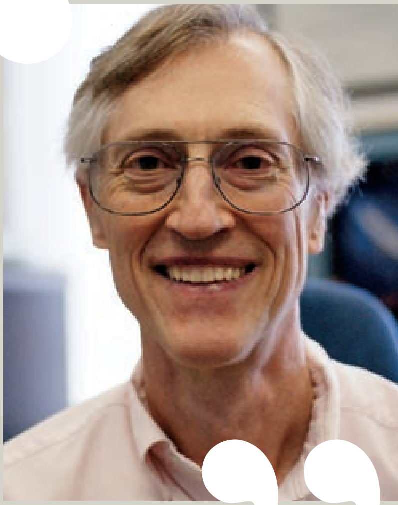
INTERVIEW WITH

John Mather

BY DON COHEN

John C. Mather was study scientist and project scientist for the Cosmic Background Explorer (COBE) and principal investigator for the Far Infrared Absolute Spectrophotometer (FIRAS) on that mission. He shared the 2006 Nobel Prize in Physics with George Smoot for measurements of cosmic microwave background radiation that support important elements of the big bang theory of the universe's origin.

He is currently senior project scientist for the James Webb Space Telescope and chief scientist for the science mission directorate at NASA Headquarters. Don Cohen spoke with him in his office at Goddard Space Flight Center.



COHEN: On COBE, how did you get from a research idea—measuring cosmic background radiation accurately—to a project that works?

MATHER: We were all hardware-oriented scientists. We tried to solve some of the obvious engineering problems, like where to put the observatory to get a protected environment. Fairly early on, we found the orbit we needed to use. The scientists were functioning as much as they could as engineers, trying to design a mission concept that could actually be built. Of course, we didn't know how to make something spaceworthy or deal with such a huge scale of effort. We were assigned to work with the IUE [International Ultraviolet Explorer] project team, which was about to launch the IUE. So there was a complete engineering team already in existence, and we had some brilliant engineers to work with at that point. They said, "We'll take you under our wing; we'll work with you to figure out what you need." Since I was the

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study scientist, I spent my life with them trying to figure out how to make this project real.

COHEN: What was that process like?

MATHER: I met with engineers practically all day every day. We would just talk: How can you do this? How hard is that? How well do you have to do this? Of course, there were quite a few things that we couldn’t calculate. This was before everybody had a laptop that could calculate anything; I wrote handwritten memos with my version of a calculation of a requirement.

COHEN: In your book, you say engineers think of scientists as “arrogant and naïve.”

MATHER: We come from different cultures and have different ways of thinking. Engineers are trained to make something that really works. The scientist says, “I know I can’t do this or that, but I want to find a way around all the things that can’t happen.” That’s why I spent so much time with engineers. They knew what could be done, and I knew what we wanted to do. They’d say, “You can’t do that,” and I’d say, “If we change our request a little bit, could we do *that?”* That’s how the project evolves. I like to work on seemingly impossible engineering tasks. A scientist has to work with the engineering team to find a way around the impossible. It’s fundamentally a science-engineering job. The part that says, “Let’s find a path that combines the engineering possibility with the scientific wish”—that *is* science. Not all scientists have a talent for that.

COHEN: Have you worked with the kind of scientists who don’t work well with engineers, who just say, “These are my requirements?”

MATHER: None of the people I work with are like that. There are people you would call theorists who have no interest in hardware or talent for it. We need those folks, too. They figure out what this information means.

COHEN: How does a hands-on scientist develop the practical skills he needs?

MATHER: You have to do hands-on stuff. In graduate school, I had to learn something about everything on the instrumentation we did there. The other scientists I worked with on COBE did the same. They built balloon payloads; they built laboratory hardware; they sawed, drilled, and soldered; they made circuit boards. You have to do stuff until you get some instinct about what hardware is like and how it acts. Someone was telling me recently that almost anybody who is anybody in ultraviolet astronomy got his start with Stu Bowyer at Berkeley. He was doing sounding rocket programs. A sounding rocket is like a miniature space program. It's got all the problems that space observatories have, but it's over in five minutes. A student has the opportunity to learn every aspect from beginning to end by working on such a small project. Similarly with balloon payloads, which most other people who have developed into hands-on space scientists have done. Those are the two basic categories: start off in school working in a lab where they do this stuff, and learn by doing. Watch how other people do it. If you were to look around at people who are now scientific leaders within NASA, you would find a large fraction of the PIs [principal investigators] and project scientists on flight programs got their start on sounding rockets and balloons.

Alan Stern [associate administrator for NASA's science mission directorate] at headquarters is pushing hard to show that there is a career path for PIs or project scientists that leads through hands-on stuff. Now, for instance, if you look at the PI requirements for the SMEX AO [Small Explorer announcement of opportunity] that we're about to open, you have to prove that you've done something on a space mission, which includes balloons, sounding rockets, and real space missions. Alan is saying, and I think he's right, "Show me that you've learned how to do stuff."

COHEN: On COBE, were you able to communicate your excitement about looking for fundamental facts about the universe to engineers, and did that help the collaboration?

MATHER: Yes, and it did help. They knew they were doing something important. That's the only way I can explain why they cheerfully came in nights and weekends. Eighty-hour workweeks were not uncommon, especially at the last part of the project. I think we eventually developed a pretty good relationship between scientists and engineers, because we'd learned to know and trust each other. Now people tell me this was the best project they ever worked on.

COHEN: Do they tell you why?

MATHER: For two important reasons. One: the work was obviously important. Two: it was in house. Engineers love to do things. Going out to California to watch somebody else do work is not really much fun.

COHEN: In your book, you say the work was done in house because you couldn't have contracted out such groundbreaking instruments.

MATHER: We did not feel there was any way to write a contract to do what these instruments had to do. Even after we had settled on the design, it was hard to say, "These are the requirements," because we just couldn't analyze well enough. Maybe these days we could analyze better in advance because we've got better computers and numerical modeling tools.

COHEN: Would you still recommend in-house work on groundbreaking technology?

MATHER: I would, but not unconditionally. In-house teams face hazards as well. University labs can do certain things better than we can. It's harder for us to bring in the radical thinking of graduate students. Thinking about small prototype equipment is a good thing to do at a university lab. We did that with COBE, in fact. They built a prototype for the FIRAS instrument at MIT and told me that I had designed it wrong, that the focusing wasn't working. That was correct, and we fixed it. I don't think we would have found it as quickly and as easily in our labs here. When you're hunting over a wide range of territory with lots of ideas to try out, it's hard for an engineering team to shift into that mode.

COHEN: What kinds of problems—other than engineering realities—did you face?

MATHER: Some were organizational. We had something called "matrix management," which we love and hate. The good thing about it is there's a huge pool of talent you can draw on. The bad thing is those people are not yours. When you want their time, they may be busy doing something that someone else said was important. We had a cartoon that showed two boats with lots of oarsmen. Matrix management is people paddling in every direction and no manager at the end of the boat. The other one is project management the way project managers like to do it: they know who's in the boat; there's a guy at the end beating a drum; everybody is paddling in the same direction. Our problem wasn't about scientists versus engineers. It was engineers, managers, and everybody fighting over a scarce resource.

So priority really matters. COBE was set up as an in-house project that could draw on Goddard resources, but it had low priority. We were a training program; we helped recruit bright, young people. When Hubble had difficulties, they could swipe our engineers. It's hard to make progress when you're the lowest priority. You don't get very far when your team is frequently taken away from you.

COHEN: When the *Challenger* disaster happened in '86, it became clear that you wouldn't send COBE up in a shuttle and would have to cut its weight in half for a rocket launch. You've written about deputy project manager Dennis McCarthy pulling people together in a "skunk works" to continue the project.

MATHER: It was the only way to do it. And once it was clear that it was going to be possible, headquarters said, "Great, do it now." So we went from the lowest priority to the highest, or second only to the Hubble telescope. Suddenly we were able to accomplish things and build a project management structure with people dedicated to the team and working together in one place. The fact that JWST [James Webb Space Telescope] has priority matters immensely and mattered from day one. When Dan Goldin, then head of NASA, said, "This is really important, and we're going to do it," brilliant people came from everywhere to work on it. If he had said, "It's a good idea, but it will have to compete with a lot of other good ideas," I don't think we would have made nearly the progress we've made.

COHEN: The advantages of bringing people together seem clear. Can it be done without a crisis?

MATHER: There's no particular reason why every project can't be like that. The challenge for management, though, is deciding whether they can afford to put a person on a project full time. The project manager says, "I need to know who's on my project all the time. If someone completes a particular job, I've got something else for him to do." The matrix manager says, "If that person's job is done, I want him to work on another project." It's hard to cope with matrix management flexibility if you're a project manager. The lesson learned on matrix management is it's OK, but assign people full time and make sure they know whom they're working for during big blocks of time. In the earliest days of COBE, we had people charging a tenth of their time. They were able to go to a meeting, but they didn't have time to produce anything useful. A tenth really equals zero. It drove us crazy, and I don't think it made those people happy.

COHEN: What was it like working with McCarthy and [project manager] Roger Mattson?

MATHER: I loved working with those guys. Roger's been gone now a long time, bless his heart. Dennis is still around. When you walked into his office with a problem, you'd talk for a while, and then he'd sort of give you a wink and a grin. You'd know

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he understood what you'd asked for and was going to do something about it. Tony Fragomeni, the observatory manager, was another person I loved working with. He used colorful expressions that were not always polite, but people knew he meant what he said and was going to get the matrix organization to work with him.

Tony used to sit at the end of the table with a plastic baseball bat and make sure he heard from the right people. Running meetings well is a tremendously important skill: how to hear from all the people so that you don't miss good ideas; how to send people away knowing something's going to happen. You have to say, "I understand that this is the decision." Absolute clarity is required. If you dither around and put off the decision for another week, you'd better have a plan for what you're going to do instead. Drawing decisions out of discussions and actions out of ideas is the secret for getting anything done. If we could have a training program for scientists and engineers, I would say the number one thing would be how to run a meeting. You can piss away people's good will and their time and money with meetings that do nothing.

COHEN: I'm struck by the fact that COBE experienced several "happy accidents"—like the time a delicate instrument escaped damage in the 1989 San Francisco earthquake because the man who would have been testing it went off to be married that day and put it in safe mode. Are there ways projects can increase the chances that the accidents that happen will be happy ones?

MATHER: The thing that helps ensure happy accidents is people working like crazy to make the good things happen. Of course we were aware that earthquakes happen in California, so stuff was strapped down.

COHEN: There's an element of forethought.

MATHER: There's some forethought. The test program is a way of trying to make happy accidents happen. Murphy was right: things will go wrong. Our job in the test program was to think of them all and make sure we had a test that would find them before we launched. In order to have good luck, you have to work like mad thinking of things that could go wrong. Harvey Moseley says being a scientist is about fixing what's broken. Building a space mission is like that. The test program tries to break it. There's no possibility of designing something right the first time.

There was one case of technological change made for the DMR [differential microwave radiometer] instrument. We were delayed for various reasons and needed to save some money, so we ended up eliminating one of the frequency bands of the DMR and using the saved resources to up the technology on the others. If we hadn't done that, we wouldn't have found the big bang bumps. That's one of those happy technology accidents. This one was accidental because cosmic bumps had never been predicted well enough to tell us how hard we had to try.

COHEN: You made an educated guess that this trade-off was worthwhile.

MATHER: We knew it would be worthwhile; we didn't know it was critical. If we had not made that change, we might not have discovered the CMB [cosmic microwave background] bumps. Or it would have required four years to get the sensitivity we got in one year. That's one of those happy accidents of technology.

COHEN: Are the scientific aims of the James Webb Space Telescope you're now working on an extension of what came out of COBE?

MATHER: For sure. COBE and WMAP [Wilkinson Microwave Anisotropy Probe] and Hubble have all been pointing us at science of the early universe. With COBE, the DIRBE [diffuse infrared background experiment] instrument was specially designed to find the stuff nobody could ever see before: all the light from the earliest galaxies. We thought we'd never have a telescope big enough to see those galaxies. Now, we think we have, and we're building it. The COBE DIRBE instrument found light from unknown sources that are still unknown. If you find something that wasn't supposed to be there, you should build something to find out what it was. JWST is it.

COHEN: Did your COBE experience help with designing JWST?

MATHER: It's hard to be specific about that. When you start a new mission, the hardest problem is figuring out what shape it is and where it is going to be. It's a geometry problem. The orbit you put it in tells you the thermal environment. The shape tells you what temperature it's going to be. The whole thing is geometry at the beginning. I love geometry. In high school, I would sometimes lie awake all night trying to solve a geometry problem. There was a lot of that with the initial phase of the JWST. It's remarkable that the concept we're building now looks an awful lot like the concept we had on the boards a few weeks after the start of the JWST studies. It took a few weeks to find the right shape and the right orbit, at least in general terms. Everything else is detail.

COHEN: When is it supposed to go up?

MATHER: 2013. It seems like a long time, but it's only six years, and we're running like crazy. We have a good plan, and we're quite far along.

COHEN: What are the main challenges?

MATHER: The biggest challenge is not screwing up. Even manufacturing stuff that we know how to make is hard. Probably the hardest part that anyone will see is the mirrors. We've got eighteen wonderful beryllium hexagons to build. We've got to get process control so we do every one of them right. It's so easy to find a way to screw up. If one person pushes the wrong button one day, you lose some important piece. We'll have a long period of time to test the observatory after it's finished. We are counting on that to find and repair any problems that are still there.

COHEN: Do you find some of the same spirit on JWST that you had on COBE?

MATHER: When things are working well, people enjoy the process. They don't mind going to the meetings. People on this hall who don't work on JWST have told me they hear laughter coming out of the project meetings. They say, "I want to work on that project." A good sense of humor combined with getting the right thing to happen is important. I think the project management sets the tone a lot of the time. It's not easy to tell people how to do that; some people have that talent. ●