HUBBLE SPACE TELESCOPE OPERATIONAL ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

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INTERVIEWED BY CHRISTOPHER GAINOR
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The questions in this transcript were asked during an oral history session with Dr. Robert Brown. The text has been amended for clarification and for publication on this website.

GAINOR: So, it is December 14th, 2016. It's Chris Gainor, and I'm talking on the phone and Skype with Robert Brown, and you're in—where are you right now?

BROWN: I'm living in the desert, south of Tucson, Arizona, and I'm still working half-time at the Space Telescope Science Institute in Baltimore. I'm working on JWST [James Webb Space Telescope] related documentation at the moment.

GAINOR: Right. So, do you want to tell me about your career with the Hubble Space Telescope [HST]?

BROWN: Yes. I was working in the late 1970s at the Lunar and Planetary Laboratory at the University of Arizona, doing ground-based astronomy—particularly studies of the emission clouds around the Jupiter satellite, Io, and also measurements of the Uranus rotation rate before we had a spacecraft to measure it in place. And the prospect of the Hubble Space Telescope was a great attraction. I knew people who were involved in it. My mentor and hiking companion, Richard [M.] Goody, was involved in some assessments of the telescope in the early 1970s at the National Academy [of Sciences], and it was really through Goody's experiences that I became aware of what a revolutionary concept and amazing system this 2.4-meter mirror would produce. Shortly after, in the early 1980s, I was in contact with Riccardo Giacconi and Donald [N.B.] Hall, his deputy, who were putting together the first staff of the Space Telescope Science Institute. My specialty was planetary studies, and they didn't have anyone working yet on planetary observations at the institute. So, that was the role I applied for and was invited to join Riccardo in that role. So, I moved to Baltimore [Maryland]. I think it was 1981. And I've been a member of the institute staff since that time.

The situation with Hubble when I arrived at the Institute, was that the instruments were well along. The telescope was well along, and everyone thought that there was going to be a launch in the next couple of years. What happened next was that a close look at some of the problems that were being encountered in the development of the telescope and in the ground system put pressure on NASA to delay the launch of the telescope in order to provide more time to solve problems on the ground. And there was considerable turmoil in NASA about this re-baselining of the program. One result was that they wanted new scientific leadership in the project at the Marshall Space Flight Center. So, only two years after I had arrived in Baltimore, I was moving to Huntsville, Alabama, to serve as the Hubble Space Telescope Project Scientist, which I did for two years. And then in 1985, I returned to the Institute.

My earliest recollection of a Hubble-type issue that the institute was trying to solve was related to planetary science. Everyone—all the scientists involved with developing Hubble on the instrument teams—expected to be able to point the telescope at planets in the solar system. But planets in the solar system appear to move against the background of stars, and stars, guide stars, are the basis for pointing the Hubble Telescope. In other words, there is a whole system that produces the guide stars that would be needed for a particular observation, and then those guide stars are locked onto by the guidance system of the telescope. But if you're trying to point at an object that's moving with respect to the background stars, and also rotating, which is a big effect if you watch the rotation of Jupiter, it's clear that some provision needs to be made to move the telescope gradually, in such a way that it tracks either a planet, or a feature on a planet, or a satellite of a planet. And so, since this was my bailiwick at the institute, I went and looked deeply into the literature (by literature, I mean the documents that define the Hubble project), and in one of the assigned documents for the ground system, there was a section called, "For Moving Targets" or "Planetary Targets." And the upshot in that document was that planetary tracking was equal to a straight-line linear scan. But planets don't move in straight lines, particularly because of the parallax of the Space Telescope orbit, which causes every 90 minutes, any object in the foreground to move in an elliptical motion, with respect to the background stars, and a straight line just wasn't going to do it. And so, this was a theme for maybe the next three years, including when I was at the [NASA's] Marshall Space Flight Center [Huntsville, Alabama]. I was working to find a solution to tracking planetary targets, and it turned out to be a big success. We got software from JPL [Jet Propulsion Laboratory, Pasadena, California] that gave us proper ephemerides of the planets. And the ground system was upgraded to take information from the JPL software and plan observations where the guide stars would actually be pulled and moved by the Fine Guidance System [FGS] in exactly such a way that a planetary target would remain fixed on the focal plane of the telescope, and therefore fixed on images and spectra.

So, I think my experience at Marshall was to really appreciate how [through] process and people working within an organization according to rules and standard methods, you can end up accomplishing a great thing that's much more than the sum of the parts, and in which thousands of people make contributions, but at the same time, the role the individual scientist or engineer can make unplanned, unexpected contributions that turn out to be important in the long run. So, the Hubble Telescope is a story, both of concerted actions of the combined effort of many, many people and the story of individuals who at one moment in time make some contribution that causes the whole program to move in some direction to solve or understand a problem. And the same thing was true later on when we were dealing with spherical aberration. We had both a NASA system through which anything that got done, would have to be done, but we also had individuals whose genius and insight were absolutely instrumental in coming up with a successful result. So, a project like Hubble is a combination of things—important things at the macro-level and important things at the micro-level.

So, I arrived in Baltimore. I spent two years there. I went down to Marshall Space Flight Center for two years, and returned to the institute around 1985, and it was then five years. Then we had the [Space Shuttle] *Challenger* [STS-51L] accident, of course, which imposed a delay in the launch of Hubble.

Five years after I had returned to Baltimore, the telescope was launched, and the first images didn't look right. My colleague, Christopher Burrows, was the first person to know that it was a spherical aberration problem. He was able to simulate what was being seen in the real images, by a certain amount of aberration that, when he put it in, you couldn't tell the difference between what was being simulated and what was in place. And so, that became a very interesting time for me and for the institute as a whole.

So people were in despair. There was a lot of hand wringing, but no clear direction to take. I think the idea that we first heard came from NASA, probably from Goddard [Space

Flight Center, Greenbelt, Maryland], was let's send a shuttle up, grapple the telescope back into the hold, bring it back to Earth, fix it, and relaunch it. That was totally impractical, I think most people agreed immediately. If you brought it back to Earth, it would never be qualified to go back into space again. And so, with far-fetched ideas being floated, it was clear (to some of us) that somebody had to instigate a process that would resolve the problem in a convincing manner. If it was impossible to fix it, then, in a way, you have to accept that. But we thought that a systematic look at the options might turn up a solution. At the institute, every person there had a personal stake in it, as did astronomers all around the world.

So, we knew we had good will, if we put together an activity, and so, we did. Basically, Holland Ford and I developed an idea with Riccardo that we would put together a group of experts (with unassailable credentials and integrity) to review the situation, establish what was known about the problem, and then look at possible solutions and concepts for fixing the spherical aberration. And I think you have a copy of my strategy for recovery.

GAINOR: Yes.

BROWN: And in it is a list of luminaries who gave their time to this project. Basically, we had four meetings in three months. And they were spread over just a few months of time, because we knew time was of the essence. We didn't want the system to be committed to going in some direction that wasn't going to be fruitful. We wanted to have confidence in whatever direction was taken. So, the group met four times. Once at the institute, once in Garching [Germany], near Munich, where the European Southern Observatory [ESO] was set, which is also the home of the European Coordinating Facility for Hubble. So, there was a lot of interest in Europe, and we thought we wanted their perspective. And two final meetings at the institute to deliberate and decide the final recommendations.

GAINOR: And I think they might have been listed in the report, the meetings.

BROWN: The plan was to develop every possible idea that the group could come up with. To treat them all equally for a while. Work them up into individual descriptions of what the approach would be, and what could be expected of it. I think there were 18 or 20 individual concepts that came out of the group, and then at the last meeting, we all voted in favor of one particular solution, which was to basically deploy pairs of mirrors in the optical beams that were headed for the individual instruments. Both these mirrors are about the size of a quarter. The first mirror reimaged the pupil onto the second mirror. The pupil is where the problem was. The spherical aberration was due to departure from the desired mathematical surface. That situation was recreated on the second mirror which was manufactured with the error in reverse, and that cancelled the spherical aberration on the second mirror. And then the light proceeded from there to re-enter the existing instruments, and the wavefront was perfect. When this was implemented, we basically completely solved the spherical aberration as an optical problem.

I guess the last thing—in addition to the fact it was a success, for which I'm proud of my part—the amazing thing was the cast of characters who contributed to the solution. I remember, after the decision was made, and then shortly after that, NASA made the decision to go ahead and mount a previously unplanned servicing mission to install this COSTAR [Corrective Optics Space Telescope Axial Replacement], which would deploy the pairs of mirrors. During that time, Lyman Spitzer, who'd had the original idea for the Hubble Telescope back in the 1940s, he was on this committee. Not only that, he was one of the most active members of the committee. He was doing optical calculations of all kinds of different things. And he was speaking daily with Murk Bottema, the chief optical engineer for one of the original Hubble instruments, back in Boulder [Colorado], at Ball Brothers.

I guess I should mention as part of the story that it was all enabled by the confidence that we had, that we understood the problem, and understood it, exactly. Such that these corrective mirrors could be manufactured and could go up into space and be deployed by an astronaut and actually solve the problem. And that was where Chris Burrows came in, and Roger Angel was on the committee. It was the bedrock of the whole exercise that we knew exactly what the problem was, and we could deal with the simply technical problems of how to install the solution.

GAINOR: And then there was the famous shower.

BROWN: [laughs] Well, right. Yes, that's an apocryphal story. I believe it's correct. That was at our meeting in Munich.

GAINOR: Right. Jim [James H.] Crocker.

BROWN: Jim Crocker, yes. Jim played a very important role, which launched him into a wonderful career as a leader of American aerospace. Is he on your list of interviewees? I hope so.

GAINOR: Oh yes, I've already talked to him.

BROWN: Oh good.

GAINOR: And then, of course I hear a lot about Murk Bottema, over at Ball.

BROWN: Well, Murk Bottema is who I was mentioning that Spitzer was talking to daily. Murk was an optical genius of the first magnitude. And I think it was one of the crowning achievements of his life to work this optical problem, and to get it right.

GAINOR: Now, one of the folks at Goddard who was involved in this, who has passed away, unfortunately, was [H.] John Wood, but I have, about five feet away from me, all his detailed meeting notes from that period.

BROWN: Oh, from the period when we were finding and implementing the solution.

GAINOR: That's right.

BROWN: Yes, so, I remember he was around. He wasn't on my committee, but he was one of the key Goddard people in the room.

GAINOR: And, of course, there were actually two fixes there. There was the COSTAR and also the WFPC 2 [Wide Field Planetary Camera 2], but I imagine you weren't really involved in the WFPC 2, or were you?

BROWN: WFPC2 was part of the solution. I mean, it's true that JPL was developing an instrument where you could put in these mirrors, and that was done, and it was a great success. So, there was an implementation inside WFPC2, and then other sets of solutions that were deployed by COSTAR.

GAINOR: Right. Okay. I've got the impression a little bit that this effort was led, somewhat, by the folks from the institute. Or is that unfair? Was it everybody kind of pitching in from wherever they were?

BROWN: Well, the institute conceived, organized, and conducted this process, end to end, and produced and distributed the final report, "A Strategy for Recovery." And NASA was grateful. I don't know if you interviewed anybody at NASA Headquarters, but you know the name Charlie [Charles] Pellerin.

GAINOR: I've talked to Charlie, and I've talked to Ed [Edward J.] Weiler.

BROWN: Oh good! When Holland Ford and I were putting together this committee, this strategy committee, the first thing that I did was to go down and visit Charlie Pellerin at NASA Headquarters to make sure that he understood what we were doing, didn't misinterpret it, so that he could support it from his angle. Particularly upward in the management structure at NASA, and Pellerin was the entrée, since he ran the Astrophysics Division. And when I went to visit him, early in the process, and explained what our approach and organization and concept would be, he expressed in the strongest terms his gratitude that the institute was taking the lead in addressing this problem. So, that's always been a symbol for me that we were doing something useful, namely that Charlie Pellerin was grateful we were doing it. I don't know whether he expressed any of that to you.

GAINOR: I would have to check. We had quite an extensive discussion about a lot of things.

BROWN: Well, in any case, he was an important player, and an important player later, once the study was done, and we produced our report. We then gave it to Riccardo and Riccardo took it to NASA. And Pellerin, and the Associate Administrator at that time (whose name I can't remember at the moment).

GAINOR: Lennard [A.] Fisk?

BROWN: It was Lennard Fisk. And Lennard Fisk told me, in private, sometime after that that he really liked COSTAR. So, it was welcomed by NASA once it was a real thing that they could do. And basically, that outcome was due to the fact we had on the committee, people who understood what was being done from all the different angles. We had an astronaut on the committee, and he worked with Jim Crocker to make sure that when the idea of COSTAR being installed in place of an existing instrument, that this all could be done; that the space where these things would be deployed was, in fact, free, and that the astronaut corps could support the installation.

GAINOR: Bruce McCandless.

BROWN: Bruce McCandless, right. I remember receiving a telephone call from one of the leading astronauts, a woman—I forget who it was—but she gave me a call sometime early in the process, saying, "Don't forget that Bruce McCandless is now retired, and that he can't speak for NASA." But what he did was to speak for NASA's expertise on matters like this and gave very responsible encouragement to our process from the beginning by participating in the committee.

Oh, by the way, I just wanted to emphasize that Riccardo's rendition of that whole story is accurate, in my opinion. It's a good description.

GAINOR: Okay. That's good to know. Do you want to tell me about some of the things you've done since then, that relate to Hubble?

BROWN: Yeah.

GAINOR: I guess you did the second decade thing, and all that?

BROWN: There was a question about what new instrument should be developed for the telescope. And already before launch, there was an approval of the second-generation instruments, which were NICMOS [Near Infrared Camera and Multi Object Spectrometer] and

STIS [Space Telescope Imaging Spectrograph].

So, those instruments were being developed, and at the time of Hubble launch, and after the fix of spherical aberration, the next logical question was what will we build as a new instrument after the two that are being prepared? So I was asked to put together a committee to look at the question, and it ended up being called the Future of Space Imaging Study. What we did was lay the case out for building what turned out to be the Advanced Camera for Surveys [ACS]. Holland Ford was on the committee that made this recommendation. He played an important role in building COSTAR, but then he became the PI [principal investigator] of the Advanced Camera for Surveys, which is absolutely a fantastic instrument, and contributed a great deal to what will be the legacy of the telescope. It was a terrific instrument, and the one that was built was more or less along the lines of the one that the committee envisioned. The wide field of view taking advantage of the very high resolution and the stability of the telescope. Those are the unique factors of space that make a new instrument outstanding, and those are the features, or potentialities of the instrument that should be taken care of, and that should be the basis for the new instrument. And that was true in the case of ACS.

Did you talk to Holland Ford?

GAINOR: I have, yes.

BROWN: Oh good. He's been a great contributor to the success of Hubble.

GAINOR: Yes.

BROWN: Later on, in the late 1990s, the question arose, what new directions should the telescope take; what should be the priorities or modes of use. The institute organized the second decade study to address this question, and I led the study. The Second Decade Committee made three recommendations. First, it recommended the Hubble Treasury Program, which would allocate 20 percent to 30 percent of Hubble orbits in the second half of the mission to large observing projects, using a separate peer-review process. Looking back, the Treasury Program has been an outstanding scientific success, bringing vast data sets to bear on a variety of forefront problems in astrophysics.

The second recommendation was to invest in visionary concepts for the Hubble data archive, which would support research with Hubble data in the years after the telescope stops operating. As computer and network technology develop, powerful new approaches to data analysis will become possible, such as synergistically combining data from multiple missions. Today, this is the [Barbara A.] Mikulski Archive [for Space Telescopes] hosted at the institute.

The third recommendation was to augment the Wide Field Camera 3 with an additional channel for infrared observations. Wide Field Camera 3 is up there today, and one of its most exciting sources of new observations has been the infrared channel that the Second Decade committee recommended.

Do you have that report, also?

GAINOR: I believe I do, but I will check and if I can't get it, I'll let you know.

BROWN: Okay. I think that it wasn't a hard-bound report. It was individual reports for the recommendations, and one of them was about the archive. It was clear to us at the end of the 1990s that one of the most valuable aspects of Hubble was the terrific, well calibrated, highly stable data that came down, that could be used again and again for other purposes in the future. And so, we promoted the archive, which has been a tremendous success. We not only archive for Hubble, as you probably know. Many other missions are using the institute's systems to archive and curate and distribute, over the internet, the data.

GAINOR: I'm doing a little section on that; I think that's quite important. So, is that kind of it in a nutshell for Hubble?

BROWN: Yeah. There's one other storyline that I wanted to share with you that other people might not have picked up on, and that is Hubble history with respect to the very exciting new theme in astronomy, which is the discovery of planets around other stars. And the whole question of origins, and whether life may have appeared on other planets—there's a whole ball of wax there of interesting questions that are raised, if the Earth is not unique in some sense. And philosophers going way back have reviewed and considered this question of the uniqueness of the Earth, and it just is within current history that it's become possible for science to inform that question.

Planets around other stars were mentioned by Spitzer, back in the late 1940s, when he first began to talk about what would be the Hubble Space Telescope. And if you look in that list of science projects in the first few pages of the call for proposals, you'll find that planets around other stars are one of the goals of the Hubble Telescope, before it's developed. I mean, it's not that it's a goal; that list is sort of NASA's idea of typical things that might be done.

And there it is; it's one of the pieces of the list. The Faint Object Camera [FOC], which is the European contribution to the telescope instruments, included what is called a coronagraph, to suppress starlight, and make a planet visible. There's an enormous factor of difference in brightness between a planet and its host star. Something like a billion to one in brightness, so it's a real instrumental problem to create an optical system, a special Fourier optical system that will suppress the bright star light and make the planet visible.

Unfortunately, the people that worked on the FOC before launch didn't have a clear idea of what the aberrations would be in the telescope, and furthermore, there was no requirement on the optical performance of the telescope to support imaging planets, rather than stars. If they'd tried it, they probably would have decided it was impossible to do a proper job on it, but they didn't and then what happened next, unfortunately, was that the Faint Object Camera's coronagraphic channel was not fixed by the mirrors that were deployed by COSTAR. Other channels in the Faint Object Camera were corrected, but not that one. So, there was no sensitive coronagraphy with Hubble. It next came up later in the 1990s, when I actually wrote a proposal for a Hubble instrument which was a coronagraph that could deal with the aberrations in the mirror. It actually used what was called a deformable mirror, where the shape could be changed electronically. And it could correct any wavefront errors and then make the coronagraph function properly. Unfortunately, while NASA rated my proposal "selectable," they didn't select it.

This line of investigation is only increasing in interest and in capability, and there's no question that it's going to be at the center of astronomy as a key theme and goal, to test, if you want to say, the uniqueness of Earth, we already know we're finding planets; we're not taking pictures of them yet, but someday, we'll be detecting Earth-like planets around nearby stars.

Then we'll build optical systems that can isolate the light from such an Earth-like planet and say something about the atmosphere. The atmosphere can tell you, for example, if there's an abundance of free oxygen. The only way we know how to do that is, on Earth at least, by life, you know, through photosynthesis. So, there are myriad implications and opportunities on that science topic, and it was there with Hubble from the beginning. Hubble took the problem so far, and now, we've got new generations of instruments, and astronomers. There's only one direction that it's going to go; we're going to learn more and more, and it's going to be more and more revolutionary. The man on the street can appreciate immediately what the significance that line of research is.

GAINOR: Okay, yes. I'm glad you spoke about that, because that's quite important. Going back, you were talking about your planetary work in the early days, and I got the impression that in the early days of Hubble, there was a little anxiety as to whether the planetary folks were really going to be served by Hubble.

BROWN: Yeah, somebody told you about George [B.] Field's famous speech.

GAINOR: I'm not sure if I did hear about it or not. Doesn't ring a bell.

BROWN: Well, this is during the mid-1970s. He came to a meeting of the Division of Planetary Sciences of the American Astronomical Society [AAS], which is the planetary group. He came to a meeting—it was in Hawaii, actually—and he said something like, "You planetary scientists have had a lot of big missions." And of course we did have Pioneers, and

Voyagers, and all kinds of things, and George's point was that our community had been well served by big NASA investments, and here was something that was for the astronomers. And it's their turn. I don't think he dwelt any time on what the planetary program of Hubble might be, but he just gave the people in the audience the feel that their interest wasn't particularly welcomed. And then the next thing that happened after that, which was several years later, was I stumbled over the fact that the telescope was being built without a capability to track planetary targets, even though one of the level one requirements of the telescope was to track planets. So, it was a clash of perspectives.

GAINOR: A full and frank exchange of views.

BROWN: Right. You know, there are two. It's a concatenation of two independent things. One was the perception. The drama at that time was really that the astronomers themselves weren't united behind Hubble. It took a lot of thinking on the part of astronomers to realize it was going to be a cultural change and an enormous opportunity to have this telescope available. There's no precedent for an instrument that was so precise and so capable as this thing, and so George Field, on the one hand, was showing that he appreciated how important Hubble was going to be.

But most of his community were in a wait and see mode on Hubble. Many astronomers at that time, if you'd asked them what would be more important, building another four-meter telescope, like the one on Kitt Peak [National Observatory], or putting a space telescope into space? They knew about how to deal with the ground-based telescope and make use of it. But they didn't so much know what the future would be like if they had something as revolutionary to work with as Hubble would be.

GAINOR: Just before I turned on the tape here, you were telling me the story about Richard Goody and the data, and I think I'm going to ask you to tell me that again for the tape.

BROWN: Yeah. My colleague, Richard Goody, led a National Academy study in the early 1970s. The purpose was to revisit the recommendation, or lack of a recommendation from the Greenstein Decadal Survey, which just a few years before had decided not to give their highest-level priority endorsement to what would be the Hubble telescope. And that was the wrong answer. Many people realized it, and the way to address it was to go back and revisit the recommendation, which the Goody Committee did, and came forward with an endorsement. Goody may have some document in the archives of the National Academy about that period. I'm not sure. But he told me first hand.

So Goody became very knowledgeable about the telescope, what it was, and how it would operate and what it would do. And his impression was that one of the major unexpected or unforeseen, so far in the early 1970s, was the volume of information that would pour down from this telescope. It would be up there, relentlessly taking beautiful pictures, minute-by-minute, hour-by-hour, 24 hours a day, 365 days a year, no weather, nothing to interfere. Only point the thing at the right place and take a picture. And each of those pictures was a very large data volume, particularly if you could give somebody one image, and they could hurt themselves with it, go away trying to figure out how to look at it. That was at a time before we had much image processing software, [before] the graphic interfaces that everyone now enjoys. So, if you just did a back-of-the-envelope calculation about how much information was going to be coming down every day from this telescope, there was no trained cadre of scientists to look at that data at that time. Goody likened it to a gully washer, maybe in a canyon that there's a lot of rain upstream, and suddenly you have a tidal wave of water, or in this case, information, coming down and sweeping away everyone standing in its way, until such a time as tools and methods were developed for making good use of it.

Now, thank God for the internet revolution and the information technology revolution that put computers on everyone's desk sometime in the early 1980s. There's no question that the information technology and the internet are the foundation on which Hubble has achieved its success by basically enabling scientists to do what scientists can do with this wonderful abundance of data, namely look at it, make calculations about it, try to simulate it, try to draw information from it. When you get something like the Hubble Deep Field [image of a small region in the constellation Ursa Major], just as an example, so much information there, that it's impossible to think of getting at it and finding meaningful results without serious computational and communications capabilities that simply weren't there at the time the telescope was envisioned.

GAINOR: Well, I think that pretty well covers it. So, I want to thank you.

BROWN: You're very welcome, Chris. And good luck with your book.

[*End of recording*]