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RETA F. BEEBE
INTERVIEWED BY JENNIFER ROSS-NAZZAL
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ROSS-NAZZAL: Today is April 25, 2017. This interview with Dr. Reta Beebe is being conducted at New Mexico State University for the Science Mission Directorate Oral History Project. The interviewer is Jennifer Ross-Nazzal, assisted by Sandra Johnson. Thanks again for sharing some time with us today. We certainly appreciate it and know you're busy working on many other projects. I wanted to start by asking you about your interest in astronomy as a child.

BEEBE: My background is strange in that I was a country girl, I lived out in the country. I went to a small school, actually a three-room school, for most of the time. My parents were displaced by the Dust Bowl problems, so my father worked mainly in construction and repair of farm buildings. He was a private contractor. My father was 54 when I was born, and in his younger days he had been a genuine cowboy who ranged the West.

In those days, there were remittance men who were very well-educated misfit Easterners. Their family paid them to stay out West; that was why they were called remittance men. In the wintertime, because my father didn't have a home to go home to, he frequently worked in what was called a line shack. Your major job was to keep track of the water, especially for the cattle. Frequently, his companion in one of these line shacks would be one of these well-educated people.

My father was what you would classify as a naturalist. He had a sixth grade education, but he had an amazing amount of information he had collected himself on anatomy and biology. So I grew up in a well-informed environment that was not identified at all as "science." Of course, having lived out like that, he knew all the constellations and knew which planet was which, but I didn't know that was science when I was growing up.

The other side of my childhood was that we were not affluent. I was not a desirable companion for other people my age, especially as the mothers looked at it. So I didn't get caught, in the period that I grew up, where the major ambition of a female was she was supposed to go to college, find an engineer, and have two and a half children. I was left alone to do my own thing.

I started out in high school with a real interest in art, but I wasn't arty so I had trouble fitting in. My second year of college I switched over to chemistry. I was going to teach school and paint on the isle of Mykonos [Greece] in the summer. I taught school for three years, but I never got to Mykonos, because I got involved in curriculum development. I actually had moved into teaching Earth science instead of chemistry. I was developing curriculum for eighth grade Earth science and decided I didn't know enough so I went back to graduate school.

Even though I was on leave from my junior high, I decided to stay put and continue working on a Ph.D. in astrophysics. It was the Earth science study that drew me in. I had married my senior year of college. My husband was a chemical engineer who had returned to become a teacher, and we both went back to graduate school together. We went through graduate school together, and we still haven't divorced.

ROSS-NAZZAL: That seemed rather unusual to me, to see that the two of you were going to graduate school together. You were a female in an environment that probably didn't have many other women.

BEEBE: At the University of Indiana [Indiana University, Bloomington] there was a professor named Marshal [H.] Wrubel who had a lot of forward insight. One of his major interests was the application of computers into simulation and modeling in astronomy. He was really quite open-minded.

The year that I went into graduate school there, they had installed a program of introductory astronomy that was actually being televised outward. The department had gotten several new assistantships. The faculty decided that they would grant some of these assistantships to essentially weirdos—looking for some originality—figuring if these people dropped out, then the following year they could refill these positions with some[one] that was more traditional. The one that my husband and I entered—both funded, which was really surprising—was this class where they were looking for something other than the standard. Quite a few of us survived.

ROSS-NAZZAL: Were you the only woman that was selected as a TA [teaching assistant]?

BEEBE: No, no. At that point in time they already had two females in [the department]. There was an attitude in that department of diversity you might say. That department also had Benjamin Franklin Peery, who at that time was the only black professional astronomer in the world, I think. Certainly in the U.S. I was lucky to get into Indiana University at that time.

ROSS-NAZZAL: What was the state of affairs in astrophysics at that time? What was the field like?

BEEBE: We were pretty limited by computing. What was really interesting, though, was that the astronomy and physics students were already ahead of almost every other group of students on campus. There was a central computer which had quite a bit of capability. The astronomy and physics students were allowed to use it from midnight to 7:00 every night, so we essentially lived in the computer center and did quite a bit of modeling.

ROSS-NAZZAL: So you had quite a bit of experience before you started working with modeling for NASA.

BEEBE: Actually, as an undergraduate—I had a very fractured undergraduate. I went to Washburn University [Topeka, Kansas] my freshman year. Then I went to the Kansas City Art Institute [Missouri], and I thought maybe because I wasn't really deeply into art that I was a misfit. Then I decided no, I'm a misfit. So I went to Kansas City University [Kansas] and started taking math and science. Then I came home to Colorado, to the University of Colorado [Boulder], and finished the degree in chemistry with education credits to teach.

When [my husband] Herb [Herbert A. Beebe] and I decided we wanted to really go to graduate school, we needed to do some makeup [classes]. As a chemical engineer and a chemistry major, we didn't have enough math and physics. So we went to the University of Idaho [Moscow] for two years, and that was great.

Our selection of the University of Idaho was based on three things. One, tuition was cheap. Two, they had really an excellent reputation of their undergraduate students going on to outstanding universities. And three, it wasn't close to either one of our families so we wouldn't be disrupted. We knew we were headed for a cram course if this was going to work. It was a great place to be for that. So we finished that and then went to graduate school.

When I was at Idaho University, I actually took a class in computer science and then got a job working in the computer center there. By the time I started graduate school, my computer skills were considerably better than the other students. I actually worked programming for two of the different faculty members, because at that point in time the faculty members really weren't that outstanding in computing—except for Marshal Wrubel.

ROSS-NAZZAL: What was your dissertation on?

BEEBE: A red giant, a star that has evolved to the point that the atmosphere has extended greatly. Most of my work had to do with identification of molecules in the atmosphere. These stars have gone through a process where they've generated heavy metals internally and then transported them to the atmosphere. Looking for wonderful things like zirconium and trying to figure out how to build an atmosphere that would predict the spectra that we were getting from Palomar [Observatory, California Institute of Technology, San Diego].

ROSS-NAZZAL: Sounds like an awful lot of work.

BEEBE: No, it was fun.

ROSS-NAZZAL: Your husband came down here, as I understand it, and became a faculty member here, but there wasn't enough space for both of you. You ended up working for Los Alamos [National Laboratory] for some time?

BEEBE: As a graduate student I worked at Los Alamos.

ROSS-NAZZAL: Oh, you did?

BEEBE: Yes, summers. Because of the work that I was doing, I had experience in coding molecular formation and dissociation. So I was useful at Los Alamos in terms of interpreting atmospheric phenomena. After Herb came down here, I continued to work there. Then I started essentially consulting, because the computer I was working there was the same one we had here, so I could simply transfer my codes here.

The university actually gave me office space and computer time to be able to continue my work down here. I had been here a fairly short time when Bradford [Bradford A.] Smith decided he needed—I think NASA told him that he needed more modeling and interpretation among his team. He had essentially taken over from Clyde [W. Tombaugh]. Clyde was still the figurehead for the group, but Brad Smith was running it. So he hired me to start to work on the modeling and the interpretations.

In 1973, I was working full-time for him. Then he left and went to the University of Arizona [Tucson]. They did a faculty search, and at the end of the faculty search they decided that they didn't really want to hire any of those people, so I was hired. By then Herb was

department head, so you've got nepotism problems. But Vice President [Donald C.] Roush was a pretty smart character. The way he solved that problem was that basically I had a letter that said that Herb was not my boss. Any decision that was made in terms of my promotion or anything would be made by the dean of [the College of] Arts and Sciences. So that solved that problem.

I took over the group that was working on planetary science here, but that was the point in time where the group needed to transition between an aging staff and encompassing graduate students.

ROSS-NAZZAL: So before you came on board there were no graduate students that anyone was advising?

BEEBE: There were graduate students in the department, but the planetary group had been working under Clyde Tombaugh for quite a few years. They were just staff-oriented. They used undergraduate students to do real peon labor, but they hadn't encompassed graduate students into the program yet.

ROSS-NAZZAL: What did you start working on? Did you continue the type of work that you were doing for Los Alamos?

BEEBE: No.

ROSS-NAZZAL: You started working on atmosphere for Jupiter?

BEEBE: Yes, I was trying to do analysis. The first project I worked on was the clouds of Venus, and looking for periodic returns of cloud patterns. That was a challenging project because we observed Venus in the daytime at the observatory in the bluest light we could reach.

You see these cartoons of the telescope sticking out of the slit. When we observed Venus, our telescope stuck out of the slit. We actually had another attachment that we put on the top of the telescope to keep the Sun from shining down onto the mirror. By the time that we got that on, it was literally outside of the slit, so somebody stood up in the slit and watched the shadow of the Sun to make certain it didn't hit the mirror. If it hit the mirror and had come back on the secondary [mirror], it would have probably shattered the secondary. So you had two people observing at all times.

We also had a lid that we would put down on this attachment, which had a bean shape in it. If we needed to get really close to the Sun, we could make certain that this side over here [demonstrates] was where the Sun was coming in. It was lots of fun to do that kind of thing.

Then you actually studied the images, mapped the structures you could see in UV [ultraviolet light], and attempted to look for recurrences. It was a four-day period that came out of it. The conclusion was that that four-day period was not being generated at some longitude on the planet, that it was randomly generated. That was just the rate at which it moved. You weren't looking for some high mountain ridge that was creating a pattern, it was just a global phenomenon that recurred.

ROSS-NAZZAL: How did you get involved in working on the [NASA] Voyager project? I know that Bradford Smith was the PI [principal investigator] for imaging science.

BEEBE: Yes. We were observing Jupiter, and we were funded by NASA to try to understand the conditions in the atmosphere of Jupiter as those guys got ready to run their mission. Elmer [J.] Reese was the person who was doing a lot of the analysis when I arrived. Elmer Reese was a [great] teacher and a wonderful guy. He was one of the last astronomers who did their own reading. He was an unschooled amateur who grew into being a real professional. He died only a few years ago [2010] in Houston. He had retired and gone there with family.

He was just tremendous. I worked with him implementing quick looks, then using the measurements that he was doing to get wind speeds, and then do predicts. Basically, our job for Voyager was to do the predicts of when the long-lived features would be visible on the planet so that they could do the long-term planning and scheduling.

We did Voyager 1, and then we had enough time to do Voyager 2. We did Voyager 2 with the understanding that we would redo it as we got closer. But we didn't redo it because our predicts were good enough, and the cloud system is consistent enough, that we could use all that we had done before. It saved a lot of time. We were really deeply involved in the scheduling of what would happen.

ROSS-NAZZAL: That's fascinating. You knew enough about the planet to have an idea of what would be coming, what to photograph.

BEEBE: The atmosphere is deep enough that once [a large] cloud structure forms, it takes a long time for it to dissipate. So once you've characterized it pretty well—there are events that speed them up, so you may have to correct it later, but we would have known how it speeded up. On

Jupiter, the way it speeds up—it's like somebody kicks it quickly and then drags it down slowly. We could do pretty good predictions. Even if one of our features had sped up, we could do a prediction of how its rate would decay and be able to predict when it would show up again.

ROSS-NAZZAL: How knowledgeable were you about the imaging system itself before Voyager went out?

BEEBE: Voyager spacecraft is an interesting spacecraft. The cameras were very, very well-defined, very well-calibrated. They were electrostatically focused. They weren't CCD [charged-couple device] cameras like we have now. They burned little dots in the face, so that every image that we had had these little dots. When you calibrate the Voyager data, you have to geometrically stretch it to bring it back to where the dots should be instead of where they appear.

It was all very well-controlled. Compared to the CCD cameras, the major thing that I see that's different is that there was a tendency for the radiation that had fallen on a single point on the detector to spread a little bit. So we didn't get as sharp a spatial resolution as you can get with the CCD cameras. The CCD cameras that the amateurs are using now are just wonderful. They've got them linked into their laptops, and they're doing really great image reconstruction.

ROSS-NAZZAL: I imagine technology has changed. When you were working on Voyager, were you out there for the entire time—there was the Jupiter encounter, Saturn encounter?

BEEBE: No, I was teaching as well.

ROSS-NAZZAL: I was curious about that, how you juggled the two.

BEEBE: I split my time between the two. Half of the time I think I was a walking zombie. I could leave here and go to El Paso [Texas], get the first flight out to LAX [Los Angeles airport, California], get a rental car, go to [NASA] JPL [Jet Propulsion Laboratory, Pasadena, California] for a meeting, and when it was over I could get back home again. If it was something critical I could do that.

Otherwise, I tried to have my classes either Tuesdays and Thursdays or Monday, Wednesday, and Friday so that I could find a time when I had a little more than 24 hours to do it. In the summertime, I spent time out there working on it. A lot of the early targeting we did was done in the summer, but when the thing was under way then I would just simply take a break for a real encounter and be out there.

ROSS-NAZZAL: What are your memories of Voyager 1 when all of that data started coming in? Were you out there or were you back here in Las Cruces?

BEEBE: I was out there, yes.

ROSS-NAZZAL: What are your memories? And what are your memories of other people's reactions?

BEEBE: Some of my earliest memories were that we weren't that great at pointing. One of our jobs was to watch the data coming in. It would come in on a TV screen in a very fixed format.

You had this format, but the image itself would wander around because our pointing was not as stable as it should have been.

So the result was that we would watch, and if it started to drift off you would open a line which took you to the [NASA] Deep Space Net [Network] that was receiving the data. What you wanted to find out was whether those engineers knew whether it was offline or not. So you would open the line and you would hear the commands going around that, "We've got it." You would know they were bringing it back in, so you didn't have to say anything. If you opened the line and there was nothing going on, then you would have to wake them up to the fact that it was drifting off. That was one of the things I remember doing.

I was sitting there watching these images come in. Of course we were looking at Jupiter first, because it was biggest and the features on it are big so we could see things on it. You would see the [Great] Red Spot in five different color filters. When you're looking at it in ultraviolet or blue, it looks almost black. By the time you get as far out as we could see in the red with the Voyager camera, it would just be blending into the background.

The Red Spot—unblue is a better way to describe it. Little kids love that idea, that it's unblue. Whatever the contaminant in there that makes it look red, it's because it absorbs the blue and part of the green light, so that what you see coming back is selected light. It was neat to watch the resolution grow, because it got beyond anything I had seen on Earth. I had been seeing these features on Earth, but now I could see details inside of them. I could see more of it. That was very interesting.

Then, when we got to the point that we were near the encounters, that was strange.

ROSS-NAZZAL: Why was it strange?

BEEBE: The Voyager mission was so popular that the press just descended on us as herds. Foreign press—you had Iraq and Iran there, you had Northern Ireland and southern Ireland there. PR [public relations] people were making certain they had them all seated properly so that things didn't happen. The place was totally jammed with these big trucks with their transmission antennas.

In those days, a lot of the PR was done in hard copy. We had this procedure where the day before the press conference you would decide which images you were going to release. Then you had to process the images and clean them up. You took that product on a tape under your arm, and you trotted over to the photo lab [laboratory] where they had a device that converted it to a negative. They ran off the negatives, and then one of us trotted over to the photo lab to get the negatives to take them to the press conference. They were passed out as hard copy, and then they were scanned and sent. You had all of that process going on, so you were working day and night.

ROSS-NAZZAL: How did you come up with the process of deciding what were the best images, and the captions and writing those press releases? How did you make those decisions?

BEEBE: You knew what you had planned for the day, to start with. You knew what you thought the highlights would be, so you would start with those and get your first rough cut by seeing what had come down. Then you would look at what had come down and you would decide which ones were ready for release. There were PR people that worked with us to get the

captions. We would write a caption, and they would edit it into real English. A couple of them were really very good.

ROSS-NAZZAL: I imagine that was difficult cutting those down.

BEEBE: I didn't have that much trouble, because I was teaching at the same time. You had to really make certain that you defined everything.

ROSS-NAZZAL: I've seen some interesting photos where it looked like the press were just surrounding desks and looking for that lead story.

BEEBE: That's right. During that period of time—I've forgotten which encounter it was, but it was fairly early in the mission. I think it was Andy [Andrew P.] Ingersoll [who] decided that the press needed to be educated. At about 2:00 on the previous afternoon, they would open the von Karman Auditorium [at JPL] to the press. Members of the team would go down and sit on the edge of the stage and have what was called a bull pen.

There would be a bit of a briefing on what was happening for the next day and then answer a lot of questions. There were science reporters in the crowd who reported for things like *Sky & Telescope* that were really good. [J.] Kelly Beatty was one of those. The tutorial actually came from Kelly asking the question and then hearing the teams respond. That filled in these people that were looking for their story. It had been translated and they knew what was coming, so then in the press conference these other press people could ask intelligent questions and get their bonus points with their bosses.

That process worked very well. We carried it through that whole mission. It's still done to some extent for various missions. We used it very heavily during the period of time when the [Shoemaker-Levy 9] comet hit Jupiter [in July 1994] and we were using the [Hubble] Space Telescope. We very quickly put the bull pen back in for that because the press really needed to be educated to do what they could do best.

[When the Voyager images] started to come down [and] you could really see the highest resolution, especially when we first started to get Io [the moon of Jupiter, there was a delay in response]. Although Stan [Stanton J.] Peale at University [of California] at Santa Barbara had written an article about the fact that the tidal interaction of the various bodies around Jupiter should generate quite a bit of heating, the geologists that were on the team really hadn't swallowed that completely. So when we started to see these really strange features, they didn't immediately land on volcanism. It just didn't fit the way they were thinking at the time.

It wasn't until after the mission was really over and looking back—Linda [A.] Morabito saw the big plume. Then all of a sudden it was, "Oh, yeah! Oh ho ho, well I wonder what the lava is? It's got to be some really low temperature lava or wouldn't be working." Well, sulfur. The atoms are heavy enough you wouldn't lose them. As you processed, you would slowly enrich and end up with [a lava] that was really pretty rich in [sulfur].

ROSS-NAZZAL: Would you tell us how that team worked? My understanding, at least for when you went by Saturn, was the team consisted of 26 people. I don't know if there were that many for Jupiter. How did you operate? Were there a lot of debates about what you were seeing? How did you reach a consensus?

BEEBE: This is true on the Cassini mission [to Saturn] right now as well. At JPL you have people who have a lot of responsibility on certain areas. As far as imaging went, Candy [Candice] Hansen [now Hansen-Koharcheck] was the tech [technician] who was really a coordinator. There was another fellow who worked with her, Jimmy [L.] Mitchell, who eventually died of [HIV/]AIDS [human immunodeficiency virus infection and acquired immune deficiency syndrome]. Those kids basically were responsible for a lot of the organization.

There's more than 27 people, by the way. There's a crew behind each one of those guys. They're the big shots. What you do is you develop areas of expertise, so you've got subcommittees, and all of this goes on long before you do the observations. You do the planning, and then you have got to bring these druthers together so that they will fit in a schedule.

A guy named Ellis [D.] Miner at JPL was a really good coordinator for that problem. When you're doing that problem, you've got really bitter battles going on, because maybe that's the only time they can possibly get that [observation], and they're going to lose it to somebody else. There's a lot of fighting and compromise. We would fight to a certain point, and then Ellis would call, "That's the end of that." He would go off and then very carefully try to do some refits by putting compromises in, then bring it back to us. It was always better than what he had left with and allowed much more to be gotten out of it.

You worked with people who were the experts and who were defending their turf, being coordinated by somebody who's interested in getting the most they possibly can out of the mission. That's pretty well-tuned in terms of how these missions are run.

ROSS-NAZZAL: Can you give us an example of something that was hotly debated, or something that you felt strongly about on Voyager?

BEEBE: One of them I remember working to coordinate—it was interesting because when we first started I was supposed to be representing imaging, and the person who was representing the infrared spectrometer thought I was really in competition with him. After we had had a few rounds, it became pretty apparent that I didn't have to be in competition. I could be supportive, because he had low spatial resolution and high resolution in terms of wavelength, or color, in the infrared. I had far better spatial resolution than he had, but I didn't have much resolution in terms of color.

If we were to target together, then I could put constraints on his observations and he could put constraints on mine. So as we began to really develop the early part of the targeting, it became apparent that there were these combinations that you could put together that would actually yield a lot more solid science.

The thing that is hard for people to remember is there's more compute power in this [smartphone] than there was in the entire JPL lab when we flew these things. The Voyager memory was very, very small. It had a front end and a back end. You loaded the front end and checked it to make certain that you got it going, and you turned it on. Then you loaded the back end and checked it and hoped that you were finished before it was going to slide into the back end, so you could load the front end again. You were constantly working these uploads which were very, very limited in terms of the number of bits you could have in your upload.

The result was that a lot of the targeting we did was done by little routines which might do a two-by-two look in three colors. The only option you had was where you were going to set

it and what filters you were going to put in there to get the colors. The rest of it was hardwired. By doing this, we got much more efficient. It was funny as the mission went on, because we would listen to stuff coming back from the press about our artificial intelligence and the wonderful things that Voyager did. It was all bullwork. You had so little memory that you thought out every piece that you had to fit it in.

Now on Cassini we've got lots more memory, so what problems do you have with Cassini? First of all, the Deep Space Net is not infinite. So you've always got to worry about how many bits you can drop at a given time. You're right back at the same thing. You're right back to you plan the thing and they look at it, and "Oops, we can't download that." "Okay, you guys, you got to cut back. Where can you cut back?" It doesn't matter how many resources you give a team, there's always this problem of having to give and take to get where you want to go to really optimize things.

ROSS-NAZZAL: How far in advance were you coming up with these steps? Was this five minutes out from a photo, or are you talking days?

BEEBE: Oh no, we're talking days when we could do the loads. It was because we had these little units that were really efficient that we could pack it that tight. The result is that you fight like crazy. You become brothers and sisters. You fight like crazy, but don't let anybody else try to do anything to us. To this day I can be sitting here in a telecom, and we don't have to identify ourselves. We know each other's voices to the point that it's just open conversation.

ROSS-NAZZAL: One of the people that I noticed was on the [Voyager] list was Carl [E.] Sagan. He was very much a public figure at that time. What did you think, being an academic, about having him on the team and his push to get public interest in the mission?

BEEBE: It's the public's money. If a mission doesn't give it to the public, there's something wrong at NASA Headquarters [Washington, DC] as far as I'm concerned. Because that's the whole thing. The stimulation that this can have for kids and for the public, understanding the worlds that they live in, is the real justification for doing it. I have real admiration for the people who do this well.

Carl was a strange guy, pretty lovable in lots of ways. I can tell you some interesting incidents about him. Carolyn [C.] Porco, who is on the imaging team for Cassini, has tried to emulate Carl. She has worked her tail off, and she has come up with some wonderful things. The last one she came up with was she had her team schedule to look through the rings of Saturn to the Earth. You've got the rings of Saturn, and there's one little bitty spot that is the Earth. It gives kids some concept of how far away you really are. I think she's doing a great job with it.

Carl worked hard at it. When we were doing the Saturn encounters, Carl was working on *Cosmos [A Personal Voyage* television series], so he wasn't there very much. But he waltzed in and took over the press. Then he started to feel guilty about this, so he gave us a party at his studio. He put out a spread—I don't know where he found the caterer, but as far as I was concerned they came straight from heaven. It was just wonderful stuff. The centerpiece of it was this giant chocolate Saturn with spun sugar rings.

The entertainment was that he showed us how he did special effects in the movie, set up the cameras. We got to walk through his "cathedral" as we called it. We gave him a bad time

about that. We also gave him a bad time about the fact that his face shows up so often. Carl called that cheap fill, but the public loves it. They love to really be able to identify with someone who's doing it.

I used to ask him about his little daughter, who was his last child, and one time he said that he was jealous. She was five, she had a boyfriend.

When we were doing the second Saturn encounter I took my nephew, who was 11 years old, with me. I had him in my office the day before the press arrived. I couldn't have had him there the day, but he was there the day before watching stuff come down. I realized he was missing. "Oh shit, where's the kid?" Then I heard Carl's voice down the hall. "I hope you appreciate what your aunt has done. This is like being invited along on [Christopher] Columbus's second voyage." I walked down the hall. As I walked down, I picked up my Polaroid camera and Carl gladly posed with his arm around the kid. What was interesting is this had caused enough of a rumple in the group that quite a few of the techs had come down to see what was going on. They all happily posed and got their pictures with Carl.

ROSS-NAZZAL: I remember the TV show from my younger years as a child, so I was curious about that. Did you guys ever encounter any problems with the spacecraft and have to do things on the fly to ensure that you would secure these wonderful images that you got?

BEEBE: During the Saturn encounter (the second encounter of Voyager 2), a lot of the observations that I was depending on to really define the wind field, the rate at which the clouds appeared to drift, were lost. As we flew by, we were so busy slewing here and slewing there that we warmed up the system enough that the lubricants became ineffective and it froze. There was

a period of time where the engineers were essentially hammering it, getting it to go this way and this way and this way, to break it loose.

They broke it loose, but then we had lost a whole section of the observations observing Saturn in green light where you could see the tops of some of the cloud decks that were visible. But we got it back into operation again to get the really high phase angle which allows you to understand the structure of the atmosphere where it's really thin. You've got to be able to look through and get the forward scattering from the Sun to do that, and we got it back into operation for that.

ROSS-NAZZAL: That must have been nerve-wracking.

BEEBE: They're unhappy, stressful times when you have that going on. Any time the spacecraft goes into safe [mode], it's tough.

ROSS-NAZZAL: Especially if you're counting on that data.

BEEBE: It's not only that. These spacecraft develop personalities, and you get emotionally hooked to the thing somehow.

ROSS-NAZZAL: Really? Would you tell us about the personality of Voyager 1 and 2?

BEEBE: You should have seen us when we went by Neptune. The last day, when the press was dissolving, we're all crying. Can't keep it in anymore.

ROSS-NAZZAL: I can imagine. You've been with that project for so long.

BEEBE: Yes. Now I'm working with the team to recover all of the documentation from Cassini, and you can see it building into this team, too. They're going to kill their baby.

JOHNSON: I imagine that's hard.

ROSS-NAZZAL: Yes, all the time and effort you put in. That's challenging. I wanted to ask you—I found a quote from Bradford that basically said, "Everything we are seeing on Saturn is brand new." I was curious about that. What did you learn on Voyager 2? Why didn't we know that much about Saturn?

BEEBE: Let me see if I can find you one [image]. Herb sent me one [demonstrates].

ROSS-NAZZAL: That's beautiful.

BEEBE: But you can't see anything. Oh they're lovely. Here's another one [demonstrates].

ROSS-NAZZAL: Oh, that's a big difference.

BEEBE: That's his colored one, but you still can't see clouds. You can't see any of the dynamics that are going on very easily. You've got to get to very high resolution, and you've got to get as

far out in the infrared as you can. The cameras that we had on Voyager were red-blind. You could see out into the orange, and that was about as far as you could go. So we used a very broadband green filter, and at high resolution you could see faint cloud tops. But nothing like you could see on Jupiter, where the clouds would roll and move and you could see the interactions.

We didn't have anything that good from the Earth when we were observing. Our cameras were less sensitive. We had to expose for longer periods of time. The jiggling of the Earth's atmosphere smoothed everything out for us. An English amateur was bragging to me today that he's got a new camera that's 100 times more sensitive than the previous one, which means he'll cut his exposures and be able to catch those [times when the atmosphere is quiet].

With the computer systems that they have, you can do what they call an edge finder. You can come in and select the ones where the brightness changes the most steeply, and those are your best resolution. You can throw the others all away, and you can coadd those. You can build up the signal and beat down the noise by coadding them. So these guys, they just ratchet it as they're going, and then they go through and only pick the good ones and put them together. They're doing wonderful things.

JOHNSON: These are amateurs? Is that what you said?

BEEBE: These are amateurs. These are guys that are not planetary scientists, they're engineers and that sort of thing.

ROSS-NAZZAL: That's a ground-based photo?

BEEBE: Yes.

JOHNSON: It's amazing.

ROSS-NAZZAL: I know. I wouldn't think you'd be able to see that from Earth.

BEEBE: Maybe that one [demonstrates]. That's a Jupiter image that he gets, and you can see [many] more structures. Let me see if I can find one that's got the Red Spot on it for you.

JOHNSON: Amazing.

ROSS-NAZZAL: I know, it's amazing, that it's here on this planet. Oh, look at that.

BEEBE: Here's the Red Spot coming off this. They're doing tremendous stuff, and we use it. If we use it, they get to coauthor the paper.

ROSS-NAZZAL: If you use their image, they get to coauthor the paper? I've never heard of such a thing.

BEEBE: It's their data. It's not just an image, it's data. If it tells us something that helps us integrate into the stuff we're working, they get the credit. They also monitor for things like stuff falling in [the atmosphere], although they haven't gotten a good one of those lately.

JOHNSON: How many are out there doing that?

BEEBE: This [organization] is called ALPO. It's the [Association of] Lunar and Planetary [Observers]. It's gone universal. There's a biologist in London who is the coordinator of it now. It used to be a guy that worked over here. But now [John H.] Rogers [Ph.D. Jupiter Section Director, British Astronomical Association] is the coordinator, and they share it all backward and forth. He writes various reviews where he combines [input from the amateurs].

On the Juno mission [to Jupiter], the camera is not rated as a scientific instrument. It's getting information and we're archiving the images that it gets, but it was designed for public education. Those images are put on a website where people can access them and process them and work with them. So these people now on ALPO are working on Jupiter, and they're using the Juno data and their own data and arguing back and forth. They're having a great time.

ROSS-NAZZAL: They include you of course.

BEEBE: Yes. I can be sitting here working in the evening, and I will get images that were taken tomorrow.

ROSS-NAZZAL: Things have definitely changed over the years. That was one of the things that I wanted to ask you about. I know that you coauthored an article for *Science* about what you learned about Jupiter with many of the people on your team. I wondered, how did that work in

the ’70s? Of course today we have e-mail, or even earlier we had fax machines. How did you sit down and coauthor an article so quickly about what you had learned and worked together?

BEEBE: What you would do is you’d put together an outline, and you would assign tasks to do this piece, do this piece, do this piece, and there was a main editor. The main author would be the editor, and you would generate your components and send it to him. He would integrate it, then you would circulate it. Pre-fax, we could send short bits and pieces backward and forth in the early one. Then we got up to being able to actually transmit things.

This computer that’s sitting over there [points] is a relic. There was an electrical engineer who built a board that’s in that computer, and he understood the whole structure of it. His board has little arrays in it that are 256 by 256 [pixels]. It turns out that the images from Voyager aren’t much better than that, so it was really quite useful.

The way he set it up, you can use that board to make a movie. You could process eight different images, and then blink through them to see things moving. When he helped us put that together—at that point in time we were taking such huge steps forward in the computer industry that that made us competitive with JPL, with their full-up lab. That little guy could do as much as JPL could when we went by Jupiter.

We used that a lot. We could navigate the images. We could map-project them. We would do all sorts of useful things with it. That meant that my students could work a lot on the data. By the time we were working on Saturn and Uranus and Neptune, we had the full projection capability, so we were really moving forward.

ROSS-NAZZAL: That gets to something else I was curious about, about using the data. Once those images were down, did you bring them back with you? Or how were you able to access them?

BEEBE: On tapes.

ROSS-NAZZAL: On magnetic tape?

BEEBE: Yes.

ROSS-NAZZAL: How big were those tapes at that point?

BEEBE: This big [demonstrates size, about 12 inches in diameter]. They came in boxes.

ROSS-NAZZAL: How would you transport them back? Or did they send them?

BEEBE: We shipped them.

ROSS-NAZZAL: What sort of equipment—you weren't using that computer at that point, were you? You were using something else then?

BEEBE: I had a tape reader here. It was almost as big as that table. That way I could read the tapes.

ROSS-NAZZAL: Did everyone on the team get a set of these tapes to take back with them?

BEEBE: No, you ordered the ones you needed. You had your plan, and you would say, "Okay, now I want to study the Red Spot, and I need these images." They would load those onto the tape for you. Then you had the set that you were working with. You would end up with a dozen tapes for your project. By the time I got this [computer], then we could put them on floppies [floppy disks].

ROSS-NAZZAL: The big three-and-a-half-by-five-[inch] floppies?

BEEBE: No, little floppies. Little ones that really packed the data in neatly. Yes, the little colored box you see over there is the reader for one of those floppies.

ROSS-NAZZAL: Things have changed. How long were you working with Voyager data? Are you still working with Voyager data from Jupiter and Saturn?

BEEBE: I'm not, but people still are. Now they're comparing it with Cassini. Occasionally they're finding weird things in it that weren't found before.

ROSS-NAZZAL: There was a book that was written by Henry S. F. Cooper [Jr.] called *Imaging Saturn [The Voyager Flights to Saturn*]. He followed around quite a few of you. I was

wondering what you thought about that book and his inclusion as you were working on the project.

BEEBE: Henry was an interesting guy. Press like Henry, who were not going to write tomorrow's scoop, were given quite a bit of access just to come in and sit in meetings and do that kind of thing. They signed that they weren't going to do scoops and releases, so he spent a lot of time with us. The joke about Henry was he would come into the room and he would say, "What did you discover today?" You'd look at the download, somebody'd come in, "Well, what did you discover today?" sort of thing.

ROSS-NAZZAL: What would you tell him?

BEEBE: If we had something good we would explain what we had to him, but that was always his opening line. I remember one time he wrote an article—or it's in that book, I've forgotten which—where he describes me as brown-haired and mid-40's. Some of the people at JPL were taking offense. He was offended, because he had tried to be as honest as he could be. Didn't bother me at all, because it was true.

ROSS-NAZZAL: I did wonder about that myself when I read those passages. What did you think of his portrayal of the events and the people?

BEEBE: I thought he did fairly well. What was interesting is that he caught me—that was when we were going by Neptune, right, that he did that?

ROSS-NAZZAL: I think it was Saturn when he wrote the book, but he may have done some articles on Neptune.

BEEBE: He did Neptune too, because I walked into the room and I said to Andy [Andrew P.] Ingersoll—and I forgot that Henry was there—"I wonder why God likes the southern hemisphere?" Because we had this big blue spot [Great Dark Spot] on Neptune, and again it was in the southern hemisphere. Andy said something back to me.

Henry included this in the thing that he reported, and it was picked up by the *Wall Street Journal*. It ended up in the left-hand side. It's important to get into that section. It was amazing how many contacts I had from people I had known previously who were nowhere near planetary science, who were stunned to realize that I was there. When you make that corner, apparently you've arrived.

ROSS-NAZZAL: I imagine it was a big deal for you to be on the team, being from New Mexico State University.

BEEBE: Voyager was extremely popular here. When they were getting ready to bring down the data from Neptune we actually used the VLA as well.

ROSS-NAZZAL: What's the VLA?

BEEBE: The [Karl G. Jansky] Very Large Array, the radio telescope [in central New Mexico]. We actually used it for some of our dump because we were far enough away now the signal was really weak. Ellis Miner came out, and they had this big thing for the press about the fact that they were using the VLA and how great it was. He said that he was really surprised at how well informed our press was.

ROSS-NAZZAL: Here in New Mexico?

BEEBE: Yes, he'd been doing lots of press. He encountered the people here, and he was really impressed with what they were after in terms of understanding it. The university, for each of the four planets, had me select the best, prettiest image of the planet. They reproduced them and framed them and delivered them to every member of the legislature. They were on the walls of the legislature, and a lot of them had all four of them on the wall. It was big.

Galileo was crippled, so we had problems with it. But Cassini hasn't tweaked the public's imagination like Voyager. You've got to go where no man has gone before to really turn them on. As you saw with Pluto, Pluto was big.

ROSS-NAZZAL: It was big. I wonder if that has to do with the fact that there was so much debate going on about whether or not it was a planet.

BEEBE: That certainly had made the public aware that it was something out there. Then for it to have such interesting character, to have been demoted and then be that interesting.

ROSS-NAZZAL: Those images that you picked, were those four of your favorite images? Do you have a favorite image from Voyager?

BEEBE: They were picked to be pretty and to be readily recognizable. It was the full image of the planet that was selected for those.

My favorite images have to do with the Red Spot. There was this wonderful little girl, I think she was at Pasadena City College [California], she was black. She was one of my support people. When we would get a high resolution view of a cloud area, we would do a mosaic to get it. They would print these up, [using] a really crude printing method, and then she would trim them and paste them so we could see the whole mosaic.

She came into my office with a pile of these one day, and she said, "I have absolutely no idea what to do with these."

I looked at them. "Oh, oh, oh. What we're doing here is we're doing a scan. We're in so close now to the planet that we're doing a scan inside of the Red Spot. So when you get this put together you'll be the first human being to ever have seen the Red Spot at this spatial resolution."

There was a fellow [scientist] on the team, Garry [E.] Hunt, a Brit, who was [involved in a lot of] PR. He really worked at it, too. She disappeared, and she came running back in and she said, "Reta, Reta, come look at this." He realized that she had something outstanding. I followed her in, and we're leaning over the table, looking at it. He comes in the door, and she looks up at him. She says, "Hey, white boy, do you want to be the first male to ever look at this?"

ROSS-NAZZAL: I'm sure she got a good laugh out of that.

BEEBE: I did. He did too. He thought she was wonderful.

ROSS-NAZZAL: If you have a copy of that image, we'll have to get one and put it with your oral history. I'm sure you have it readily available.

BEEBE: It's up there. [Points] That one on the board.

ROSS-NAZZAL: That longish one?

BEEBE: Yes, that's faded.

ROSS-NAZZAL: I would not have guessed that that was Jupiter.

BEEBE: It's probably available at JPL. They've probably got the pasteup of that one.

ROSS-NAZZAL: We'll have to see if we can get the number, so we don't pick the wrong [image].

BEEBE: I don't have a number on it. You just ask them for the highest spatial resolution of the Red Spot out of Voyager.

ROSS-NAZZAL: I will do that.

BEEBE: The infrared spectrometer was observing along with that, so that really was a good data set.

ROSS-NAZZAL: What did you learn from Voyager about Jupiter and Saturn? What were some of the key things that you found?

BEEBE: When we were trying to do it with ground-based [telescopes], they were much less useful than this. There's one there [demonstrates] that would be about as good as you got with the old cameras that we had. We would get measurements, but we got them by doing it for several days and then doing a fit to it. There were all sorts of arguments that what we were getting wasn't real, because things could change and we could have been looking at various things. A cloud can be translating, it can be expanding, it can be evaporating, it can be rolling and changing. The measurements we got were always in question.

With the two encounters of Jupiter, we got really dense measurements of cloud motion. You could start to take this apart and understand what was translation, what was wind motion, and what was cloud evolution. That was the big yield in terms of the work that I was doing, because I was working on the dynamics of the atmosphere.

With Saturn, from the ground-based [telescopes], as you can see even with these guys [demonstrates], you have to wait till there's a major event, and that is not typical of the wind field in the clouds. You don't get enough resolution on Uranus and Neptune, even now, to be able to resolve the actual cloud translation. Again, even now with the best stuff we've got, you're working on cloud events instead of the overall dynamics of the system. So what we got

that was of real interest to me was a lot more information that would either say yea or nay about ideas of the dynamics of the system.

Then we got Galileo, with its broken antenna and a good camera. Better than the Voyager, and capable of looking farther out into the red. What we got there is that map that you see there [demonstrates] with the little colored spots on it. Those are the high resolution views we got with Galileo, with its broken antenna. You really had to work, but what you got was a kind of resolution that you could fold into the Voyager and you could keep working on this.

Then we had a Cassini flyby that had some very nice data, and now we've got the amateur cameras coming in. The amateur cameras give us very interesting information on dynamics. When you work with the images the way they're doing it, you destroy much of the color information. You just don't constrain them the way you should. They put edge finders and sharpeners on them, but the dynamics are still there. Starting with Voyager, now we've got these broken sections and some ground-based follow-up, and Juno [data] coming in, that fill in quite interestingly.

I'm not really doing that anymore. The major thing I spend doing is trying to document the data and make certain that it's well-archived.

ROSS-NAZZAL: I did want to talk about that tomorrow. Because that sounds really important, we understand that.

BEEBE: That's hard work.

ROSS-NAZZAL: It sounds like it, making sure everything's consistent. I wanted to ask about Uranus and Neptune. It was many years later, you had to wait until the flybys. I was curious, were there still the same people on the imaging science team, or had some people retired or passed away? Did things change?

BEEBE: Some of them had retired, some of them had died. Some of them had done some pretty interesting things. Linda [J.] Spilker, who is the project scientist for Cassini now, was a tech on Voyager. During these breaks she got a Ph.D. out of UCLA [University of California, Los Angeles]. So did Candy Hansen. They worked on every encounter and have continued to work on missions as they go. So you saw that development among the techs that were working with us at the time.

Some of the people retired right afterward. But, for a large part people lasted for the whole time. They did other things in the meantime. Because most of them were profs [professors] at universities, they'd been stretching themselves for the encounters to start with, so now they could do some research on the data. NASA kept us well enough funded to support graduate students so work could go forward.

ROSS-NAZZAL: Were you there for the flyby of Uranus?

BEEBE: Yes.

ROSS-NAZZAL: What are your memories of that moment?

BEEBE: Frustration.

ROSS-NAZZAL: Why is that?

BEEBE: As a dynamist, I need to see clouds and I didn't. It was just pretty. Just a beautiful blue ball when you turned it.

ROSS-NAZZAL: Did you get any information at all that was helpful to your studies?

BEEBE: Very, very little. We got a hint that the rotation was quite different than Jupiter and Saturn. On Jupiter and Saturn the equatorward winds translate eastward, and on these two others it's such that they translate westward. You don't develop the full multiple cells that you do on these warmer big planets. You get large cells that are more like big turnover cells. We did get that out of them.

They've continued to monitor infrared and use HST [Hubble Space Telescope] and its red capabilities. JWST [James Webb Space Telescope] is going to be able to reach and get better spatial resolution, so there'll be more dynamical studies on those too with JWST.

ROSS-NAZZAL: One thing I noticed was that fairly soon after the flyby, *Challenger* [STS 51-L Space Shuttle disaster] happened. What are your memories of that? I understand that the press conference pretty much fizzled as a result.

BEEBE: Yes. There was a guy named Bob Martin, and he was like a soldier of fortune. He did a lot of really good freelance reporting. Bob would show up wherever there was a war, and you would see a bit coming in on different stations from Bob. He wore a flak jacket and carried everything he needed to shoot on his body. He worked as my press agent during the Uranus encounter. He had cleared himself with the PR people, with the promise that he would not report on anything except my activity that he was following around. He wanted to do a "day at Uranus" kind of thing.

He had been around a bit during Saturn. The PR people found him very easy to work with. They said that he could spend most of the day walking around with me, and then he would go over to their place and use some of their equipment to uplink his edited versions to all the sources that he was putting them out to. They said that he did the same work that five or six people for most of the other PR teams did. He was really impressive in the way he could do it.

He was with me, and we went into an auditorium full of people to watch the [*Challenger*] launch. It blew up, and you're sitting among people that know exactly what happened. It was a long period of time when no one said anything. Then you could hear people starting to cry and get up and walk out. Bob never said anything about it. He never reported on it, even though it was probably one of the wildest things he had ever seen. He had signed his paper, and he stuck with it.

ROSS-NAZZAL: That was a difficult time for the Agency.

BEEBE: Yes, it was.

ROSS-NAZZAL: Did things change on the ground as you were working with images and how you got images? As we talked about today, technology on the ground changed. Of course the spacecraft couldn't change, we couldn't go out into space and make changes to it. But I'm curious, were there changes?

BEEBE: The engineers got smarter and smarter about how far they could push it. They figured out how to lengthen exposures as we went outward. The spacecraft didn't change, the crew evolved. The more they learned about it, and the more sure they got that they could push it, the more they could get out of it.

ROSS-NAZZAL: But not enough for you.

BEEBE: There's never enough; there's never enough.

ROSS-NAZZAL: What about Neptune? Were you out there for Neptune, or were you here?

BEEBE: Yes, I was there for Neptune. The neatest thing—I remember being told that what I was saying couldn't possibly be true.

ROSS-NAZZAL: What were you seeing?

BEEBE: I was seeing clouds disappear before my eyes. At these temperatures, they certainly couldn't be evaporating. That's still a question.

We were seeing some upwellings in the atmosphere. The motion of the atmosphere would carry up and over, and you would get a condensation. Then it would disappear when the stuff descended again. That's all perfectly logical, except it was so damn cold out there that it's really hard to figure out how those clouds disappeared once they formed. They definitely were doing that, and it took us quite a while to finally say, "Hey, we got to stick our neck out and say this is true, and we don't really understand how you can get rid of the stuff that quickly."

What are the clouds composed of? Then you get into really complex things, because the type of crystal that forms will really control things, and creating that environment in a lab is not easy. So there's still questions on what was going on. When we first started saying, "This is what we're saying," the theorists on the team were going, "No, it can't be true. It can't be true. We can't say that."

ROSS-NAZZAL: Those were some big debates. What are the temperatures like on that planet?

BEEBE: It's 30 times as far from the Sun as the Earth. For a given area on that planet, it's getting one-nine-hundredth of the radiation that the Earth is getting. The solar heating is almost nil, though there's still some internal heating coming up. I've forgotten what the temperature is, but the heat sources are really low out there. It's cold. You're not going to see water, that's way down below. You're going to see other things that are being pushed up, maybe. Ammonia ices, methane ices.

ROSS-NAZZAL: You had told us previously when the Neptune flyby was over, people were pretty sad. At JSC, when there's the end of a mission there's usually a splashdown party. Did you guys have any sort of event to mark that occasion?

BEEBE: We just sort of went away. We were so damn tired by the time the press left, we just sort of collapsed. Picked up our tapes and went home.

ROSS-NAZZAL: You were still using tapes for Neptune or had things changed?

BEEBE: I forget what we were transporting on at that time. I think it was still tapes that we were using.

ROSS-NAZZAL: Still magnetic tapes?

BEEBE: I think so. I'll have to check that because I can't recall what I was moving things on then.

ROSS-NAZZAL: While you were working on Voyager and in between the Saturn and Uranus encounters, what sort of things were you working on [at NMSU]? You were working with graduate students obviously. Were you primarily working with the Voyager data and doing publications?

BEEBE: I was teaching undergraduates, and I was working with graduate students, leading them through their research. I had a lot of PR going. The Voyager was really demanding along that sort of thing.

One of the other things I did, which was lots of fun, is that there's a unit on the planets in the local school system. Either in third or fourth grade they study the planets, and I would go into the classrooms with the kids and talk about my favorite pictures. The kids were really funny. There's Mesilla Park Elementary School over here, and I went to that one. The teacher was wonderful. In their curriculum, the kids are supposed to write a letter to someone requesting something. They're supposed to, of course, have an outside person, and they're supposed to write a thank-you note.

She put those all together, and she contacted me. I suggested three different topics I could talk about. Then the kids picked the one that they wanted. So I put my presentation together. I got there, and I was met at the car by three little kids who helped me take all of my stuff in and set it up. The teacher sat in the back of the room with a smile on her face. Another little kid welcomed me. I did my presentation, and another little kid took over for questions. Of course, they had preconceived questions because they knew what the topic was going to be.

Then, when it was almost over, this little boy—he was a tiny little thing—was assigned to take me down and introduce me to the principal. We're walking down the hall, and he had wrapped up my hand and tucked it in his tiny little hand, and he's leading me down the hall. He looked up at me and he said, "Do you ever call in sick?" I said, "I don't remember ever doing that." He said, "I didn't think so."

ROSS-NAZZAL: What a great memory. That must have been a lot of fun working with schoolkids.

BEEBE: They were, yes. They were so unpredictable and so smart. One of the things I thought was really cute was they would ask me how big the solar system was. When they were trying to understand that they would just shiver.

ROSS-NAZZAL: Too much to handle?

BEEBE: But their faces would be all lit up as they were trying to do it.

ROSS-NAZZAL: I think I had read on the Hubble Space Telescope [Science] Institute that a fourth grader got in an argument with you about your job and whether or not anyone would pay you to do this kind of work, which I found amusing. She just thought this should be a hobby? Or what was her argument?

BEEBE: That's right. These kids come from families that have jobs that are labor. It just surprised her that somebody would pay you to have fun.

ROSS-NAZZAL: It's a fascinating career. You mentioned you were doing a lot of PR work for Voyager. Would you tell us about that, not being at JPL, but being here in Las Cruces? What did that involve?

BEEBE: It's amazing how many different organizations there are that are looking for speakers. You would end up doing Rotary [International service club] or something else like that. They're the taxpayers—it's their mission, it's not mine. So you owe it to them really. It's hard work to find the time to do it, but it's always really rewarding to talk to the people and see their reactions.

ROSS-NAZZAL: In the early '80s under President [Ronald W.] Reagan there was some discussion about whether or not the country could afford the Galileo mission. For a while, there was some question about whether or not it was going to be funded. Do you remember that time period and whether or not you were involved in discussions about the value of that mission?

BEEBE: I remember a lot of time periods like that. That happens almost every time that we come up with a flagship mission that's going to cost $4 or 5 billion. Even now, any mission that costs more than $1 billion is highly controversial whether it should be done or whether it shouldn't be done. The main controversy usually is whether they should commit themselves to such an expensive project and whether it's going to fit in the budget. Yes, that happened then. Happened again with Cassini.

The original Cassini mission was a mission to Saturn and a mission to a comet using the same kind of high-powered observation. By the time we got the Cassini mission finally funded, the comet mission had disappeared forever. The Cassini mission had been stripped back to the point that it had no scan platform. Voyager has that platform that sticks out so you can do this [scan] while other instruments are doing other things.

Cassini looks like a porcupine. Everything is on it, and every time you want to go, you've got to roll the whole telescope. The operations of Cassini are much more complex. It

was because of budget cuts. The engineers [kept] getting more and more inventive to keep the mission alive as the costs of it were just driven, down, and down to try to get it into the budget.

This goes on all the time. It's been going on now with the Europa [Clipper] mission [to Jupiter's Europa moon]. Whether it's going to have a lander, whether it's not going to have a lander, how much money you're going to put into it. I personally would have liked to see it have a lander. The amount of information we would have got going forward would have been much larger. But costing these things out and getting approval of the chunk is always a major step forward.

ROSS-NAZZAL: Has there been anything that you found as a researcher, as a scientist, that really helped bureaucrats or Congress to say, "Oh, this is really beneficial. This is worthwhile investing in those sort of projects"?

BEEBE: I can't think of any specific thing that I found. I think probably the biggest support I have given is the PR that I have done over the years. One of the reasons that NASA stays in pretty good shape in terms of budgets is that it's got suppliers in almost every state. It's got a very large educational outreach, so in the legislature you've got supporters for something that is important to their local people. The selling of these missions is really important in terms of keeping public support and keeping enough money in NASA that you've got some sort of a reasonable ongoing approach to things.

ROSS-NAZZAL: Around the time of Galileo, of course NASA was supporting the Space Shuttle. They had been building and designing the spacecraft for many years, and it flew for the first time

in ’81. It was supposed to launch Galileo, but we had some problems, we had *Challenger*. What sort of impact did that have on your role in the mission?

BEEBE: Because I was involved in a university, a mission was more of an overburden. I certainly could find 100 percent of my time fully occupied with what the university expected from me and student demands. It represented a delay of when things were going to turn on. I didn’t have any graduate student who was absolutely dependent on getting data out of that at that point in time, so there was no student who was deeply impacted by the delays.

The fact that the delays and the transporting of the spacecraft backward and forth jammed the antenna really threw a clinker in what we were planning to do. The [resolution of] the data that was downloaded from Galileo was superb, but the amount that we could get down was really small. The engineers did their very best to understand how to compress the data. The teams did their very best to select observations that would have the highest yield, but it was a tough ongoing sort of thing.

ROSS-NAZZAL: So you did not get much from that mission?

BEEBE: No, I didn’t. But, by that time I was working at NASA Headquarters. Actually, while I was at Headquarters I ran the grants program for the data reduction of Galileo. So I saw what the guys were doing in terms of the whole thing.

ROSS-NAZZAL: I was curious if you could talk a little bit about how—you’re a faculty member here at New Mexico State University, but you’re provided funds by NASA but also state funds.

I'm curious how that works. How is that allocated? Like you said, you found 110 percent of your time could be spent just working on university stuff, but you still had NASA requirements that you had to meet. How does that all work together so that you are not trying to work two jobs?

BEEBE: Since May of '97, I haven't had any state money. I've been supported by NASA, at whatever level I've been supported, by whatever jobs I've been doing. Before that I was supposed to have a reduced teaching load, but so are most of the faculty in the department because of recognition that research is very critical.

New Mexico State has three roles. One is to educate anyone who comes through your door. The second one is to do creative research. The third one is to educate the public off-site, essentially. You continue to do those things. If your research leads you to heavy commitments, you just figure out a way to stretch it. If I had been a mother, I would have probably been called in by social workers for abandonment. The fact that I was married to another astronomer, [we] compromised. He retired early and had a marvelous time traveling. He wasn't complaining. It was full commitment, and it just sort of eats you up. Of course I did some really neat things while I was being eaten up.

ROSS-NAZZAL: When you were working on Voyager, how much funding was NASA providing you versus state funding? Was it half and half? Half your time technically was supposed to go to NASA? Obviously that didn't work out.

BEEBE: No, it was less than a quarter time that NASA provided. And travel, [NASA] covered all the travel that I had to do.

ROSS-NAZZAL: That also provided funding for your graduate students?

BEEBE: Yes. That's the big piece that makes the university happy, that you have that sort of thing coming in.

ROSS-NAZZAL: You've supervised quite a few graduate students over the years.

BEEBE: I had 13. They're retiring now.

ROSS-NAZZAL: And here you are still working. You're still having fun, right?

BEEBE: Yes.

ROSS-NAZZAL: When I was looking at Galileo, I read you were providing contextual images based on the Hubble Space Telescope. I was confused by that statement because I didn't know how that would work. The Hubble Space Telescope wasn't deployed till 1990 but Galileo was launched in '89, I believe. I was curious, did that in fact happen? Would you talk to us about that?

BEEBE: That's what we could do in terms of mapping the planet with Galileo. While we were getting that, we were getting observations from the Hubble Space Telescope. Those were global, so you could embed these high resolution ones into the lower resolution, and get a higher yield out of it.

ROSS-NAZZAL: I misunderstood the media. I was confused, I was thinking you were providing them before the Galileo mission left. I had also read that there was a contest that you participated in where you were looking at where the Galileo probe had entered Jupiter. You were offering a student a chance to look at one rotation of Jupiter, and you would help them with the analysis. Do you recall [that contest]?

BEEBE: My story on that is that I had two students, Nancy [J.] Chanover, who's one of our faculty now, and Amy [A.] Simon-[Miller], who is at [NASA] Goddard [Space Flight Center, Greenbelt, Maryland]. They went to JPL for the summer school program that JPL provides for graduate students, and they came back having met David [H.] Atkinson, who was on the Saturn probe. As graduate students will do, they informed me that I should help David, help him understand where he was entering. Amy worked with me closely on that. Amy was the student who did that sort of thing. If you want to get her input on it, you can ask her about it.

We weren't particularly happy with the press releases where they called the entry point the "mother of all hot spots." We were working closely with David, and the wind field he was getting, as you went down, would have smeared that thing out. It couldn't have been a system that developed and was static, but the implication by saying it was the mother of all hot spots

was that it was some sort of static feature similar to Red Spot. Instead, it's a wave operation that's expansion, cooling, that kind of thing.

That came later, but what was happening was that we had recommended that the probe be put in right at the equator, because they wanted a typical entry point. But as the mission was delayed, the location where you could put the probe in kept shifting northward. By the time Galileo got there, it dumped into probably the most atypical place on the planet. So that was part of what Amy was interacting with David [about]—what was going to happen, where are you going in, "Oh, oh shit."

ROSS-NAZZAL: That wouldn't have been exciting to pick something that was an anomaly to learn more about? You wanted to learn more about the whole planet?

BEEBE: If you didn't know what the typical was, then it's pretty hard to understand the anomaly. What we had hoped to get is real isotopic distribution as you went down. You wanted a place that was more static, but the delays destroyed that possibility.

ROSS-NAZZAL: Were you there when the Shuttle [*Atlantis*, STS-34] launched Galileo [October 18, 1989]?

BEEBE: No. I was there when we launched Voyager 2 [August 20, 1977]. We launched Voyager 2 before Voyager 1 [September 5, 1977].

ROSS-NAZZAL: Would you tell us about your memories of that launch?

BEEBE: It was disappointing, because I had had the advantage of watching Black Brants [rockets] go off out here at White Sands [Missile Range, New Mexico]. When you got to do that, you got to stay outside when they launched and then you had to run into the bunker before the [rocket] stage came down. That was spectacular, you were right there.

I remember one time we were out there, and there was a storm coming in from the north. It was really, really dark at the site, and they had this green laser. They were ranging the storm, because if it came within seven miles of the pad they weren't going to launch. But the storm turned and came through San Augustin Pass. They launched, but it was a really cloudy night. The Brant took off and it went up, and when it fired its second stage the cloud was so thick that only the longest wave red light that you could see made it back down. The whole place just lit up in this dark red color. It was just spectacular.

I got out there [Cape Canaveral, Florida] to see the Voyager launches. You're way off across the lake, and probably the most exciting thing that happened was after you've watched the launch then the sound hits you. It's coming across this lake, and there's all sorts of small convection cells, so it hits you as a staccato, like the thing is breaking up. You're looking at the spacecraft and it's not doing anything, and the sound is just beating on you.

The same Garry Hunt was there with his small children, and Brad Smith was there with his long range camera. Brad is down near the soggy shore, and he's got his camera lined up with a telephone pole to steady it. He's going to get the greatest shot of the launch. One of Garry's little girls said, "I say, Smith's getting a close-up of that post." She was delightful.

ROSS-NAZZAL: I'm sure everyone was laughing. Did he share the photo that he took with the rest of the group?

BEEBE: I don't think I ever saw that one.

ROSS-NAZZAL: Nice kickoff to a great mission.

BEEBE: Yes. Carl Sagan was there for that launch, and there was a big press conference. Carl showed the golden record [gold phonograph with recordings of life on Earth sent aboard the Voyager spacecraft]. There's an Irish company that has been working on a [documentary] movie that they call *The Farthest*. It's the entire history of the Voyager mission. They have a picture of [Carl's] oldest boy and his mother on the beach during that launch.

ROSS-NAZZAL: I remember reading about the photo that was taken of planet Earth by Voyager, when Carl Sagan had suggested that. Was there any big discussion amongst the image folks about why we should or shouldn't take that photo? Or was [there] pretty much agreement about that?

BEEBE: Candy Hansen is the person that could fill you in on that entirely. They actually interview her. I was an adviser on this movie, so I've seen a lot of the pieces of it. She does a good job. It's nicely done.

ROSS-NAZZAL: I think this might be a good place for us to stop today. That gives you a few minutes to catch your thoughts before your telecon. We appreciate your time today.

[End of interview]