche you want to talk about in the last 10 minutes.

LAWRENCE: No, I think that's fine.

JOHNSON: Okay. That'll give you a few minutes back in your day to catch up after your travel and get ready for your next travel. I appreciate you talking to me today.

[End of interview]