DISCOVERY 30TH ANNIVERSARY ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

BRUCE G. BILLS
INTERVIEWED BY ERIK M. CONWAY
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CONWAY: This is Erik Conway. I'm in the office of Bruce Bills at JPL [Jet Propulsion Laboratory, Pasadena, California]. Today is January 16, 2024. So, Bruce, I'm going to start out with a bio sketch here. Tell me where you were born.

BILLS: I was born in Salt Lake City, Utah.

CONWAY: And how were you educated?

BILLS: I went to the normal local schools, and then after high school I went to Brigham Young University [BYU] in Provo, and as you might guess from that, I was raised in a Mormon home, though I'm not practicing at all now.

CONWAY: And was your major physics?

BILLS: Physics major, math minor. Then after BYU, I went to Caltech, where I had a planetary science degree. Then after I left Caltech [California Institute of Technology], I came to JPL for my first episode at JPL. I was there for seven years. Then I went to the Lunar and Planetary Science Institute [LPI] in Houston [Texas] for seven years, and then I moved to the NASA Goddard Space Flight Center in [Greenbelt,] Maryland for seven years. This seven-year thing

just happened; it wasn't planned. Then I continued as a Goddard employee, but moved to San Diego, where I was at Scripps [Scripps Institution of Oceanography, La Jolla, California], and I was there for twelve years. Then I came back to JPL, and I have a weekly commute between San Diego, where my wife and kids are still there, and come up here on a weekly basis. I've been doing that for thirteen years now.

CONWAY: Wow. That's quite a commute. So what did you do at Caltech for your planetary science degree?

BILLS: I was looking at the gravity fields of the Moon and Mars and Venus. Back in those days, those were sort of recently being explored and so on. In fact, my thesis advisor, Al [J.] Ferrari, was a JPL person who had sort of an appointment at Caltech, so he was splitting his time between JPL and Caltech. I had already, when I was at Caltech as a graduate student, I was developing connections to people doing gravity work at JPL. When I graduated, coming to JPL was kind of a no-brainer. That was where the people I was working with were working.

CONWAY: So it was an easy transition for you.

BILLS: Oh, yeah.

CONWAY: What interested you about gravity as a field of study?

BILLS: Good question. I've been interested in lots of different things over my career, but I've pondered if I had it to do over again, would I do things differently, and I'm guessing I might have, but I found both measuring the gravity fields and using the gravity information to get orbital trajectories of spacecraft orbiting the various planets was interesting, so most of my career has remained in that sort of planetary geodesy either looking at analyzing gravity or looking at the spacecraft trajectory perturbations that are produced by gravity.

That's kind of what I've done most of my career. I've found it to be interesting, although there was [laughs] a period of time when I was finishing up my Ph.D., I had gotten interested in work being done by various people trying to communicate with whales, and I thought, "That sounds more interesting than gravity." But I looked around and talked to people and concluded that that wasn't a very good job choice, although it seems like that field is making progress these days, so maybe after I retire, I'll try and find another career, talking to whales.

CONWAY: Sounds like a thing you can volunteer for, volunteer to work on that. That sounds fascinating, but there's a lot less money in it than gravity, I think.

BILLS: Yeah, yeah.

CONWAY: So when you leave JPL the first time, you go to Lunar and Planetary Institute.

BILLS: Yes.

CONWAY: What do you do there?

BILLS: Gravity.

CONWAY: So you didn't really change what you did.

BILLS: The focus of my research did not change at all, and part of going there, Roger [J.] Phillips, who had been at JPL, left JPL to become the director of the Lunar and Planetary Institute, he called me up one day and said, "You haven't responded to our advertisement. What's going on?"

And I said, "Well, yeah, I saw it, but I thought it was rigged for someone."

And he says, "It was, you idiot. It was rigged for you. Please apply." [laughter] And so I did. He was ending up his directorship, and Kevin C.A. Burke took over.

I continued doing gravity research, and because of the way LPI is set up, it has sort of an outreach connection, so that I spent some time, in addition to doing my research, they had an internship program, so each summer I'd have an intern and train them to do gravity stuff. So it didn't change the focus of my work, but it put me in a position where I was doing more mentoring of young people and stuff, and I found that interesting.

CONWAY: You found it interesting. Is there any particular planet or moon you were working on at LPI?

BILLS: Well, I mean, it was, again, Moon, Mars, and Venus were the bodies on which gravity data had been collected and was being collected and analyzed, so I sort of continued mainly

focused on those bodies. I was interested in keeping current with what was going on in planetary science, exploring other bodies, but I sort of kept those three, the Moon, Mars, and Venus, as the focus of most of my work.

CONWAY: So you weren't yet interested in moons of the outer planets, which I guess we didn't have much data for.

BILLS: Well, I was interested in them, but I wasn't doing any active work on them.

CONWAY: Fair enough. When you leave LPI, you got to Goddard, right?

BILLS: Yes.

CONWAY: And why leave? Why did you change locations again?

BILLS: Very similar story. I was at an AGU [American Geophysical Union] meeting. I went into a meeting hall and the session hadn't started yet, and there was a guy named Dave [David E.] Smith, who I knew from Goddard, and the seat next to him was vacant, so I sat next to him and we started chatting, and he said, "Bruce, we've got a position that I'd like you to apply for at Goddard."

And I said, "Okay."

So I applied and I got hired. It was essentially, he had been the head of the Geodynamics Branch at Goddard for thirty years and was moving up a step in the administration, and he hired

me to replace him, basically. So it seemed like an interesting move and it put me in a management position for the first time. In our job interview, towards the end he said, "So you don't have any managerial experience. Do you think you can do it?"

And I said, "Well, I think I can. I hope I can. Let's give it a try."

And he said, "Sounds good."

Then Andrea [Donnellan] came to Goddard.

CONWAY: Oh, so that's the connection, then, when she came to Goddard for what was a postdoc, I think.

BILLS: Yes, yes. Then she and I went to Bolivia not too long after she got there and did work, which I was doing work on something other than gravity. When I was at LPI, some of the people there, in addition to doing planet Earth stuff, were working on stuff in South America on Altiplano [Plateau, Peru], and one of them, Sean DeSilva, told me, he said, "Well, there are shorelines of a paleo lake," and he knew that I was interested in that, Lake Bonneville. I had grown up in Utah and I knew the shorelines are very conspicuous, and I had gotten interested in them, and that was one of the terrestrial things that I had worked on sort of starting when I was at JPL the first time but continued through LPI. And then when I went to Goddard, I had decided it would be interesting to go see paleo shorelines of a different lake, so we went to Bolivia and made GPS [Global Positioning System] measurements of altitudes of shorelines and stuff, that Andrea was our GPS expert in. It worked pretty well.

We still haven't gotten all of—I mean, the results getting published has been a very—I mean, many, many years later, it's still on my to-do list, but that's sort of a side issue.

CONWAY: So it sounds like at Goddard you were able to do some things other than gravity. You talked about one, but what other things? Were there other kinds of field experiments you got involved in?

BILLS: Well, no. I mean, looking at shorelines of big lakes, lakes that are big enough that the water actually depresses the crust down for the shorelines that the form, their level when the lake goes away, the center rebounds and the shorelines get kind of domed up in the middle, and measuring that allows you to estimate the effective viscosity of the subsurface. So it was a geophysical inverse problem associated with making surface topography measurements on shorelines. I had done some of that in the Bonneville Basin when I was at LPI. I'd done some of that in the Bonneville Basin, and then transitioning to doing similar stuff but in a different place was what the activity in Bolivia was about that.

CONWAY: So it was a larger question you were just explaining. Then you become a manager at Goddard. One of the things you said in your notes was that you had more authority there than here, basically. Before we talk about that, tell me what other kinds of things you were doing at Goddard. I think you mentioned that you did other kinds of Earth-related things. Talk about that. What other things did you do?

BILLS: Well, okay. So the thing that connects later to Psyche is that shortly after I got to Goddard, I met Ho-Jun Paik, who was a physicist at the University of Maryland, and he had been working for some time developing a gravity gradiometer instrument and was interested in flying

it around the Earth. At that point in time, NASA had put out a call for proposals to do an Earth gravity mission. There had been Earth-orbiting satellites that sort of measured the gravity field just as a matter of course because they need to navigate, but the idea of actually having a dedicated gravity-measuring mission was something kind of new.

So I got involved in the science team for this gravity gradiometer proposal that we were writing, and part of my job as a manager at Goddard, and if I had wanted to, I could have been the principal investigator [PI] on that mission, but I didn't want to. I thought that would be an interesting thing, but it would limit my ability to do whatever I want to do.

CONWAY: To do research.

BILLS: Yes, exactly.

CONWAY: You don't have your research time as a PI.

BILLS: Running a mission is a big job. So my secondary job there was I had to figure out who should be the PI, and I went down a list of people that I knew that were obvious candidates, and I started calling them and saying, "We've got this gravity gradiometer that we want to propose."

The first five or six people that I called all said, "Oh, the University of Texas with Mike [Michael M.] Watkins—

CONWAY: And Byron [D.] Tapley.

BILLS: —and Byron Tapley have a mission concept, and I don't want to compete with them." The answer was either, "I'm already on their team," or "I don't want to compete with them."

I finally found Marcia McNutt, and she was willing to be the PI on it, so we wrote what I thought was a pretty good proposal and submitted it, but when the selection was made, we lost—kind of as expected—to the Texas enterprise. GRACE [Gravity Recovery And Climate Experiment] was selected. A number of reasons why, but one of the reasons we didn't get selected is the gravity gradiometer has a superconducting sensor in it, and in order to have it be superconducting, it has to be kept at very low temperatures, and the only way that we had available at that time to do that is to put it in a big vat of liquid helium and insulate that vat as well as you can. So the cryogenics group at Goddard was heavily involved in trying to make sure that this vat was as good an insulator as we knew how to make, but the time-variable gravity, which was the main focus of the GRACE mission, required it to operate for multiple years, and we thought we could maybe operate for almost a year, and that was not what got selected.

So, again, in what I wrote up, when I was at JPL, Daniel Wenkert and I had decided sometime earlier that we should try to figure out what would be a good target for the next Discovery [Program] mission. We'd meet once a week and sort of discuss what were past Discovery missions and what could we learn from them, and what were the remaining interesting targets, and we ended up deciding that there were lots of interesting questions that still hadn't been answered but that could be addressed with a—you didn't need a very expensive mission. A Discovery mission would be good enough to do lots of interesting things in the asteroid belt. The Dawn mission had gone to Ceres and Vesta and showed that both interesting science can be done there and, at least in that case, they were able to go to one, go into orbit, and then leave and go to another one.

So we started thinking about are there classes of asteroids that we could study, and eventually we decided that doing multiple asteroid encounters like Dawn had done, it maybe wasn't the right thing to do, but in the process, at one of our meetings Daniel came in and threw down a copy of a paper he had just seen that Lindy Elkins-Tanton was lead author on. They were discussing sort of what I like to call stealth differentiated asteroids, asteroids that are differentiated in the interior structure, but you can't tell it from their surface.

We started thinking about, well, what would you do if you wanted to explore that concept. We had decided that the instruments we'd like to have on it would be a magnetometer to measure the magnetic fields, like if it's got an iron core or something or a significant amount of iron, there should be a magnetic signature of that, and then a gamma ray neutron spectrometer, which is something that we thought we needed because these bodies were going to be different than—I mean, most of the terrestrial body surface measurements are done with infrared spectrometers, and we figured that the kind of body that we ended up with Psyche on is different in that it's got a lot of iron, so the usual toolbox for planetary exploration of asteroids was deficient in that way, so we thought we needed a gamma ray neutron spectrometer and then a camera just to see what the surface looks like, and then a laser altimeter we thought would be a good thing to have to measure the topography very well.

So we came up with a suite of instruments and a mission concept to go to explore things like what Lindy had written about in the paper, and we thought, well, maybe we should call her and see if she'd be interested in being involved in this mission. We picked up the phone and called her and explained what we were doing and that we were looking at possible future Discovery missions and we had in mind doing one that was pertinent to this paper that she'd written, and wanted to know was she interested, and she said, yeah, she was.

Then emboldened by that, I sort of said, "Would you be willing to be the PI on that mission?"

And she said, "Yeah, sure."

We were pleased with what we had been able to get done, so we went and talked to Brent Sherwood, who was at that point in time running the Discovery mission portfolio at JPL, and we told him of our success. He proceeded to tell us that we were not supposed to do that kind of thing, that offering a PI-ship on a mission was to be done by people on the top floor over there, not just engineers and scientists. So I had erroneously assumed that what I was able to do when I was at Goddard carried over at JPL, and was sort of informed that, "No, that's not the way it works at JPL."

CONWAY: You were management at Goddard and you're not here. Is that the difference?

BILLS: Well, I think so, yes.

CONWAY: A thing I know about Brent Sherwood is he always thought we submitted too many proposals and wanted that we submit fewer, better-funded ones, and we kind of stepped on his toes doing this.

BILLS: Yeah.

CONWAY: Did you know Lindy before calling her up?

BILLS: No.

CONWAY: Wow!

BILLS: I had not met her at all. In fact, I just saw her this morning. She's at JPL.

CONWAY: Is she here? Not surprised.

BILLS: But, no, I knew of her through this paper and that was all I knew.

CONWAY: Wow.

BILLS: But, you know, one of the things that we learned when we were being read the riot act for having stepped out of what we were supposed to do is that they were actually very pleased that Lindy was interested, because she was on the list of people they were trying to get to be PI. We got this sort of lecture. We also were given bonus checks for having done some of the work that we weren't supposed to do.

CONWAY: Sort of a mixed signal.

BILLS: Very much a mixed signal, yes.

CONWAY: Lindy told me that story, but when she told me that story, she left me with the impression it was a longer conversation, like over weeks, not in one phone call.

BILLS: That's actually probably correct. I think we had a phone call when we asked whether she was interested in this concept, and then I forget how much time elapsed, but we later called her and asked her about would she be willing to lead the effort.

CONWAY: So there had been some additional dialogue between those two moments.

BILLS: Yes.

CONWAY: Okay, great. Let's see. We didn't talk about why you left Goddard.

BILLS: Oh, well, it's complicated in several ways. So I first left Goddard in Maryland and moved to San Diego.

CONWAY: To Scripps.

BILLS: I was at Scripps, but I was still a Goddard employee, and I had talked to Dave Smith, who was my supervisor, I mean he was one step above me, and I said—Goddard and Scripps had set up a joint institute, a means of working together, and I knew someone from Scripps who was actually working at Goddard. My wife wanted to move back to Southern California, and I

thought, well, maybe I could take advantage of this joint Scripps-Goddard connection by moving to San Diego. And Dave Smith said, "Fine. If you want to do that, that's fine."

So we moved to San Diego, but I stayed as a Goddard employee and I had a research associate position at Scripps and had an office there. It worked out for me very well, but then after I'd been there for twelve years, Dave Smith moved out of the management position that he had been in when he approved me going there, and the person that replaced him said, "Who is this Bruce Bills character and what's he doing in San Diego? If he's going to stay as a Goddard employee, he's got to move back to Maryland."

So at that point, I picked up the phone and called people I knew at JPL and said, "I'm exploring returning to JPL. Is that doable?"

And I was told, "Yeah, sure." I had funding that I was going to bring with me when I came. So leaving Goddard, I left physically after seven years, but then I left my connection to Goddard when Dave Smith moved out of the management position that he had been in. I was summoned back to Maryland and chose not to do that, so it was complicated in that regard.

CONWAY: What did you do at Scripps? What kinds of research did you do while you were there?

BILLS: Well, this will astound you, but I was still doing gravity mostly, but I taught some classes and enjoyed that, and continued working in Bolivia doing fieldwork and stuff, although when I went back to Bolivia to look at the shorelines, I did it as part of a Goddard research thing. They were using this big salt flat that I knew of as a calibration target for the ICESat [Ice, Cloud, and land Elevation Satellite] mission. They had an altimeter and they needed a flat surface, and I said, "I know of a very good one," and so I met with people from Scripps that were going there

to use this salt flat that's on the bottom of where the lake used to be, and I spent part of the time I was there working with them, but part of the time I sneaked off and did some GPS measurements on the shorelines.

Most of my work when I was at Scripps was continuing my planetary geodesy gravity stuff, but also had started exploring Galilean satellites in Jupiter and gravity of other bodies, but I was mostly doing my own stuff, but was interacting with—there's a very good geodesy group at Scripps, and I had the advantage of—as I've moved, I've found that—I mean, this seven-year pattern that I followed, I didn't plan it that way, but when I was a graduate student at Caltech, the guy I've already mentioned, Al Ferrari, he was my thesis advisor, but he was a JPL employee, and he was very interested in how science organizations work and stuff, and he one time told me, he said he had been involved in a study recently that said that seven years was the right amount of time to spend at any organization, that after seven years, people consider you to just be part of the furniture, you know, and if you want new, exciting interactions, new people and new experiences, you should change jobs every seven years. I did that for a while. My ladder or two have been twice that long, and I'm at some point going to retire, but I haven't figured out when.

CONWAY: So the movement brings you to new people, new ideas and both helps feed your head and also, I guess helps you build a larger community around your work?

BILLS: Yes, yes. That has certainly been my experience. I've got people at JPL and at LPI and at Goddard that I know very well because I worked for years with them, so I'm, I think, better connected at that level than I would have been if I had stayed in one institution my whole career, although this business of sort of coming back to JPL, you know, what I did, I thought, "Well,

maybe I've spent seven years here and then go back to LPI for another—repeat the seven-year cycle." But that hasn't happened and is unlikely to happen.

CONWAY: Now, Psyche. We've talked about how you and Dave Winker got the idea together and invited Lindy.

BILLS: Yes.

CONWAY: So tell me how you guys get the payload finally chosen, because ultimately your lidar goes away.

BILLS: Well, okay. By the time Lindy had been designated as the PI, her job was to select the instruments. Daniel and I had come up with a list of instruments that we had told her about, but she needed to be the one that made the decisions about if you're going to do a magnetometer, which magnetometer. There's a group at JPL, there's a group at Goddard, there's a group at MIT [Massachusetts Institute of Technology, Cambridge].

CONWAY: There's a group at UCLA [University of California, Los Angeles].

BILLS: Yeah, there's lots of groups that do magnetometry. With gamma ray neutron spectroscopy, the options are more limited. Then the laser altimeter was initially obviously going to be Dave Smith and Maria [T.] Zuber that sort of owned laser altimetry in the solar system, but it emerged that the Psyche—let me back up.

So this was being done, trying to select instruments and trying to design a spacecraft were occurring concurrently and the spacecraft ended up having a number of new things. I mean, it has a propulsion system that was very different than had been in most spacecraft, and then the communication system, for reasons that I still don't understand, it was decided fairly early on that it would be an X-band system. I had advocated from the very first meeting that we had when Lindy came out to JPL and met with David [Y.] Oh, who was still at that point in time working for Brent Sherwood and we had this small group of people that were interested, but I had given my view of what the gravity investigation should look like. I said that we could do a better job of measuring the gravity fields, which is an important part of understanding whether the bodies differentiated or not, if we had a Ka-band transponder instead of an X-band transponder. But I was told by David Oh at that point that it was going to be an X-band, and I was never given a reason why. I'll get back to the rest of the payload.

So part of the process was choosing who's going to build the spacecraft. One option was to build it in-house, but it was deemed, given the various other things going on at the time, most of the spacecraft people at JPL were already very busy. Building it in-house didn't make much sense, so they solicited proposals from the usual suspects and some non-usual suspects.

It ended up that the company that was selected had never flown a planetary mission before but had flown hundreds of communication satellites around the Earth, and it was decided to go with that group. At a meeting after that selection had been made, I was talking to one of the people that was an employee of that company, and he was the first person that was actually involved in Psyche, so he knew a lot of background and stuff. He told me that Ka-band transponders is all they ever use.

CONWAY: At Maxar?

BILLS: Yes.

CONWAY: That's really strange.

BILLS: And I thought, okay, so this decision that Psyche should be X-band was even more puzzling, and at the present time, I still don't know why that decision was made to go X-band instead of Ka-band when it was not as good and the vendor for the spacecraft had never done that kind. They always did the better one because they were in this telecommunication thing where they needed a higher data rate. So I'm still in the dark on that.

But anyhow, I was stepping through the instruments. We got a magnetometer. Ben [Benjamin P.] Weiss is the guy who's involved in that. Then the laser altimeter got thrown off when it was decided that the camera system that's provided by [Michael] Malin's shop [Malin Space Science Systems], we're going to be close enough to the body and the stereo camera can do a good enough job of getting topography that we can dispense with one of the instruments, and because we have this X-band system, it's a very data-limited enterprise.

Now, just a side comment here. There's an optical communication test bed, DSOC [Deep Space Optical Communications] which, if it's still working when we get to Psyche, I would be very surprised if it's not used to bring back tons of data, because the instruments right now, the way things are planned, they're mostly going to be operating one at a time. They're going to be a sequence that will only use them when they're in their sweet spot. If it's decided that we move the orbit closer and closer, when you get very close, you start having problems that the

landscape's going by faster than the camera can keep up with, so you can, in principle, have high resolution, but it doesn't do you any good because it's smeared by the motion.

CONWAY: So you won't actually be able to do good stereo reconstruction because the images will be smeared.

BILLS: Yes.

CONWAY: So you needed lidar anyway.

BILLS: But it had been decided that we would do similar to what was done at Ceres and Vesta, which would be a big orbit initially to map the gravity field and understand, are there any funny aspects of the gravity field that, if we come down lower, are going to start perturbing the spacecraft badly. So the gravity, partly because it's free, I mean you've got a transponder, you're measuring the Doppler shift all the time anyway, you need it for navigation, so that will be done all the time, and you stay in a big orbit long enough to get a pretty good sense of what a long-wavelength gravity field looks like, and then as you come down, you keep measuring the gravity field better and better. I've even forgotten what sequence of which instrument is on in which orbit, but gravity's on all the time, but most of the others are not. The gamma ray spectrometer is the one that turns on at very low orbits because it has limited resolution, but the iron-to-nickel ratio is something that it can measure very well and that is a key component of trying to figure out what is Psyche like in the inside.

CONWAY: Right, the differentiation question.

BILLS: Yes.

CONWAY: That's fundamental to it, that and gravity.

BILLS: Yeah.

CONWAY: So I guess that explains roughly the payload selection, lidar goes away because you can do stereo reconstruction of the imagery from high altitude. At low altitude it won't work, but by then it doesn't matter because the topography is not changing, we assume, anyway.

BILLS: Yes, yes.

CONWAY: So I didn't ask you, you and Daniel came up with this mission concept, but neither of you want to be the PI. Why not?

BILLS: Well, I had seen, from watching Dave Smith and Maria Zuber in their various missions, being a PI takes a lot of time and effort doing things that are not directly science, and I thought I would rather have the freedom to pursue the science. I'd like to be involved in the Psyche mission, and if things had turned out differently, I would have liked to have had a bigger role in the gravity investigation than I have. There's an instrument suite and there's a bunch of people involved in it, and I'm one of the sort of peons in that, but, assuming that the spacecraft stays

healthy and it gets into the orbit it's supposed to be in, it will do a semi-okay job of measuring the gravity field, but it's not a gravity mission per se. I mean it's not a dedicated gravity mission. If we were going to Psyche to measure the gravity field, there are various options we could have explored to do a much better job, but that's not what's been selected.

So the direct answer is that being a PI involves work of a type that I would prefer not to do.

CONWAY: That's a fine answer. It's a perfectly fine answer. So then you work on other gravity things. Do you have a role, for example, in [Europa] Clipper's gravity work?

BILLS: Yes.

CONWAY: Because you had done a paper on multiple flyby and gravity.

BILLS: I proposed to be on the gravity team. I even proposed to lead the gravity team and was not selected for either of those. I do have a minor role on the magnetic team. I had longtime involvement when NASA and ESA [European Space Agency] were both exploring Jupiter and Saturn missions, and I had been involved in the Europa Study for a long time, and then the intention was to measure gravity and magnetic field, but the person who had been leading the magnetic field investigation left the study team, and Bob [Robert] Pappalardo asked, "Is anyone willing to step up to do the gravity stuff?"

And I said, "Well, gravity and magnetics are both potential fields. They're nearly the same." I volunteered to lead the gravity investigation for a while and did that for a couple of

years. I was essentially tasked with exploring, "could a magnetometer on Europa measure the induction signal"—I mean, Europa's flying through a very strong magnetic field from Jupiter and it's a strong enough field that it produces signals in Europa that should be measurable.

So I tasked myself with deciding, can we decide, based on what we know about the magnetic field of Jupiter, and assume as little as possible about Europa and figure out can a magnetometer measure the induction signal well enough to be worth doing, and I eventually convinced myself that it probably could do a good enough job to be worth including a magnetometer, so I made a presentation to that overall team. I explained the calculations I had done and why I thought the magnetometer would see the induction signal well enough for it to be worth doing. But I was hoping that my involvement at that level would make me an obvious candidate to be on a magnetometry proposal, but Carol [A.] Raymond wrote a proposal and I was not included. We were at a meeting one time and she kind of apologized to me for not including me. So I have this very minor role in the magnetometry, but it was a big disappointment to not be involved in the gravity, and my involvement in the magnetometry is going to be minor, but, you know, it's interesting. And the spacecraft's getting ready to go, and I think it'll be—it's a long trip, but it'll be interesting to see.

CONWAY: We have about ten minutes left to go. Tell me what in your career did you wish you could do but weren't able to.

BILLS: Oh, jeez. I just mentioned that I would have liked to lead the gravity investigation at Europa. That didn't happen. That was kind of a big disappointment. Over my entire career, I would have to say—I don't know what you're looking for, but I have been mostly pleased

with—I've had the freedom to work on things that I was interested in, and I know a lot of people in science positions are constrained enough on what they can work on, it's a problem for them. But I've mostly been able to do what I wanted to do. Again, I guess the biggest disappointment was this Europa gravity team, but given my white hair, it's a long-enough-duration mission, they needed some younger people, and I understand that, but I at least had hoped to be involved at some level, but that didn't happen.

CONWAY: So then the flip side of that question is what's your career highlight. What do you think the best thing has been?

BILLS: Ooh. I'm going to go out on a limb and say the best thing I've ever done is something that I'm currently working on. We have a notion for, instead of using the Deep Space Network to send microwaves to Mars and to Venus to measure—the cornerstone of celestial mechanics, motion, motion in the solar system, orbital motions of the Earth, Mars, and Venus are constrained mainly by microwaves sent from Earth to Mars, and secondarily Earth to Venus. I'm working on a Laser Trilateration Network, where we would have pairs of spacecraft sending lasers back and forth between them. We'd have one orbiting the Earth, one orbiting Mars, and one orbiting Venus, and they'd be measuring distances to better than a centimeter for sure, and probably much better than a centimeter, whereas the microwaves can do better than a meter, but they don't do that well. So we're working on—there are a number of people, myself and the phone call that I got from Kris [Krzysztof M.] Gorski, we're working on an Interplanetary Laser Trilateration Network that will, if we can get it built and flown, will do dramatically better measurements of the positions of the Earth, Moon, and Mars, and therefore it will measure the

asteroids that perturb those orbits. It will also measure gravity waves and a frequency band, where the LISA [Laser Interferometer Space Antenna] mission that's going to measure high-frequency gravity waves, this will measure much better at low-frequency gravity waves.

So the reason it's a copout is it's not something that I've done yet; it's something I'm doing. But it, to me, has got some real potential, although how we're going to sell a billion-dollar project is hard to know.

CONWAY: It's not that expensive anymore, since the Discovery Program is running $800 million.

BILLS: Yeah, yeah.

CONWAY: Which is insane.

BILLS: Yes.

CONWAY: So it's both a new baseline for solar system motion and it has some additional scientific benefits, gravity waves you mentioned and so forth.

BILLS: Yes.

CONWAY: So actually it kind of makes sense.

BILLS: Good, good. Glad to hear it.

CONWAY: You just have to kind of sell it that way.

BILLS: Well, yes, we're trying to figure out how to sell it.

CONWAY: But that's one way, right? A new baseline plus you get additional science out of it.

BILLS: Yes.

CONWAY: My famous last question: what haven't I asked but I should have?

BILLS: Oh, my.

CONWAY: It's kind of a way of asking what didn't I know enough to ask about.

BILLS: You've done a good job. I'd like to think that having written up some stuff and sent it helped, but you've asked a good set of questions. There's nothing outstanding that I can think of. Maybe it'll come to me, and if it does, I'll let you know.

CONWAY: You know how to reach me.

BILLS: But for right now, I think this has been a pretty complete summary of my career and how it plugs into Psyche and stuff. I don't know.

CONWAY: Okay. Thank you.

BILLS: Oh, it's been fun.

[End of interview]