NASA SCIENCE MISSION DIRECTORATE
ORAL HISTORY PROJECT
ORAL HISTORY TRANSCRIPT

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INTERVIEWED BY JENNIFER ROSS-NAZZAL
LAS CRUCES, NEW MEXICO – 26 APRIL 2017

ROSS-NAZZAL: The planned maneuvers [for the Cassini mission]—it was interesting how they're hoping things are going to go through the rings and [plunge into] Saturn. Not elsewhere, where they think there might be life.

BEEBE: There's a database that they use for planning. The teams have this coded request and they submit it. It will be for a time interval, and there will be pointing demand and that kind of thing. That's all stored in a database called CIMS [Cassini Information Management System]. I'm slowly learning how to penetrate CIMS in order to retrieve useful information about the whole data set and the way it was acquired.

I decided "Well, okay." I looked at the little bodies, three of them. "Oh, that'll be easy. I can build a quick table for them, full description." Then I pulled the Titan [largest moon of Saturn] one out, and there's 10,526 requests. Now, these are for blocks of time to collect data, so there can be many, many, many files in one of those requests. We need to characterize 10,000 different requests to really get the information that should be stored for the future. Now, we won't be doing Titan anymore. Essentially that mission component is over, so I can start work on it without having to revise it and revise it, as I've done some of the others as the mission went on.

ROSS-NAZZAL: That sounds like a lot of work. That's going to become part of the PDS [Planetary Data System], this work on the CIMS as well?

BEEBE: Yes, this thing that I'm working on will be expanded. If you follow a line across, there'll be a description and you can understand what was involved there. I will simply build a very big spreadsheet that will be available for people to mine to get what they want out of it.

ROSS-NAZZAL: I thought we would start today by talking about the PDS. Maybe you can give us a history of when it was created, why it was created, what it includes.

BEEBE: In [January] 1996 there was a special issue of *Planetary and Space Science*. It described the PDS. Previous to that, there had been an ad hoc self-appointed committee that interacted with NASA Headquarters [Washington, DC] demanding an archive. Then COSPAR [Committee on Space Research], which is an international organization, came up with some criteria for how science should be archived. Out of that, Bill [William L.] Quaide at NASA Headquarters set up a prototype. It was PPDS [Pre-PDS].

At that point in time, there were most of the nodes that we have now [in the PDS]. University of Colorado [Boulder] had the [Planetary] Atmospheres Node, then they [NASA] moved to the Planetary Data System. I think that [contract] was competed, but these people who had already been in the prototype had so much advantage that it was just sort of a handoff. It was more forcing them to do a full description of what they were going to do. University of Colorado was not appreciated. They were actually trying to build interactive interfaces before

the web was in position. They were penalized for not rushing to archive all the old data that was decaying at that point, and they were not selected in the next go-round.

About 20 years ago, the Planetary [Atmospheres] Node was put up for competition. At that point in time, Lyle [F.] Huber, one of my students, had just told me that he didn't want a Ph.D., that he wanted a life. I probably pushed him into the traffic one or too many times. So basically I asked him if he wanted to apply with me for this node, and he said yes, so we applied and were selected. Lyle Huber is still downstairs working on this.

ROSS-NAZZAL: Did he end up getting his Ph.D.?

BEEBE: No, he didn't, no. He was really serious. Lyle is the kind of guy that you can walk in and make some comment about a sports event 15 years ago, and he's got great recall. He likes what he does. He's got a family, two kids that are now in college. As far as he's concerned, he's happy with his choice.

ROSS-NAZZAL: So you ended up competing for this, and you ended up winning. This is just for the Atmospheric Node portion? Or is this the entire PDS?

BEEBE: Actually, when they put out this competition they selected other nodes in other areas. To them there wasn't an acceptable Atmospheres Node, so they reissued a request for proposals. Before that, we were a subadvisory node for the Boulder node, so we didn't compete with them when they went in for competition. After they had been eliminated, then we did compete for it. We got it, and there have been several competitions since. We have been renewed. The last one

occurred last year, and I'm no longer the PI [principal investigator]. Nancy [J.] Chanover is the PI. She's one of my former students, and she's now my boss.

ROSS-NAZZAL: Would you tell us about what you proposed to do with the Atmospheres Node? In terms of what was different from UC-Boulder and what you were going to do to save all that data that was slowly dwindling?

BEEBE: In those days the PDS was an archive, it wasn't a public interface.

ROSS-NAZZAL: Can you explain what an archive is for a planetary scientist? I know what it is for a historian.

BEEBE: What we were basically doing was building data sets. When we finished a data set, we had a mailing list. We sent out CDs [compact discs] that contained the data sets so that the various institutions had their own copies of these data. Various people who were interested in this particular mission, this type of instrument would get those CDs and have them in their own desk drawer. It was a mail order place, because anyone who wanted one would just send a request and they would get the hard copy shipped in the mail.

The major concentration then, in order to get selected, was to recognize the data sets that needed to be preserved, to show that you had some expertise in this area, and then a plan of the time schedule in which you were going to get it done.

ROSS-NAZZAL: How far back did the archive go? I know, for instance, from looking at your book [*Jupiter: The Giant Planet*] that you did some work in London [United Kingdom] into the British astronomical archives. Was it going that far back, or was it just NASA missions?

BEEBE: The PDS is limited. NASA was not keeping good track of its data that it was generating. A lot of it was essentially lost. Not all of the Pioneer data, for instance, is available.

ROSS-NAZZAL: It just disappeared?

BEEBE: People just weren't archiving. The idea was that the PI owned the instrument, and it was his data and his team produced the science results out of it and the publications were the end product. It wasn't until this ad hoc committee—are you interviewing Ray [Raymond E.] Arvidson?

ROSS-NAZZAL: I don't think so. His name doesn't ring a bell, no.

BEEBE: Washington University, Saint Louis [Missouri]. He was much involved. He was the Mars component of the gang. Got Larry [Laurence A.] Soderblom on your list?

ROSS-NAZZAL: No, but he was on the Voyager team, correct?

BEEBE: He was too, yes. Ray [Raymond J.] Walker, UCLA [University of California, Los Angeles]?

ROSS-NAZZAL: No.

BEEBE: Those people were all involved in that. Got Jeff [Jeffrey N.] Cuzzi at [NASA] Ames [Research Center, Moffett Field, California]?

ROSS-NAZZAL: No, but I've seen his name multiple times.

BEEBE: He was the initial rings proposal.

JOHNSON: These are all names that we could go back and suggest [we interview].

ROSS-NAZZAL: We can suggest them to Dr. [James L. "Jim"] Green.

BEEBE: Those are all basic people that started with the PDS. Then there's this [journal, the *Planetary and Space Science* special issue on the Planetary Data System]. You'll want to take that reference because there are descriptions of all of the nodes except the Atmospheres Node, which didn't exist at that point in time.

ROSS-NAZZAL: Would you tell us about what you proposed, and then what eventually ended up happening here at New Mexico State [University, Las Cruces] with that node?

BEEBE: We proposed to essentially get the data, which had been safed in various NASA places, and transfer it here and set it up so that people could get to the documentation and create CDs. You had masters so that you had a mail order situation set up. It was basically retrieve the data that could be retrieved.

They had been dumping it in the NSSDC [National Space Science Data Center] at [NASA] Goddard [Space Flight Center, Greenbelt, Maryland], but in forms that were, in many cases, not really retrievable. We worked on the Pioneer data, the tapes that we could get, for months. They were labeled the "flyby of Jupiter." When we finally broke out the codes, we found out that all we had was cruise data on the way out. The other was lost. The cruise data wasn't very useful, because it wasn't documented. That was a lot of the kinds of things that we found. The imaging data for Pioneer was stored on microfiche.

ROSS-NAZZAL: Did it have vinegar syndrome?

BEEBE: It had syndromes before they ever stored it. There's a really nice color publication, special report of NASA [*Pioneer Odyssey,* NASA SP-349/396, 1977], that encompasses the Pioneer imaging, and that's about all there is. If you go to the UCLA PPI [Planetary Plasma Interactions] Node and look at Pioneer, they will have slots for the instruments, but they will specify that the data is uncertified. All they have managed to do is save the bits.

ROSS-NAZZAL: Did you try and reach out to the former PIs and ask if they had materials? Maybe those tapes?

BEEBE: Oh, yes. That's where I got these tapes that were supposed to be the Jupiter flyby. I went to University of Arizona [Tucson], where the PI had been. They looked, and they got me computer printouts on some stuff. They got me these tapes, but the tapes didn't contain what they claimed to have, so I didn't find it. It hadn't been archived in the NSSDC, it wasn't retrievable.

ROSS-NAZZAL: What a shame. How long did that process take, from the time that you found out you were going to be establishing this node until things were up and running?

BEEBE: That one was pretty quick, because NASA Headquarters had decided they just wouldn't have an Atmospheres Node. Then they got blowback from the community, so they put it in and implemented it. It was just an add-on, so that went pretty fast.

ROSS-NAZZAL: It was just you and Lyle? Or did you have other graduate students helping?

BEEBE: We had some graduate students, but the budget was very small because they had redistributed the budget. So now they had to come up with a pocket of money to fund it. When we first started, our node was underfunded compared to the others by quite a bit, so we were slow coming up.

ROSS-NAZZAL: At what point did you make the switch from mail order to being live and online?

BEEBE: I guess it was about 10 years ago that we started pushing to come online. The students were online before other people were, and the students are still better at it than we are. We still use undergraduate computer science majors to do a lot of our work. Something sneaky about this—we can pay students, but the university won't let us give students the salary that they deserve. They've got this upper lid. Many, many, many kids can be employed at peon labor [rates], but there's a gotcha that you can use—you can pay the tuition. So you can get kids that are really committed to helping you, and good ones.

ROSS-NAZZAL: Oh, that's a nice perk. Before you went live, were you accepting data in different formats? You had this mail order system, but the web was really coming into its own before 2007.

BEEBE: We were going to leave mag [magnetic] tapes because they require so much maintenance. The question then was what medium would we go to. It wasn't until a business association accepted the CD as their archiving medium that we made the shift. When they recognized it as a useful medium, then we figured it would be around long enough that it would be worth doing.

Those were CDs, then we transferred to DVDs [digital versatile discs]. By then we had Internet, but there were quite a few people that still wanted the data they asked for on the CD. So we had this transition period. Even now, a lot of what we design is trying to minimize the number of bits we transfer, because people don't have high baud rates where they're trying to work. If you're stuck in a hotel room and you're trying to finish a proposal, you want the

minimum amount of bits to dump that you need. We design our webpages to satisfy that kind of thing, as well as someone who wants the whole data set.

ROSS-NAZZAL: How long did it take you to make that transition from physical data to online digital data?

BEEBE: Several years. Because you can start it, but you still have to service the other one until everybody is up. People that are located at universities don't have a lot of money to keep up with the latest events, and that was slow in coming. The communication links were bad, so you had to be able to deliver on hard copy for quite a while.

ROSS-NAZZAL: Internet connection can vary.

BEEBE: Considerably.

ROSS-NAZZAL: Yes. Were there any significant challenges that you had to overcome when you made this transition?

BEEBE: No, Lyle was one of these guys who liked to play on the web, so he was up-to-date on it when we started. There wasn't that much of a problem. That was like 20 years ago that we started to be able to access the web.

ROSS-NAZZAL: I had read recently that you were managing the PDS node when it was in trouble. I was curious about when the node was in trouble.

BEEBE: The PDS node is always in trouble.

ROSS-NAZZAL: This was an award that you had won.

BEEBE: You've always got people complaining. It's amazing who they will complain to, they'll go to their senator to complain.

ROSS-NAZZAL: What are some of their complaints?

BEEBE: Just rage that it doesn't work. The standing joke with us is that there are people who want to put in their name and the title of their paper and have it spit out for them.

ROSS-NAZZAL: We understand that.

JOHNSON: We call it they want an easy button.

ROSS-NAZZAL: They think you can type in a [question], and the computer spits out an answer for you.

BEEBE: They all want the data in the format they want it, and that's almost a red flag saying this guy doesn't know enough about manipulating data to put it in his own form. You're going to let him go and let him run.

Dan [Daniel S.] Goldin [former NASA Administrator] used to talk about the brilliant sophomore in high school who ought to be able to do creative research if we had our system set up right. Well, that brilliant little guy ought to be learning something about instrumentation. If he's going to change the world, he should know how clunky some of these things are and be able to do something else instead of sucking up some kind of finished numbers that he applies somewhere.

ROSS-NAZZAL: I had also read that the [National Research Council] decadal survey [*Vision and Voyages for Planetary Science in the Decade 2013-2022*] mentioned the PDS and that it was so vital, so important to researchers that it needed to be supported. Can you talk about that? That was a recent publication.

BEEBE: I'll give you a little bit of history on the decadals. We're in our second decadal now, I think we're about five years into it at this point.

ROSS-NAZZAL: Yes, I think it came out in 2013.

BEEBE: Back when we did the first one, Ed [Edward J.] Weiler was managing the science division [Science Mission Directorate] of NASA. Astrophysics had done these decadal studies before, and he was an astrophysicist. He said he couldn't sell the other science components on

the [Capitol] Hill if he didn't have decadals. The decadals are generated by the National Science Academy [National Academy of Sciences], and the people on the Hill think the National Science Academy speaks truth.

They do, in the sense that they boil the subject down to the point that they really get to the nucleus of the problems. There has been a fairly longstanding relationship between the agencies—NASA, NOAA [National Oceanic and Atmospheric Administration], and the Academy. The Academy is privately funded, but what happens is Congress will decide that a study should be done on some aspect of NASA. NASA and the Academy then negotiate this. They define the terms of that study very closely and the cost value of it. It's a flat contract that the Academy takes from NASA, and NASA then gets the chance of reviewing the report as well and reacting to it.

It is really a good working system. He wanted that kind of credibility tied to things, so we did the first decadal study. I was the chair of the outer planets subcommittee. The way it's set up is you have a main committee, and you have subcommittees. The chair of the subcommittee is responsible for the report. Your cochair or your subchair, whatever you want to call him, [(this was the case)] is a member of the major committee, so he's responsible for integrating your component into the main one. Andy [Andrew P.] Ingersoll was the person for the outer on the first one. We did the review and recommended what flagships, what intermediates, and what smaller missions should be accomplished in the 10-year period and the characteristics of those missions.

When the first one was done, there was a lot of naïve approach to it, even inside of NASA. It didn't have the right cost constraints to really accomplish what they claimed they were going to do in 10 years.

So when it came time to renew that, in the second one, NASA Headquarters negotiated that contract so that any mission that was proposed had to be subjected to a preliminary costing. It had to fit in the right [cost] bucket, or you couldn't put it in that bucket in the report. I thought there was a major step forward when we did the second one. On the second one, I was only a member of the outer planets committee. Heidi [B.] Hammel was the chair and Amy [A.] Simon-[Miller] was the person who represented us on the main committee.

The comments about data archives and the PDS were generated in that main committee, so they looked at what was going on. One of the things that people don't realize is that the budget for the PDS is really small compared to the budgets that are set up for archiving at HST [Hubble Space Telescope Space Telescope Science Institute (STScI)] and astrophysics and the Sun-Earth and the Earth monitoring. We're much tighter in the way things have to be done. So no, we don't accomplish quite as much as some of the others do, but part of the reason is that we're not staffed to do all the cutesy little things that can be done. We don't publish glossy publications about what we've accomplished.

ROSS-NAZZAL: I think all I found was a little link to the database itself. That was it, I couldn't find too much more.

BEEBE: We're starting to argue, "We've got to do a better job of selling." We've got to get our community now to transfer over from this ODL [Object Description Language] system that they invented inside of [NASA] JPL [Jet Propulsion Laboratory, Pasadena, California] to an XML [Extensible Markup Language]-based system. The younger kids have no problem with it. The older guys are going to balk a lot unless they get stroked properly.

ROSS-NAZZAL: Can you describe the difference between the two systems?

BEEBE: The ODL has a label, and it's human-readable. It's either attached or detached to the data, but it belongs to that particular piece of data. When you go into an XML system, you've got a lot of structure in your label that links. You've got this label, and it's associated with that little piece of data, but there are links in there that will take you to the documentation that describes it.

When you take this data set that you've created, this bundle, and you put it through a registry, then everything that's in there has a unique identifier. So if somebody has generated a table in a paper, the first column will be the identifier. All people would have to do is take that and paste it in a request, and it'll come back.

It's like a DOI [Digital Object Identifier] for a journal article. Modern linkage is what's built into it. If you don't know anything about that and you unload this header, the first time you see it you go, "Good God." Unless somebody has told you. If you don't know anything about XML, just start at the bottom and read up, because the stuff that they're used to seeing is all still human-readable at the bottom. It tells you what the columns are. But the top then are the links to all of the related information that you might have in the archive.

ROSS-NAZZAL: Do you provide training for older folks who are used to a different format?

BEEBE: Actually, we have to migrate the old data to the new. What we're doing here, in our node, is keeping the old label. Now when somebody comes in and orders a product—which

would be the data file and the XML label—because the old label is small, they just get it whether they want it or not. If you belong to the younger generation, you use the PDS4 label. If you're one of the old guys and you don't want to change your software, you've got the [PDS]3 label. You can go ahead and do what you want until you retire.

The other reason we're keeping it is if we screw up in a migration, we can go back. We're not throwing it away. In XML, it becomes just another related factor. You have a link in the label for that, so when you want to fish them out, it comes out. That's part of the set that you pull when you ask for that URN [Uniform Resource Name].

ROSS-NAZZAL: When someone makes a request for this material, how long does it normally take?

BEEBE: We're automating it so that the length of wait they're going to have is going to depend on their own baud rate. We're reading the labels on a whole data set, setting up an index, and it will be the unique identifier and then the parameters are associated in the label that we've extracted. We build this help sheet so they can set their limits on the various parameters, and they can get it to the point that they're just downloading one product if that's what they want. Or they can do searches to figure out what's in it.

Since we've built the index which describes the whole data set, we allow them to download that too, and slice and dice it any way they want to. Then when they say, "Oh, there's only 20 files in here I want," all they have to do is copy those URNs, paste them into the sheet, and it will bundle that and send it to them. So most of the time is spent in the transmission.

ROSS-NAZZAL: How long is the migration intended to take at this point?

BEEBE: NASA Headquarters is pushing us to do it, but they're not coming up with the money to do it. They're starting to ask how much it would take to bring it forward. NASA does that all the time, "How much would it take to do this in six months?"

"It ain't possible, buddy. I can't go hire somebody for six months. The university requires me to be able to pay them for a year before they'll let me even advertise." That's this kind of thing that's going on now.

How do you prioritize them? The MESSENGER [MErcury Surface, Space ENvironment, GEochemistry, and Ranging] mission just finished producing all of its reduced data products. We're going to migrate it right away because the data set that we have is an ablation atmosphere. We already have a PDS4 mission to the Moon, LADEE [Lunar Atmosphere and Dust Environment Explorer], and we've already got that data implemented. We will migrate the MESSENGER so that we've got the entire data set for the community that's interested in that kind of atmospheric problems. That one will get pretty high priority.

We've got the Juno [to Jupiter] coming in. Juno was conceived and approved before we switched to 4, so that data is coming in as PDS3. We're going to migrate that one as it comes in. We already have their cruise data in house. We're migrating it so that when we get the first delivery, which will be June 1 [2017], it will go in as the dual option for people who are on their mission, who got their software all developed for 3, they can use the 3 label. The people who are outside and just starting to come in will use the 4 labels.

ROSS-NAZZAL: I'm curious about this data that's generated by American spacecraft. You mentioned you were working on the International Planetary Data Alliance [IPDA]? Can people from other nations, including China for instance, use the data that's in the PDS?

BEEBE: We're open to anyone. [Anyone] who can read English can come in and extract data. It doesn't matter what your credentials are, which means you got [to have] a pretty weird firewall.

ROSS-NAZZAL: How's that?

BEEBE: Because you've got to make certain that you've got the rest of the university fenced out of your area.

ROSS-NAZZAL: I see, that makes sense. You guys do a lot of work for DOD [Department of Defense] and other [groups]. Will you tell us about your work with the International Planetary Data Alliance? It sounds very interesting.

BEEBE: Years ago, ESA [European Space Agency] decided that they needed an archive, probably more than we do. The way ESA operates is that the countries that belong to the agency support ESA to develop a spacecraft, to have the program, and make the selections, that they're going to do. But then, the individual countries propose to build the instruments and support them. Their teams then have the first claim on the data analysis.

So for a while ESA was doing this, but the same countries that were doing this were complaining because their citizens didn't have access to the other data. They were saying, "If

you don't give our people access to all of the data, we're not going to support you anymore." It was like the left hand biting the right hand for a while. We had already developed our data system, and they sent a fellow named Joe [J.] Zender over. He spent a semester or so at the Small Bodies Node at the University of Maryland [College Park] learning what their whole structure was. Then Joe took what he liked about it back and set up the PSA, Planetary Science Archive, at ESA.

Basically, they were using a part of PDS3. That wasn't powerful enough to keep everyone happy, but there wasn't really money to decide to do a unique system. Because their users were already familiar with the PDS system, it made sense that they join us in the PDS4 development. They have been really aggressive in developing and moving forward, and moving their missions into the PDS4 mode. They have a Mars mission right now [ExoMars 2016] that's going to be their first PDS4 [based mission].

Then they've got BepiColombo [mission] that goes back to Mercury. That's a dual mission; it's two spacecraft [Mercury Planetary Orbiter (MPO) and Mercury Magnetospheric Orbiter (MMO)]. The other one, [the MMO], is Japanese [Japan Aerospace Exploration Agency (JAXA)]. For the groups to use [the data] they all need to use the same data system, so the Japanese are coming into the PDS4 database. They too have the same problem. They've all been Google-ized. So they all want this easy way to get stuff, but people have no funds to do it.

We've circled our wagons to solve the problem, and the system is pretty open. We did our best to put together an organization that wasn't administratively heavy. It's individually driven, actually. We have a face-to-face meeting once a year that will be in Berlin [Germany] this year in July, and we have telecons. We have a steering committee and a technical advisory group. Those are the only standing committees in the whole thing.

The system is based on identifying problems and defining a very well-defined project with a basic goal and a time schedule for doing it. Then somebody that's involved in either the steering committee or the advisory group will volunteer to chair that. They can pick then, from the various agencies, people to work on that together. The projects are all carried out electronically. We may, at some other meeting, schedule a day for people to get together for a real work session. When somebody implements something, the other people review it. That's working quite well.

Japan, India [Indian Space Research Organization (ISRO)], U.A.E. [United Arab Emirates]—they have an atmospheric Mars mission that they're working on, and ESA. Then the individual countries within ESA that are involved in development of instruments are also members. We're working on getting South Korea now [(South) Korea Aerospace Research Institute (KARI)]. They have a lunar mission [Korean Pathfinder Lunar Orbiter]. We're aggressive in trying to get everyone sharing, because nobody has really got the resources to do what the world would like to have.

We're barred from talking to China, so we can't deal with them in any way that is supported by any government funds. Individually, or if you're a private university and you can fence off a donor who is totally uninvolved with government, then you can have conversations. The Geo [Geosciences] Node [Washington University in St. Louis, Missouri] has done a little bit of that. The problem that we have had is every time we've established somebody in China who is really good to work with, they get promoted and they disappear. We don't have a critical mass of people.

When we have a meeting in Europe that is sponsored by a European agency, there'll be quite a few Chinese planetary people [that] show [up]. We're allowed to talk to them within a

group. The other ruling that we've had is it doesn't matter where people are from, if they come into our node, and we give them only the same kind of help we give everyone else, then we're not in violation of those rules. We don't have to ask them if they're mainland Chinese before we say, "No, that's not the way it works." But that's pretty frustrating, because I'm pretty sure that they've got a lot of development. I wouldn't be surprised if it isn't very parallel to ours, because XML is a very powerful way of hooking everything up.

ROSS-NAZZAL: I'm curious if you can talk about standardization with that committee, in terms of formatting. So many different groups have different ways of handling information and putting them into data sets differently. How do you handle that with so many different countries involved, so many different cultures? Probably even on the PDS, how did you institute, "These are the standards"? How did you tell the PIs, "This is how we need the data to come in, this is what we need you to do when you send it"?

BEEBE: The PDS4 was developed from the ground up, slowly. You start with a data model. The data model will be fairly simple when you first start, but it describes the standards. As you develop, if you're going to change anything you have to go back and change the data model so that it's pretty controlled.

Yes, there's a constant argument about which formats should be integrated in. If you decide that you're going to integrate a format in, then the type of structure that's allowed in that format is not everything that the entire community is using. It will be a very standard one. Anyone who's going to put data into one of our archives will have to adhere to that standard. There's a FITS [Flexible Image Transport System] format that the astrophysicists use. The level

of creativity that people demonstrate in that file is amazing, but the description for the PDS FITS is very standardized. You can do quite a bit with it, but you can't do some of the layering that people have done inside of [FITS files].

ROSS-NAZZAL: What sort of things can people include?

BEEBE: First of all, we like them to include ASCII [American Standard Code for Information Interchange] files as much as possible, because years from now people will be able to read an ASCII file. If it's just a table, then we really prefer for them to do an ASCII file with the simple XML label.

If something comes along that's better than XML, there'll be migration software. So if you've got the simplest possible structure in your archive, then you've got the one with the greatest longevity. If you've got an image, a 2D [two-dimensional] array, where everything is specified in the label, is the base that we would like to have. If it's a 3D [three-dimensional] then you want a simple cube.

A lot of teams in the past—with the pretense that it saves downlink, and I doubt it—[have hung] a lot of parameters off the side of every row of an image. You have to be able to decode all those parameters. Those are really forbidden. The image should be the image, and the documentation should be in other files. You're allowed housekeeping files.

ROSS-NAZZAL: What are housekeeping files?

BEEBE: Usually ASCII files, where you can put all this information that you want to save, instead of hooking it up inside of the data product. That's the part that's expensive, building the data model and setting up the structure to adhere to the data model. At this point in time, the PDS4 development is housed at JPL, but there's an IPDA representative on the council.

There's also a representative on the change control board, which is the group that have to say that a format could be acceptable. "You've got to go back guys, and fix the data plan so that it will accommodate this kind of thing." Basically, the people that are represented in the IPDA [committees] are out of ESA. A young engineer named Santa Martinez, that is really sharp and a terrific organizer, is on the committee.

ROSS-NAZZAL: We've spent some time talking about the PDS, and I stumbled across something that I wanted to ask you about. You and your husband [astronomer Herbert A. "Herb" Beebe] worked to ensure that there were certain papers of leading astronomers and other scientists like Clyde [W.] Tombaugh that his papers were going to reside here at New Mexico State University. I thought that was very interesting that, as astronomers, you saw the value in that, the importance in that. I wonder if you could talk about that.

BEEBE: Actually that's Herb's work. Herb retired fairly young. He got tired of being a department head, didn't want to be a dean, so he retired and got involved in that. He did the oral history of people who had known Clyde and worked with the library to set up that archive. So he learned a little bit about what it takes.

We had a friend [Walter Lwowski] who was a chemist. He had been at Yale [University, New Haven, Connecticut] and been part of a Nobel Prize team. He was born in Germany and

had lived there during the Second World War and had a great collection of German history books. We were his executors, and when he died [in 2010]—it wasn't in his will, but we took the risk. He was leaving everything he had to the chemistry department.

The chemistry department had an office there that was in as bad a shape as the house, so we contracted with the library. My lawyer said, "You're probably going to end up having to pay for that yourself," because it wasn't in the will. So I thought well, the best thing I can do is go talk to the guys in chemistry. I knew some of them. I took the archivist with me, and the archivist said, "We'll do the whole thing for our bid." The guys in chemistry just couldn't shove it out the door fast enough, because they had no idea what to do with it. The library was delighted especially to get his German collection, but he had enough history that they were interested in, too. Again, Herb worked with the library on that one. I didn't do that work.

ROSS-NAZZAL: You received credit for it, just so you know. The New Mexico State webpage [gives you credit].

BEEBE: I signed some of the checks.

ROSS-NAZZAL: Maybe that's why they put your name on it. I just thought that was interesting given his history, and the other folks as well that I saw, the papers that were donated.

BEEBE: I still end up as the consultant when people outside are looking for something for Clyde, and they're too naïve to know that there's an archive. They're usually absolutely delighted when they're just sent to the webpage.

ROSS-NAZZAL: It's a great resource, and it's nice to see that it got preserved. You did mention the decadal planning surveys, and I did want to ask about that. You gave us a little bit of a history on the first one, and you mentioned that of course they couldn't withstand the budgetary numbers. These missions were—to use the phrase—pie in the sky.

BEEBE: So had the astrophysics been. Now when NASA negotiates these with the Academy, they've got a definite section about realistic costing before you say, "This is the decadal plan."

ROSS-NAZZAL: In that first one that you participated in, did you reach out to other astronomers who weren't part of that group, just to get an idea of what other astronomers were thinking?

BEEBE: Oh yes, we had town hall meetings. The Academy does a very good job. When you're working on something like this, you have multiday meetings that they have planned. They bring in people who are not on the committee at all. I remember one of the guys saying when he died, if he made it to the golden gate [in heaven] he was going to check to see if they had [Microsoft] PowerPoint before he went in. You spend day after day looking at PowerPoint presentations of what you should be doing and what this group would like to have. It's a very detailed process that the Academy goes through. Then you finally put the report together based on the contract, and it goes up the chain of command in the Academy. It's heavily reviewed to see that what you're saying stays within their guidelines. When one of those is released, it's in good shape.

I worked on one of the [National] Academy of Engineering [reviews] on starting up production of plutonium-238, and the procedure is the same. The Space Studies Board presides

over the Academy of Sciences, the Academy of Engineering, and the medical group. People from all of those are represented on the Space Studies Board. The Space Studies Board gets a report from every one of these committees that are developing these studies.

ROSS-NAZZAL: What ended up happening to some of the missions that you proposed in that first decadal?

BEEBE: We just didn't make it through all of them.

ROSS-NAZZAL: Just lack of funding?

BEEBE: We won't make it through all of the ones that are in the next one, but it sets the standard. Then when NASA says that they want to do a particular mission, they have this well-grounded description of what that mission is, what the science goals were for it.

ROSS-NAZZAL: Were there any big debates for that first decadal?

BEEBE: Oh, yes.

ROSS-NAZZAL: Can you talk about some of those debates?

BEEBE: I don't remember that much in the outer planets. But when you start meshing them together and then saying that a comet mission is better than a mission to Uranus, that's where the

debates go. It's surprising what gets ironed out and what doesn't get ironed out as it goes along. In this last one, it was the Europa [Clipper] mission [to Jupiter's Europa moon] versus maybe a mission to Uranus or Neptune. That's tough to give that up because you know if you give it up you're not going to see it in your lifetime. So people fight it out.

ROSS-NAZZAL: I can imagine. Are there certain camps that you've come across?

BEEBE: Oh, yes. After we finished the first decadal, I served as the chair for a committee called COMPLEX for four years, I think. It was the Committee on Planetary and Lunar Exploration. Within the Academy, they have standing committees. They're the ones that accept these demands from the agencies to do studies. [As] that one was set up, it was peopled by people throughout all of planetary science to respond to these studies. Sometimes a study would be so specific that they'd go outside of that standing committee and set up another committee, but most of the time it's the standing committee that addresses this sort of thing. The standing committee has the right to isolate certain problems that they would like to address themselves, internally within the Academy.

ROSS-NAZZAL: During that time the President [George W. Bush] announced a new Vision for Space Exploration. Were you involved at all in discussions going on about, "we're going back to the Moon, we're retiring the [Space] Shuttle"?

BEEBE: No. After the *Challenger* [STS 51-L Shuttle] accident [in 1986], the higher-ups at NASA were really worried about the future of NASA, and that was done internally. The Academy didn't really participate in those decisions.

ROSS-NAZZAL: Talk to us about that second decadal survey. You obviously had learned quite a bit from the first one and were knowledgeable about, like you said, budgets. We have to be aware of the constraints that NASA has. What role did politics play? [Congressman] John [A.] Culberson, for instance, is really pushing that mission to Europa. Were there other people that you were keeping in mind?

BEEBE: No, the nice thing about the Academy is they really try to fence that part out. You're really trying to say, "Okay, this is the field. Where are the holes in our knowledge? How could you fill them? You've done this, this, and this. What's the next logical thing?" You can expect that anyone who thinks that they've got a big input into their community is going to be lobbying on the Hill to get things done, but that's not what you're doing when you're working for the Academy. You're herding cats when you're working for the Academy.

ROSS-NAZZAL: What were some of the major concerns of the group? What sort of things were people thinking, "this is what we would like to see achieved" for this next decadal?

BEEBE: When we did this last decadal study, we had the Cassini mission. It was functioning well. We had the Galileo mission [to Jupiter and its moons], and its probe functioned well. You

get some ground truth when you can go into the atmosphere and actually measure the components. You get some ground truth that you don't get otherwise.

One of the mid-cost mission desires was a Saturn probe that was going to finish the Cassini mission. That had to get into a bucket where the mission would cost less than $1 billion. One of the major things I did on the committee was to head up the costing study for a Saturn probe. I got to use the tiger team that JPL has for costing missions. It was fun to work with them because they're used to designing a mission that has a bell and a whistle for everyone in the whole community, but that wasn't the game we were playing.

The game we were playing is what you call the "floor of the mission." You specify what the science goals of the mission should be and then you design a spacecraft that will do that, period. That was the costing. The costing formula that they gave us was much more rigid than the one they're applying to the current New Frontiers [Program] missions that are being competed right now. It was really a tight squeeze to get it in, and it was fun to watch these engineers. Suddenly, they were digging a little deeper into their software than they had dug before. They were pretty sure if we didn't get that in that cost bucket, we weren't going to see it in our lifetime. That was fun to do.

Some of the other studies—I don't think the person from the committee was really aware of how much cost was going to play in getting missions lined up and selected. I think they allowed the teams to expand the cost of the mission more than was necessary. When you're trying to cost something like this, I'm all for designing a floor mission. By the time you get there to really build the mission, things may have changed.

An example of that was I wrote the text for a mission that would have sent a probe into Jupiter. A mission that would have done what Juno is doing but carried a probe. It got into the

decadal, and it got competed. When the guys at JPL and Scott [J.] Bolton started putting this together, they couldn't get it in the bucket with the probe. They began to realize that microwave sensing had advanced far enough that you could do a pretty good job of probing the atmosphere if you had [six] different microwave antennas on your spacecraft that were designed to look at different frequencies or wavelengths. One of them would be stopped by the absorption at a certain level, another one wasn't sensitive to that so it would go deeper. You could actually build a set of probes. So the guys out at JPL put together Juno with a microwave radiometer instead of the probe, and it fit the Frontiers budget.

Then NASA Headquarters had to question whether that fit the requirement of the probe or not. So Headquarters put together a subcommittee to advise them on this. The subcommittee said, "Yes, it does it." I was on that subcommittee. Not only did it do it, but it did something else better than what we had described, and that was because the spacecraft is rotationally stabilized.

When they take the spacecraft and it's coming this way [demonstrates] and they turn the spacecraft [90 degrees] so it's coming this way and it's rotating, the microwave sweeps across the planet. As it's making its sweeps, it's looking at the same cloud deck from many different angles. So the data that's coming out of those five sensors is not only probing to depth, but it's also getting the geometry of the cloud structures. That wasn't in the original plan. So their plan was actually better than the spec [specification]. We said, "Yes, this one is acceptable."

There were a couple others—I've forgotten which ones they were—where somebody had done something innovative to overcome cost. That's the way you want it. It's not cut-and-dried that you got to have this instrument and that instrument in order to do it. By the time they get around to doing it, there may be a better way to do it.

ROSS-NAZZAL: I think it's fascinating how you were able to work on that team and come up with all of that data for the decadal to figure out if it would fit those budget requirements.

BEEBE: We got to use NASA's costing expertise. [John Hopkins University] APL [Applied Physics Laboratory, Laurel, Maryland] and JPL volunteered to allow the Academy to use their costing expertise. That was part of the agreement of the contract, so that NASA Headquarters could trust the costing.

ROSS-NAZZAL: How long did it take you to draft those plans and to figure out that it would fall in those requirements, it would meet that bucket?

BEEBE: That probably took us six months total. You set it up so you meet about three times, working that costing and getting everything written up and justified and cross-checked.

ROSS-NAZZAL: Did you spend a lot of time working with engineers? You're an astronomer, but did you spent a lot of time working with those people working on spacecraft over the years?

BEEBE: When you're working on these, you don't even know who's who. You've got people whose expertise was computer science, you've got engineers, you've got physicists. You've got geologists, you've got meteorologists. It really becomes an integrated team, and as the mission progresses they share their knowledge and people become pretty well-versed in other people's fields.

ROSS-NAZZAL: What was the reaction of the planetary science community to the last decadal? Were they pleased with the outcome, or was there any outcry about decisions that were made?

BEEBE: I didn't get much blowback. There was something we put in there on purpose that got used later, and that was in the New Frontiers section. It basically allows NASA to choose a mission that's not in there. The reason for that was we knew Cassini was going to do the grand tour of the Saturn system, and we didn't know how rich that was going to be. There was lots of discussion about, "We can't define a Titan mission, because we don't know enough about Titan to define a mission." But this decadal report—the time it's going to span is the time that we'd probably like to do a Titan mission, if it turns out that Titan is very rich. So we put it in. All of our arguments, that I can recall, were based on protecting the possibility of doing a Titan mission.

It turns out that by the time we got done with the Saturn system, there are a lot of people who want to do an Enceladus [sixth-largest moon of Saturn] mission as well. So if you can get them in the New Frontiers bucket, the phraseology that was included in the Academy allows NASA that wiggle room. If these guys can really come up with these missions that are really worthwhile, they're competitive. Then NASA had to go back and write a description of them that was acceptable, so that the level of competition was the same for the missions.

ROSS-NAZZAL: I wanted to go back and talk about your time as disciplinary scientist at NASA Headquarters.

BEEBE: I was sitting here minding my own business—Herb had retired—and I got this phone call from Jay [T.] Bergstralh, whom I had known for a long time, asking me if I would consider at all coming to NASA Headquarters. I said, "Well, I would really have to talk that over with Herb." Within 10 minutes, Henry [C.] Brinton—whom I was really fond of, a truly honest man—who was the head of planetary exploration at the time, called me up and asked me when I was coming.

I talked to Herb, and Herb says, "Yes, it sounds like fun." We got an apartment in Crystal City [Virginia]. My salary was lower than what they had expected, because I'm from New Mexico State. I said I couldn't come unless I could keep my house. I have an old adobe down in the valley that was one of the original ranch houses. I got a housing allowance for the apartment, so we had the apartment and the house.

The first year I was there 100 percent of the time, but I still had graduate students. Amy Simon was finishing up, but she's quite an independent human being. We were used to talking to each other [by phone], too lazy to get up and walk downstairs, so there was no real problem with communication. Henry used to come and watch her communicate with me, because [around] 3:00 in the afternoon would be the time that she would make her communication with me. He had said that he would get her offices at the University of Maryland if she wanted to come and work with me, but that wasn't necessary because she was quite capable of handling herself.

So I finished working the first year there and learned all of the routines. I was managing the grant program for planetary atmospheres, and the data analysis program for the Galileo mission. The second year and a half that I was there, I commuted. I was there for two weeks

and here for two weeks. During this whole time, we kept the node going. That worked pretty well, too.

ROSS-NAZZAL: Were you on sabbatical from the university at that point?

BEEBE: I started out on loan. They have this program, IPA [Intergovernmental Personnel Act], it's renewable each year. I started to get pressure from a couple of the profs [professors] in the department that I should make my decision as to whether I was going to come back or stay. There was a young postdoc [postdoctoral researcher] in planetary science who thought the position was hers if I turned it loose, who was really pressuring me.

I decided, "I've produced enough students, I've had enough of this." I went to see the dean [E. Rene Casillas]. I told him that I would send him a letter asking him to remove me from my tenure-track position and put me in an ordinary staff position based on NASA funding, if he would guarantee that he would replace me with another planetary scientist. He said, "So what's the alternative?"

"You can't fire me. You loaned me to NASA. I'll stay in the position till hell freezes over." We knew each other.

He says, "I figured that's what you were going to say," so he agreed.

So I sent the letter. After I had been at NASA Headquarters for one year, then I gave up my tenure-track position and just worked as a staff person. That was in '98.

ROSS-NAZZAL: Was it tough for you to make that decision?

BEEBE: No, no. It gets really, really hard to keep teaching and trying to do good work and interact with the rest of the community. After all, how many people should you spawn? They were doing well, but how many do you keep putting out?

ROSS-NAZZAL: Did you enjoy your time at NASA Headquarters? It's a very unique place to be, and quite different from New Mexico, I must say.

BEEBE: I didn't have any problems with it. Henry advised me, when I first went there, to spend my money as fast as I could. It turned out to be really great advice. You actually receive your proposals, and you do your peer reviews before you know what your budget is going to be. You've got a rough cut, but you can't really set up your funding plan until after you know what your budget is going to be. But because you've got a rough cut, you can go through and set up a spending plan with possible high-water marks of what you can do if.

I would do the best I possibly could in funding the research I thought should really be funded in this plan. As soon as they told me what my budget was, then I would fill out all of my little folders and send them out to Goddard and get them out of the house. Nobody could take my money. And they do!

ROSS-NAZZAL: How much money were you overseeing at the time? Do you recall?

BEEBE: It was $3 million or $4 million in each one of those two slots, it wasn't huge. I also did a lot of internal reviewing. You're managing a series of proposals, and most of these proposals

span three years. You've got the ones that you're just funding out, and then you've got the ones that you're harassing to get their reportage in so you can keep things going in the right order.

I got quite a bit of help from a couple of people at Headquarters on how to set it up and what to do. How to minimize it, and how to make friends with the people that were going to handle the stuff out at Goddard to move it forward to get the contracts moving.

Something I found really unbelievable was a lot of the people that were working at Headquarters seemed to feel that it wasn't necessary to develop a good working relationship with the person that was going to be handling their stuff. I got some advice that I really should just get on the van and go out to Goddard and meet these people and set up some kind of agreement and arrangement.

What I agreed to was that when I sent one of my folders out, it would be in the envelope and there would be a sticky tag fastened to it, white with big black letters, that had my name on it. I guaranteed that everything they needed to process that would be in that envelope before I sent it. The other people were sending stuff that was incomplete, and then these people [at Goddard] would have to worry about all the communication and getting the pieces. When I talked to these people, I found out that their job assessment had to do with how many pieces they handled in a day.

If you're going to make friends with these guys, you guarantee that your piece can be handled. If there's anything weird about it, that's in a note right on the front of the thing. I had no problem working with them. One I inherited, the atmospheres one, was pretty messed up. Working with those people, we found money that was buried and could fund a couple of rocket-type development projects that weren't originally in the budget.

ROSS-NAZZAL: Was there any project that you funded that you really enjoyed the proposal, and you were surprised to see it come across your desk?

BEEBE: No, I don't remember that. Most of the things I remember are the kids who got their first grants when I was taking care of it. Bob [Robert T.] Pappalardo, who's the [project] scientist on the Europa mission, was one of them who got his first grant when I was working on the Galileo data analysis program.

ROSS-NAZZAL: So you've seen some of these people grow up essentially and mature into professionals. That's exciting. You came back to New Mexico State. How was it different, no longer being a faculty member and being a staff member? Was it a big adjustment?

BEEBE: I don't have to go to meetings! I can pick and choose. I don't have to worry about the state budget; I don't have to worry about the national budget. I used to have to worry about both of them.

ROSS-NAZZAL: One item we hadn't talked about—and I guess we're jumping around, I apologize—we hadn't talked about your work with the Hubble Space Telescope and I didn't want to overlook that.

BEEBE: Yes. Hubble was delayed in its launch for quite a while.

ROSS-NAZZAL: I was going to ask what impact that had on your research.

BEEBE: I chaired a group of people, and we put together a team and proposed a rather large observing program for both Jupiter and Saturn. We put our proposal in and there were the delays, but we got it accepted. We implemented it like half a Jovian year later than what we thought we were going to do initially. It included both imaging and spectroscopy of both Jupiter and Saturn, and it was for multiple years. The first time they advertised that was allowed, but before we finished up that proposal they had revised it. The load on the system was great enough that they had revised our observing program.

There was another series of events that were interesting. After they had launched Hubble and found out that the [mirror] had a problem, Saturn decided to have its most spectacular storm that it's had in photographic history, while the engineers were still using the spacecraft. The storm was observed by an amateur as a big white spot on the equator. The last one of those had been like 30 years earlier.

Ed [G. Edward] Danielson was on the camera for HST. He was out of Caltech [California Institute of Technology, Pasadena], a real good guy. I called Ed, and I said, "Ed, this is big."

He says, "Well, meet me at the Colonnade and we'll see what we can do." That was the hotel that was nearest the Hubble Space Telescope [STScI]. He had arranged for us to go out to dinner for steak and beer with two of the engineers. We discussed what it was that we had, and what we would like to do with it. They found it interesting because we wanted to do the same thing orbit after orbit after orbit. We just wanted to monitor the storm, multicolor-monitor the storm. We went to see the director [Riccardo Giacconi] the next morning, and he immediately

went like this [demonstrates]. He was a rather pompous Italian guy. To show us how impossible this would be, he called these engineers in.

ROSS-NAZZAL: Not knowing you had talked to them earlier.

BEEBE: They listened to him, and they said, "Well, maybe we could accommodate that."

"Okay, if the Wide Field Camera crew will accept this, we'll give it a try."

So we monitored, and that poster up there, the far one [demonstrates], is the result of that sequence of observations.

It was also interesting to watch the team, because the team had a bunch of astrophysicists on it that thought that planetary was second-rate science. But as they started on the deconvolution of these images, the sharp edges that Saturn's rings have, they really got turned on to it. Everybody was having really a great time on this. We got that set of observations before anybody else got anything out of HST.

ROSS-NAZZAL: That was before the mirror was fixed?

BEEBE: That's right, they had to be deconvolved. It was a major step to do them.

ROSS-NAZZAL: One of the other things I had read that you were involved with was a comet that was going to hit Jupiter [in 1994], the Shoemaker-Levy [9] comet. You spent some time out there doing some work with HST. Would you talk about that?

BEEBE: Again, I did a backdoor kind of thing. As soon as I heard that was going to happen, working with the person at HST that I knew, I put in a proposal to observe it. An open-source proposal so that anybody could use the data we got, that was to make certain that it was an open source. Headquarters started to get proposals, and the other proposals weren't quite as up on how to make certain you got what you wanted.

They ended up then setting up a campaign, and they picked Heidi Hammel to head the campaign. Andy Ingersoll, myself, [John T.] Clarke from [University of] Michigan [Ann Arbor], [Arvind] Atreya from Michigan—I've forgotten who else was on the committee. Some of us took graduate students with us to work on it, and it was an event.

Of course, HST hadn't had an event yet, so that when I saw the first stuff coming in, I was, "Oh shit."

ROSS-NAZZAL: Why's that?

BEEBE: "Here comes the press. Ay-ay-ay, what are we going to do?" I asked the gal who was heading up the group for two people on her staff to help us process images for the press. By the time she decided I could have them, those kids were already in there working on the images. They were so turned on with it. They would have spent their nights working on them if she hadn't released them to do it.

Right away, because Andy and I had worked on Voyager, we talked the people who were handling the press into the bull pen approach. We introduced them the day before to what was going to be released the following day, what was anticipated, which pieces were coming in, which others would be coming around to be seen again. It was lots of fun to work on it.

ROSS-NAZZAL: In your book, you talked about what you anticipated was going to happen. Is that what actually happened, what you observed?

BEEBE: No. What actually happened—when a piece would come into Jupiter, it was running into so much resistance that it was vaporizing pretty much immediately. It had to go somewhere, and because this pathway that it had come in on had been heated, that was the path that had the least density. So it blew right back out, out of the path that it came in on. And it blew high enough that when it came back down under gravity, it was hitting the atmosphere at such speed that it superheated. Essentially turned everything to carbon. The big black clouds that formed—and they were really in the upper atmosphere—were the result of the fact this thing went in and then blew right back out.

It turned out that there was this group up at Sandia [National Laboratories, Albuquerque, New Mexico] who had been doing modeling of particles entering the atmosphere. They had the software pretty much ready to go, and they did some real nice modeling of the rejection of the particles.

ROSS-NAZZAL: How long were you up there working on the comet that was coming in?

BEEBE: Two or three weeks.

ROSS-NAZZAL: I thought it was an interesting event to be involved with. Were there other things that you used Hubble to look at over the years?

BEEBE: Jupiter and Saturn, I continue to get time to use the system for them.

ROSS-NAZZAL: Was that exciting for you seeing the [STS-61 Shuttle] crew out there fixing the Hubble, seeing their EVAs [extravehicular activities (spacewalks)]?

BEEBE: Yes, I actually met them at NASA Headquarters after they had finished the repairs and were there to get a little award. They were pretty funny.

ROSS-NAZZAL: We've interviewed some of the crew. They had an interesting crew.

BEEBE: Oh, a really neat one was that Collins—was that the first female [Shuttle] commander?

ROSS-NAZZAL: Yes, Eileen [M.] Collins [became the first female Shuttle commander on STS-93 in 1999. The mission deployed the Chandra X-ray Observatory].

BEEBE: When she came back down and was at the spaceport in Florida, Dan Goldin went down, and [singer Judith M. "Judy" Collins] had written a song about the other Collins. Dan Goldin thought this was really great, so he invited her to come to Headquarters for the presentation for the crew. She was going to [present a concert near] DC anyway, so she accepted his invitation.

I was at Headquarters then. So we came [attended the presentation], and it was really neat to see the two Collinses because they were highly impressed with each other. It was like two fans meeting. Then Dan Goldin had her sing her song, and he stood up there and he had

tears down his face. He says, "Oh, doesn't that bring you back to the '60s?" Judy said, "Sir, if you remember the '60s, you weren't there."

JOHNSON: That's funny.

ROSS-NAZZAL: Did you ever get any opportunity to go down to the Cape [Canaveral, Florida] and see any launches other than Voyager 2?

BEEBE: That's the only one. I've had invites but didn't bother.

ROSS-NAZZAL: Too busy working on other things?

BEEBE: Yes, and it's not that exciting.

ROSS-NAZZAL: It's pretty awe-inspiring, I think.

BEEBE: The one I'm waiting for right now is much more exciting to me.

ROSS-NAZZAL: Oh, Cassini?

BEEBE: And did it make it through [the rinds]? It won't start to talk to us until [April] 27 [2017].

ROSS-NAZZAL: I imagine you're on pins and needles for a while. One of the other things that I had read about your career was that you managed the Tortugas Mountain Observatory [Las Cruces, New Mexico] for a while.

BEEBE: Yes, that was monitoring Jupiter and Saturn for the Voyager program. We continued after that, too. As time went on, I transitioned away from Clyde Tombaugh's team. [A.] Scott Murrell stayed with this, and he was a rather crusty little New Mexican who made a fabulous transition from working in that staff culture to working in the department with the graduate students. He loved the graduate students. He took them up to the mountain. He taught them everything he knew.

One of them converted him from a photographer into a CCD [charged-couple device] camera observer, handling the computer. The relationship they developed was practically father and son, just terrific. He taught Nancy [Chanover] how to drive a four-wheel drive vehicle with a stick shift. He had a pickup, and he helped the kids move when they needed to move. He just became the friend of the kids. The standing routine was that he was always 100 percent behind me, unless it had to do with a student. Then I was dead wrong. Basically he did most of the observing, or was introducing students on how to do things.

ROSS-NAZZAL: How has the astronomy department here changed since you started in '74? You've seen a wide period of time.

BEEBE: When we first came here in '69, they had just started the astronomy department. They hadn't recruited graduate students. Herb was involved in setting up the initial recruitment of

graduate students. He was just fresh out of graduate school himself at that point in time. The entire reputation of the department has developed over this period of time.

The [department carried] on, working very hard to recruit and produce the best students we could to build up a reputation. Then the department got involved in developing Apache Point Observatory [Sunspot, New Mexico] in conjunction with Princeton [University, New Jersey], [University of] Chicago [Illinois], University of Washington [Seattle], and Washington State [University, Pullman]. I think that was it when they started. That has continued to build and be developed. Various original partners have pulled out and new ones have come in over time but having that large facility has really helped the department.

As we started to get involved in that, Jack [O.] Burns joined us as department head, and he's an aggressive pusher who gets things done. He's at the University of Colorado now. He recruited a couple of pretty outstanding faculty. One of them is a cosmologist, so that opened up the theory a little bit in the department. It's a good department.

Recently, the university competed to take over Sacramento Peak Solar Observatories [National Solar Observatory at Sacramento Peak, Sunspot, New Mexico]. They didn't get that, but in the process of competing the university opened up two solar physics positions. We got really good people into those. So we've seen an ongoing evolution that's been really good.

ROSS-NAZZAL: Sounds like the department has grown quite a bit since you've been here.

BEEBE: It's a small department, but it's a very successful department. We're not very threatened by upper administrators. They don't want to mess us up because they get overhead out of us. For every dollar we spend, they pull out 48 cents. That's their wiggle money.

ROSS-NAZZAL: I wanted to ask you about your work with the Division for Planetary Sciences [DPS of the American Astronomical Society]. I know you were a member of that, and also you chaired it for a year.

BEEBE: I was on the council first [from 1982 to 1985], and I was the first female to be elected to a position in the DPS. That was a council position. Then Carle [M.] Pieters was elected as chair a couple years later. I got this call from Faith Vilas [on the DPS Nominating Subcommittee] asking if I would run for the chair. She said, "We'd like to put you up because we don't think the guys will notice you're a girl." Because I was working with the guys all the time.

ROSS-NAZZAL: That's kind of an odd comment to make.

BEEBE: Faith is blunt. They elected me as chair [for 1992 to 1993]. That was during a period of time when NSF [National Science Foundation] decided that they weren't going to fund planetary science. I was talking to Jurgen [H.] Rahe, who is gone, and Vern [Vernon L.] Pankonin at NSF. We were trying to figure out how to stop this.

At the same time, the university hired two young physicists who had grant money from NSF, and they paid them considerably more than I was being paid. So I complained to the graduate dean about this, and he sent me back this letter pointing out that their research was much higher quality than mine because it was funded by the NSF, not NASA. I faxed this to Jurgen and Vern. We wrote a letter to the head of NSF asking him to consider this attitude that academia had about NSF and not make the decision to stop funding planetary and turn it into a

second-rate applied science. It worked. That was a major action that I got done when I was chair of the DPS.

ROSS-NAZZAL: Wow, that's a big coup. Did you do any work at all with Congress or the [presidential] administration at the time?

BEEBE: A little bit. We weren't in danger there at the time. There was a guy at the University of Texas [Austin], Harlan [J.] Smith, who mentored me on how to go hit the Hill. So we did a couple of times. That was very interesting.

ROSS-NAZZAL: Any memorable anecdotes or any folks that you remember meeting?

BEEBE: Actually, they're negative enough I shouldn't talk about them. Because Harlan was well known, I was seeing the staff behave as they always do—"What are we trading off to get this? What are you supposed to do here?"—addressing the senator and shoving him out the door to go vote.

ROSS-NAZZAL: We talked about the decadal surveys, and you mentioned some of the other reports that you had worked on, one of those being the report on plutonium [*Radioisotope Power Systems: An Imperative for Maintaining U.S. Leadership in Space Exploration,* 2009]. I was curious about your involvement in that, because plutonium is so important for space science missions, particularly missions to the outer planets. I was wondering what your thoughts were

about that report and the production of plutonium, and why it was so vital to U.S. space missions.

BEEBE: First of all, there were two people from [the National Academy of] Science who were assigned to that committee, Ralph [L.] McNutt [Jr.] from APL and myself. We both worked on the outer planets. The idea was that this committee needed that sort of [science] input, as well as the technical input, to do the best argument we could.

Basically we ended up arguing that without plutonium the exploration of the solar system was not going to go much beyond Mars. You're really limited when you use solar [power] out at Jupiter. That was really a fun committee to work on because I was exposed to people that I had never been exposed to before that had real expertise and real understanding of things. Yes, it was something that was very important to us.

We bought plutonium from Russia, but then there was no more plutonium to buy there. They were willing to sell it. The Russian space exploration [program] is more like a business. If they can get some money, they can keep it for their own purposes. So it was possible to buy from them, but they aren't making any more. The facilities that might have made it are being used for medical isotopes, and that's a lot more profitable.

Basically, the problem was that either we were going to really limit the exploration of the solar system, or we needed to start up plutonium again. It turns out that the atom that we need to bombard to make plutonium, neptunium, is pretty stable. We made quite a bit of that, and we've got it shelved. So we don't have to start all the way down the chain if we want to start up again. What we really need is the processing facility to remove the plutonium from the targets and pelletize it and to reconstruct the targets and send them back.

We've got enough neptunium to build the targets. We've got reactors. If you want to make plutonium-238 instead of plutonium-235, which is the nasty stuff, you want to put your targets as close to the reactors as you can get them. When the military makes a run, those holes are normally empty because they don't want that stuff. It's totally useless to them, and they can't process it.

So the argument was that the facilities are there to make plutonium. The facility to refine it and get it out is the piece that needs to be brought up. This study that we did was part of something that Jim Green had implemented. He set aside some money to seriously look at what it would take to start up the production of plutonium-238. Then he committed a contract to the Academy to do this study. The people they brought in were people who had worked on reactors and understood all of these steps, and it was just really neat to work with them.

ROSS-NAZZAL: Did you get any pushback from people saying, "We went to the Moon, certainly we can come up with some other way of sending spacecraft into orbit"?

BEEBE: No, when you pointed out that you needed a good energy source to operate your instruments and to have a powerful enough signal to get it back home, I didn't get any blowback from people. The idea [was] that this kind of thing was really going to limit us.

With Juno it's solar-powered, so we collect our data when we go in. The teams are perfectly happy staying in a 53-day orbit because that gives them plenty of time to dump all their data. There'll be no data loss. You put it on board, and you hold it until you've pulled away from the planet. Then you download it. You've got to download it slowly, [because] you've

got to keep charging your system. To do it at Saturn or Uranus is just four [or nine] times harder than for [Jupiter].

ROSS-NAZZAL: The production has started, I heard when we interviewed Jim Green. That's going to be exciting, because I'm sure it impacted missions as you were working on the decadal. If that production wasn't there, what could you do?

BEEBE: The amount that can be produced is still small. It'll need to be accumulated. We were getting down to the point that you couldn't even heat spacecraft on the Moon or on Mars at night. Night is kind of long on the Moon, if you're going to put a station up there and do something with it.

ROSS-NAZZAL: Speaking of Mars, you chaired a committee to review Mars architecture in 2006 [Committee To Review The Next Decade Mars Architecture, *Assessment of NASA's Mars Architecture 2007-2016*]. I thought was interesting, given your knowledge of the outer planets, that you would be asked to look at Mars architecture. Can you talk about that?

BEEBE: When I worked for the Academy, the committees that I chaired delivered on time. The Academy would ask me to chair a study where it was critical that we get it out of the door at the right time. That was the one where NASA Headquarters wanted really serious consideration of where the holes were in their Mars plan. A team was put together, we used well-known people that had worked for the Academy in a constructive way before. We knew if they said they could work on it, they would work on it, and we could get the job done.

The conclusion of that was that there were two holes in the plan. One, there was no exploration of the interior of the planet. Two, there was no study of the rate at which the current atmosphere was being lost, so it was pretty hard to say that you were building a model that would tell you what atmospheric loss had gone on over the past. Those were our conclusions.

What were the two small missions that were selected for Mars? MAVEN [Mars Atmosphere and Volatile Evolution], which does atmospheric loss, and InSight [Interior Exploration using Seismic Investigations, Geodesy and Heat Transport], which does the internal structure study—we did what they needed, and they filled it with a Discovery [Program] mission.

ROSS-NAZZAL: There were just a couple others I wanted to ask you about. You served on *An Assessment of Balance in NASA's Science Programs* in 2006. Basically the [Space Studies] Board was pretty critical of what NASA was being asked to do with the fact that it really wasn't receiving much funding.

BEEBE: I don't even remember that one.

ROSS-NAZZAL: It seemed like you had so many. You did one other that I thought was interesting, in 2008 on the New Frontiers programs and the announcements of opportunity [*Opening New Frontiers in Space: Choices for the Next New Frontiers Announcement of Opportunity*]. I wondered what your thoughts were on the New Frontiers program.

BEEBE: Did I do that for the Academy or Headquarters?

ROSS-NAZZAL: It was for the Academy, that I downloaded all these reports from. I know after a while you work on some of these and they all blend together.

BEEBE: They just blend together.

ROSS-NAZZAL: I wanted to ask if you would talk a little bit about working with scientists from all across the globe. We've talked about you working with NASA and Headquarters, and your work with Voyager and some of the other missions. I wonder if you would talk a bit about that.

BEEBE: I think planetary science is probably more international than a lot of the other areas. One of the things that NASA has allowed is for countries to propose to build one of the instruments and be part of the teams, so there's been that kind of integration. For quite a long period of time, NASA was the lead in terms of providing science data in planetary development, especially Mars exploration. There's a tradition of working together.

When you work on these things, you become friends. It's necessary to become friends. There's not a lot of socializing—you get to know the people in terms of what they can do, what they can deliver. You ask them for what they can deliver, basically. That leads to pretty tight working groups because, "Okay, we've got this hole, we need this kind of thing done. Who can do it?" It may pull them in from different countries.

You develop a lot of interactions, to the point that I have trouble remembering last names. We never use them. "How the hell should I remember that name?" It's that kind of thing. As I have grown older, people have gotten kinder. They take care of me if they want something out of me.

ROSS-NAZZAL: They're being respectful. You've done some work with NASA and with ESA, JAXA, I presume some of the other agencies. Would you talk about some of the differences between those groups, if there are any, that you've noticed in working with them?

BEEBE: One of the things that inhibits [others] is the fact that they have pretty rigid approval structures. "What can you say you can do? How many people do you have to get to sign off on it before you can say you can do [it]?" In working for NASA, if you can stuff it into your day, you can do it. You have quite a bit of freedom of choice. If you really want to make a personal commitment to do something, they're not going to step in and stop you.

I find that the chains of command are more rigid in some of these countries. Japan is known for being pretty rigid, but I think it's harder to move things up the chain of command in India. India has got some other problems too. The space program has trouble staffing, because we've outsourced so much stuff at higher salaries than their government can pay, they're constantly struggling to keep the places pretty well-staffed. Japan is in a state of reorganization now. The one guy we have been working with is staying with our programs though. But you can see that he's waiting for decisions to be made on what's going to be done where.

The U.A.E. is struggling to come into space exploration. The U.A.E. is struggling in general to diversify its capabilities. They figure they've got 20 years of oil [remaining], so they're trying to get into various other activities.

ROSS-NAZZAL: Yesterday you showed us an interesting image that an amateur astronomer had provided to you of Saturn and its rings. Sandra and I were talking when we left, and we were

curious what amateurs have contributed to the field. What have they contributed that you wouldn't have known, or NASA wouldn't know or have access to without their work?

BEEBE: That Saturn storm was one where it was an amateur who discovered it and started the report going. They've been looking for impacts on the Moon. There's a gang that does this. They monitor Jupiter. If something happens on Jupiter between this perijove and the next perijove, or if it's on the other side of the planet when you go by, they'll fill that in for the mission.

The ground base is going to be an interesting baseline for the Juno mission. That's being pursued actively by the mission itself. Glenn [S.] Orton is heading up the interface between the amateurs and the mission. Candy [Candice] Hansen-[Koharcheck] is handling the camera, the JunoCam camera, but I don't think she's doing that much interaction. She's providing stuff to the guys. I myself am going to do a little tutorial and send it to the microwave guys, just a little heads-up, "Hey, this isn't quite like Voyager. Don't use Voyager to interpret it."

ROSS-NAZZAL: How have ground-based telescopes changed since you've been in the field?

BEEBE: They're not being used for planetary very much anymore, not the imaging ones. The big infrared telescopes, the interferometers, and that sort of thing are being used quite a bit. Conor [A.] Nixon at Goddard is utilizing some of that and getting some nice results out of Titan. That will carry on after Cassini. Some of the big telescopes with adaptive optics out in Hawaii are making contributions to Uranus and Neptune. It's much more longer-wavelength that is now being done.

ROSS-NAZZAL: If you look back over the span of your career, what do you think was your greatest challenge?

BEEBE: Me, it was me. My folks had a farm-ranch in southern Colorado when my mother married my father. She was a schoolteacher who came to the district to teach. Then we had the seven years of drought. They not only lost everything, but they went deeply in debt with federal loans. So I grew up as an Okie. That was the pocket that society put me in. My sister, just younger than me, once characterized us saying, "When people know that your mother is poor, pale, Protestant, and prolific, they know you're trash."

I grew up with people looking down on me, and smart enough to know they were, and smart enough to know that they didn't have any grounds for doing it because they weren't so special themselves. So I didn't have a whole lot of confidence, and there wasn't a whole lot of support for females to do things. When I applied for graduate school, I didn't apply for funding. I assumed I couldn't get it. It was Marshal [H.] Wrubel who came back with a letter saying why hadn't I applied. That was the level of confidence that I had about things.

I had developed quite a bit of computing skill, so when I started working in planetary there was a niche that I could fill right away that wasn't fully filled at the time—someone who had the science background who could also code. It was a long slow process.

Interestingly enough, there were a lot of guys that if you were to ask them now, they would tell you they mentored me. They did, and they meant to. They helped. It was a lot of positive support. Part of that was because when they gave me a job I finished it for them, which is the way you really establish credibility in the planetary group.

ROSS-NAZZAL: Were you the first female tenured professor here at New Mexico State for astronomy?

BEEBE: Oh, yes.

ROSS-NAZZAL: I imagine you were one of the few women here for quite some time.

BEEBE: Yes. Which meant I was a minority, so I got to serve on all the minority committees. I knew every minority on campus.

ROSS-NAZZAL: Obviously you overcame those things and did tremendous things with your career.

BEEBE: Yes, but I was my biggest challenge. I think that's true of a lot of kids. What you find out is that every time you move to a new group, you have to reestablish yourself. If you're not pretty confident in who you are, that's very difficult. The guys have the same problems. They just act like they're big. I tell the graduate students here that a revelation I had one time was "Those guys can't be as special as they think they are if I'm still succeeding in this field."

ROSS-NAZZAL: What do you think was your greatest accomplishment?

BEEBE: Actually, the work that I have been doing since ’97, the international integration. I worked quite a bit on European projects—I guess it’s been about seven years or so since I stopped working on specific European projects—getting to know the whole community. I’m a nagger, I’m a professional nagger. I’m the one that when the IPDA says, “Hey, we haven’t talked to the Koreans for a while. We’ve got to get back and talk to them again, see if they can push their administration to let them in.” “Hey, we haven’t heard from so-and-so for a while,” that’s the role that I tend to play.

ROSS-NAZZAL: Without you things would not get done. I’m going to ask Sandra if she has any questions for you before we finish today.

JOHNSON: You covered it already, but the changes in technology throughout your career from when you first started. Not just the technology as far as [astronomical] observations, but even day-to-day technology and how that’s affected the work you do. You pointed out this computer back here with the floppy drives, and now you’re sitting here with these gigantic screens and these Macs [Macintosh computers]. You can pull up these images so quickly. As far as the day-to-day work, maybe you can talk about that. Even the students, and their ability to access technology [is] different than when you were in school.

BEEBE: I had a student named Chris [Christopher D.] Barnet who used to say I was stepwise illiterate. He was very clever, and he was the best documenter I’ve ever encountered. He was older when he came in, and he had a really strong influence on the younger graduate students. That interaction included Lyle and Nancy. It even extended to Amy, even though they never

overlapped here. These interactions with the students were so strong that even after he left and was working as a postdoc, or for a company at Goddard, they were still relying on Chris.

He's outstanding in the sense that he basically transitioned me to being able to use that system over there [points]. He did the coding for it and the documentation for it. That system actually saved us. We were able to do imaging science without having to go to a [NASA] Center to do it, before a lot of the other people even on the Voyager team were able to do that.

Basically, a lot of my upgrading has come from my students. If you are a professor and you're working in a university, if you don't take advantage of that you're going to be quickly dated. The kids are willing to tell you you're stupid and show you how to do things, [they] don't hesitate at all. You're forced to stay on top, because every kid that comes in wants to do everything all over again. You have to know where you are in development and what needs to be done next and be able to define it, control it. The main way to stay active is to keep interacting with the younger tech-savvy kids. They'll train you for what they need you to know, that's for sure.

Conor Nixon is a neat guy. I saw him at the last Cassini meeting and he's started to work with a very good graduate student. Conor has neat ways of expressing himself. He said, "Working with graduate students is interesting. First they arrive and it's like, 'Where's my lunch?,' and then the next step is, 'What are we having for lunch?,' and then the next step when they really get there is, 'Here's your lunch.'" That's the way it goes. About the time they become really useful, you market them and they're gone. But you still interact with them for quite a while.

ROSS-NAZZAL: Is there anything that we haven't covered about your career that you would like to talk about? Or anything on your mind today that you want to share about Cassini or anything else?

BEEBE: Not really. Cassini is now a big challenge for me because Cassini is over for some of these things, like the Titan exploration. It's finished, so now I have to really start worrying about what I can build out of what they have. I went into their system, which they use for all of their plannings and their uplinkings, using a formula that one of the engineers gave me to extract all of the requests that were made for Titan. There's 10,523 requests to observe. I got the table, and there are sections of the table that I need to translate.

What I'm planning to do is to extend this to a very large flowsheet, including these [pieces] of information. I don't care how far out my columns extend or how many of them I have. What I'm trying to encapsulate is what happened, as far as Titan is concerned, during this whole 13-year period. I need to get a lot of other information. The thing that I get from this table is the request, but that was the planned uplink.

Getting the downlink is another story. I have another file that the engineers have been supplying me that just gives me the times that they had interruptions and didn't get data. I need to fold that in to indicate that some of these requests never came down, and then develop much more, all the information I can about these requests.

There's a computer program on the Navigation [and Ancillary Information Facility (NAIF)] Node. It's called WebGeocalc. If you give it a time and a mission and a target, it will compute the geometry for the footprint of the spacecraft. So I could take the midpoint of these observations, get that, and out of that I would come close to getting the closest approach of the

events. I'm now asking engineers if there's a list of these. "Are there other ways to get more stuff that I can fold into this flow sheet to make these requests much more useful for people?"

One of the other questions is, I can tell that at this particular time the ultraviolet spectrometer, the infrared spectrometer, and the imaging camera were all observing at the same time. What were they doing? What filters was the camera using? I'm trying to find all of the places where we can strip this out and start really integrating it into as detailed a description of the Titan encounters as possible. I will do it for each one of the bodies, once I get the guys to show me where to go to get all these pieces.

I have computer access to the system, I just don't know where these things sit. Not everybody knows. The telecon I was on yesterday includes one group of people who are looking at it from the point of view of icy bodies or Saturn's atmosphere or Titan. They call themselves the discipline groups. There's another group called the [Discipline Legacy Group. Shawn Boll], the guy who is heading that really understands this one system that I've already accessed. It's just a question now of continuing to muck around for the next year among the team and the four different committees I was sitting in on to find the pieces that I can use to really do the final summary of the mission that will be useful five years from now.

When people put in a request, they put in the start and stop time for that request. When we migrate this data to PDS4, I can build a spreadsheet where they'll be able to put in a series of start and stop times. That information can be referenced to another index which is related to the unique identifiers. I can build a system where it will pull all of the data that they're requesting out.

By using this master sheet, they can decide which instruments they want during which time intervals, and they'll be able to pull out all the data that was associated with that particular

system. I would assume that in Titan they might be particularly interested in the longitude and latitude, so they would want to know what the sweep across the planet looked like. I need to collect that into some kind of a file, too. I know that that one exists, I just need to get it into a form where people can access it five years from now.[1]

ROSS-NAZZAL: Right, we understand that. Thank you so much for sharing part of your afternoon with us and yesterday afternoon. We really appreciate it, and we enjoyed it.

[End of interview]

[1] I received a LOT of help from the Cassini team and it has resulted in the following webpages https://atmos.nmsu.edu/data_and_services/atmospheres_data/Cassini/Cassini.html.