DISCOVERY 30TH ANNIVERSARY ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

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INTERVIEWED BY ERIK M. CONWAY
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CONWAY: William, what were some of the difficulties and challenges you experienced as the Kepler mission just began?

BORUCKI: After receiving notice that the Kepler Program had been accepted to start development, I was asked to meet people at NASA Headquarters in January to discuss the start of the mission development. People from several Headquarters' organizations were present: people from finance, engineering, science, and management. They explained to me that no funds were available to start the development of the Kepler project at this time, Instead, the Mission must wait a year to start. I was aghast.

The Kepler proposal stipulated an explicit and detailed schedule with costs and products. A previous study by the National Academy of Sciences showed that projects that did not keep on schedule were likely to go over budget. In that situation, NASA canceled such projects, unless the U.S. Congress waived its requirement that each space mission must not exceed its budget by more than 30 percent. To stay within budget, our team had previously set up contracts with vendors to obtain critically needed, long-lead items. The contracts needed to be funded within 90 days of the mission acceptance to obtain the offered bid price and delivery schedule.

To keep the cost down and stay on schedule, we had already run a competition among several vendors that could provide the necessary 80 detectors at a price of several million dollars. These CCD [charge-coupled device] detectors were state-of-the-art systems. A previous spacecraft program had already been canceled because it had not been able to buy CCDs in sufficient quantities and quality and at the agreed-upon price. Our team had worked to overcome the difficulty of getting a sufficient number of acceptable CCDs by asking for bids from five different companies prior to the submission of our proposal. We then examined the bids and selected two vendors. Each vendor agreed to supply half of the needed detectors with an option to build all the detectors if the other vendor could not supply their share of suitable detectors.

If the Keppler project was not funded during its first year, then those contracts were null and void. That meant we would no longer be on schedule, and we'll probably overrun the cost stated in our proposal. Furthermore, one of the critically needed members of our team, Jon [M.] Jenkins, was being offered a job at a much higher pay rate if he would leave the Kepler program and move to Georgia. I'm sure it was a tempting offer because he was a young man just starting a family. Jon oversaw the development of the very complex computer programs that were required to analyze the data. He'd already proven his capability by building a prototype program that was used to process the data from the Vulcan photometer.

I asked the people at [NASA] Headquarters why they would select the Kepler Mission and cause it to immediately go off schedule, possibly go off budget, and lose critical personnel by not funding us on the schedule explicitly stated in our proposal. I told them because they had formally accepted our proposal, it was their responsibility to fund the mission development at the levels and on the schedule stated in that proposal. The Headquarters team told me that I must stop being so demanding or they would cancel the mission. I simply reiterated my demand they start funding in the next few months to purchase the time-critical items and to keep members from leaving. When I left that meeting, we all looked like Martians, all our faces were red or purple.

Apparently, NASA Headquarters understood the critical need to fund us quickly with, at least, a modest amount of funds. A few weeks after the meeting, I received a call saying they had found some funds so that we could begin to purchase detectors and long lead items. I'm sure they had robbed Peter to pay Paul. I've heard since that the Dawn mission, which was starting at the same time as the Kepler mission didn't need substantial funding for its first year because it had not yet let any contracts. Consequently, the Dawn team would let us borrow funds for a year. I was delighted that the NASA Headquarters managers had found a way to get Kepler started on time.

The announcement of opportunity, that is the AO, specified that the upper limit to the mission cost for any proposed mission was $300 million. That was to include all expenses, including the instrument, the rocket booster, the education outreach programs, the cost of using Deep Space Network, and all non-NASA salaries, and equipment. The development and operation of the Kepler mission would take several years; therefore, inflation would cause the cost of the items purchased in the future to rise above their current cost. The AO recognized this situation and required that all costs listed in the proposal must be in year 2000 dollars based on their specified inflation rate. Consequently, the real-year dollar cost of the mission would rise year by year, but the cost based on the 2000-year dollars would not.

However, shortly after the selection of the Kepler mission, Headquarters changed the rules. Now, the mission must date its cost in real-year dollars. That immediately boosted the apparent cost of the Kepler mission by $20 million. Furthermore, all costs for civil servants, such as scientists, engineers, managers, and financial agents at NASA would no longer be considered free to the mission. That accounting change caused a several-million-dollar cost increase. Before the start of the Kepler mission, NASA performed a study called NIAT [NASA Integrated Action Team] and wanted the report's findings to be incorporated in the development of the Kepler mission. That would add $8 million to the cost of the mission. Also, Headquarters required that a guest investigator program be developed for the Kepler mission. They stated its cost would not be assigned to the Kepler mission. However, Headquarters accountants ignored that instruction and added, logically, its cost to the mission.

Next, because the Kepler mission was part of the Discovery Program, our team knew that innovative approaches were required to keep the mission's costs low. To accomplish that, we proposed that our major contractor Ball Aerospace & Technology Corporation [commonly known as Ball Aerospace] would design, build, and manage the entire Kepler mission. Ball had a good reputation for building space missions on contract for the military. We proposed that the [NASA's] Ames [Research Center, Moffett Field, California] management and staff would provide only monitoring and reporting to NASA Headquarters. Our proposal was based on the "better, faster, cheaper" paradigm advocated by the NASA Administrator Dan [Daniel S.] Goldin. Our approach contrasted with a typical mission where the Center, such as JPL [Jet Propulsion Laboratory, Pasadena, California], would assign many engineers, and managers, and financial agents to oversee the work. Thus, we expected our approach would cut management costs by almost a factor of two. This approach was explicit in our proposal.

However, a few months after the acceptance of the mission for development, I received a letter from NASA Headquarters stating that the management by NASA Ames Research Center was inadequate. The implication of the letter was that only management at the Goddard Space Flight Center in [Greenbelt] Maryland or the Jet Propulsion Lab in Southern California would be satisfactory. I was to choose one of those organizations and justify my choice to both Ames management and to NASA Headquarters.

To choose between the two alternatives, my Deputy PI [principal investigator] Dave [David G.] Koch and I asked each of the two organizations to write a short proposal and make a presentation to us showing how they would manage the mission, and to provide the names and resumes of the project manager and the science liaison. When David and I and our review panel met and examined proposals, it was clear that the proposal from the Goddard Space Flight Center was superior. I set up a meeting with the Ames director and discussed our conclusions and the reasons that the Goddard proposal was rated superior. Scott [Hubbard] told me that I was in charge and that I could decide, but that he felt JPL would do a better job. Further, he said that he had a cooperative agreement with JPL, and he had already made arrangements with the JPL management; therefore, I should choose JPL.

Although I was unhappy about our wasted effort and the lack of control by the PI, I recognized that the development of a successful mission required the support from the Ames management. I went back to my team and review panel. I told them that it was necessary to choose JPL, and that JPL was a highly experienced organization that had flown many successful deep space missions, and I was sure that it would work.

A memorandum of agreement between the principal investigator and the JPL Mission Management Office was signed that detailed the agreement. The provisions of that agreement included that the “PI is responsible to the NASA Discovery Program for the execution of the entire mission and the scientific integrity of the investigation. He creates the project’s strategic plan and oversees its implementation." However, near the end of the agreement it states “JPL is responsible for the mission management of the Kepler mission. This entails the day-to-day project management of the implementation of all elements of the Kepler mission to ensure they are properly developed and integrated within cost, schedule, and performance criteria.”

That agreement immediately added $30 million to the mission cost. Thus within a few months of the selection of the Kepler mission, and prior to any action on the part of the Kepler team, the mission cost had risen from $299 million to over $404 million, a 33 percent increase in the mission cost. We were greatly over budget, and we had not even started our mission development. That was the start of the Kepler mission.

CONWAY: Thank you. You said Scott, this is Scott Hubbard?

BORUCKI: Yes.

CONWAY: Okay, just making sure I have the right Scott. I knew he was Ames Director, and I just wasn't sure exactly when.

BORUCKI: I'm not sure people like to hear difficulties, but you can see why we were always over budget and always behind schedule, and that there was no way to catch up.

CONWAY: Right, you started out behind the eight ball just because of all the management changes that went on at that time, yes.

BORUCKI: That's right.

CONWAY: Yes, so let's see, then I wanted to add a set of questions about the science merit functions. The first of those, Riley [M.] Duren mentioned working with you to develop science merit functions, so what were those functions?

BORUCKI: Once the Kepler proposal was chosen for a flight opportunity, it was necessary to optimize this design to accomplish the ambitious goals specified in their proposal and still stay within the available resources. To maximize the science return from the mission, I wrote a computer program that computed the value of a merit function that related the science value, as determined by the PI and the science team, to the chosen mission characteristics and to models of planetary systems and stellar populations.

The merit function consisted of computer models of the stellar environment, assumed exoplanet characteristics and distributions, detection sensitivity to key design parameters, and equations that related the science value to the predicted number, size, and spatial distribution of the detected exoplanets.

The merit function serves several purposes. First, it predicted the possible science results of the proposed mission; second, it evaluated the effects of varying the values of the mission parameters to increase science return or to reduce mission costs, and third, it supported quantitative risk assessments. During the later stage of the mission implementation, it was used to keep management informed of the changing mission capability and to support rapid design trade-offs when mission downsizing was necessary.

For example, the merit function results indicated that the science value would decrease by 33 percent if the mission duration were reduced from four years to three years. In another study, the merit function was used to estimate the effects of choosing 170,000 individual stars after a ground-based survey of the characteristics of 4 million stars in the field of view versus simply observing the brightest 170,000 stars without conducting a survey. The merit function showed an increase of 40 percent in the science value, and an additional 100 small planets would be discovered if the ground-based survey were conducted. The Mission funded the survey. Those are the two examples of the use of the merit function, but there are many others.

CONWAY: Okay, so how were the science merit functions developed?

BORUCKI: In consultation with my science team I wrote a computer program that ranked the value of the expected science results versus changes to the Mission design. It was my response to a question asked by Riley Duren, the JPL systems engineer who asked; "Bill, how would you try to evaluate the science?" My first response was "You couldn't, the science is everything." But later when I thought about the question, I realized that a more useful question was how to rank the expected science products versus Mission capabilities and the changes to those capabilities. It took me several months to develop a computer program and to check with the science team about the assignment of values to various outcomes. In particular, assigning the relative value of Earth-sized planets versus planets twice as large, versus those that were in the habitable zone, versus those that weren't in the habitable zone, versus those that orbited a Sun-like star, versus those that didn't, etc. was complex.

Further I needed to write a program that made quantitative predictions of what we expected to find based on the characteristics of our Solar System and a model of the distribution of the types and brightness of the stars in our galaxy. The model for the stars was modified to select only those stars with apparent magnitudes and size that would provide a signal-to-noise ratio of at least a 4-

sigma detection based on the computed orbital periods and transit durations for the type and brightness of each star in the galactic model. The program also contained a model of the structure of planetary systems based on our Solar System. Given that information and the parameters in our instrument, (such as aperture size, detector performance) and the cadence and duration of the observations, the program made quantitative predictions of the results and generated relative science values based on the input values. A more comprehensive discussion of the merit function was published in a paper by Borucki, Duren, and Jenkins in 2020. [*Science merit function for the Kepler mission*] by Borucki, Jenkins, and Duren, *Journal of Astronomical Telescope, Instruments, Systems,* 044003-1, Volume 6, 2020.

CONWAY: Okay, great, thank you.

BORUCKI: You're welcome.

CONWAY: You already gave me the examples I asked for, so we don't have to do that again. You suggested, and I don't know if you want to do this now, but you suggested talking about the meeting that changed the name from FRESIP to Kepler.

BORUCKI: The first proposals in 1992 and 1994 were named FRESIP, Frequency of Earth-Sized Inner Planets. Prior to our first proposal we needed to choose a name for our Mission. I suggested FRESIP because that acronym expressed some of the Mission goals. We wanted to find the occurrence frequency of Earth-sized planets. We preferred inner orbits because they imply that the planets are in or near the habitable zone and they provide numerous transits during the mission lifetime to increase the planet's detectability.

In 1996, however, several members of the team including Dave Koch, Carl Sagan, Jill [C.] Tarter said that they really didn't like that as an acronym and requested that it be changed to *Kepler*. [Johannes] Kepler, was the person who discovered the planetary laws of motion. These were used in the merit function to relate orbital period and distance to the mass of the star. With the star's brightness and size, the model calculated the planet's position relative to the habitable zone. Kepler also developed the laws of optics that guide the grinding of eyeglasses and telescope optics. These were pertinent to the Kepler instrument design. Consequently I was delighted to change the mission name to Kepler.

CONWAY: Did a particular person come up with Kepler, or did you think of it and suggest it?

BORUCKI: I think that Dave Koch came up with that name. Dave was very active in every aspect of the mission. He would have discussed the proposed name change with Carl Sagan, Jill Tarter, and others to be sure that he had their backing.

CONWAY: Okay, fair enough, thank you. Is there anything else you want to talk about before we before we stop?

BORUCKI: No, I think that's it. Erik, it's been good talking with you. What's the next step?

CONWAY: Oh, well, I'll re-edit it and there's a little bit here that I think you didn't add before, I'll get that added and send it back to you.

BORUCKI: And what happens after that?

CONWAY: It goes to, because this is for the Discovery Program, the NASA's Oral History Program has a website [https://www.nasa.gov/history/history-publications-and-resources/oral-histories/] that these eventually go on once you approve it and release it, and so then it becomes available to other authors.

BORUCKI: Okay, so it'll be on a public website because people ask me what happens to this?

CONWAY: Yes, that's what happens.

BORUCKI: Okay, Erik have a good day.

CONWAY: Thank you for your time, have a great day.

[End of interview]