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JOHN C. MATHER
INTERVIEWED BY REBECCA WRIGHT
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WRIGHT: Today is June 11th, 2013. This oral history is being conducted with Dr. John Mather at the Goddard Space Flight Center in Greenbelt, Maryland, for the NASA Headquarters Oral History Project. Interviewer is Rebecca Wright, assisted by Sandra Johnson. He currently serves as the Senior Astrophysicist in the Observational Cosmology Laboratory at the Goddard Space Flight Center, as a Senior Project Scientist for the agency's James Webb [Space] Telescope Project [JWST], and he is a recipient of the 2006 Nobel Prize in physics. Congratulations from us, and thank you so much for finding time in your busy schedule to talk with us today.

MATHER: Happy to do it.

WRIGHT: Thank you, we're glad to hear that. Let's start at an interesting point in your time, how your life began to change once you learned that you were going to be receiving the award.

MATHER: Oh, golly. I knew immediately that it was going to be all different, but I couldn't tell how it was going to be different. I realized suddenly I was going to be on the public stage a lot, even more than before. I was already doing a lot of public talks about the new telescope and telling people this history of the universe in one way or another, so I already had a public lecture more or less ready for updating for the Nobel events. I was a little afraid because suddenly, you make your mistakes in public, so I thought, "How is this going to go?"

It went fine. Right away, we had a press conference that very day, and then the next day, we had a giant party over here at Goddard Space Flight Center, which was a very moving experience for everyone involved, because many hundreds of people here worked personally on that project. In the back of the book [*The Very First Light: The True Inside Story of the Scientific Journey Back to the Dawn of the Universe*], there are about 1,500 names, and most of them are here at Goddard, people that really did something. It was our community, our family project together had been recognized, so they were so thrilled and I was so thrilled and overwhelmed by this process.

I still remember the feeling of coming into this giant hall, Building 8 auditorium, which holds many hundreds of people, everybody standing up, and I'm a little late for the event—because I'd just come back from [NASA] Headquarters—so, how am I going to get to the front? I pulled out my badge and I held it up and I walked to the front, and everybody knew that was me coming. I realized, as I did that, I'm signaling to everyone that I'm one of us. This is us that are doing this. I'm still getting goose bumps, remembering that feeling.

Then, I talked to them about what we had done, and most people knew already what we had done, but it was a chance to be very appreciative and recognize what everyone had done together. To me, it's so much not *me* that did this project; it's so much *us*, and so much the people who gave their nights and weekends and their thoughts and their dream time to make sure that it would come out right. People that woke up at two o'clock in the morning and said, "Oh, my God, it's not going to be right and we have to fix it." That happened to me, too, of course, but people that just put their hearts and souls into this project to make it go. That was much more tangible to me even than the science results. It's interesting.

Curiously enough, the scientific results, one of them was a big surprise—although not totally—and one of them was very much expected. That was also a little interesting change. We should maybe come back to that because your question was how did my life change, I guess.

Suddenly, I'm very much in the public eye. It became clear to me that I didn't really like being that much in the public eye. When I got to the hotel in Stockholm [Sweden] and there were all these autograph-seekers hanging out, and I just wanted to go inside and go to the bathroom, and they wanted their autograph. Now, six years later, I find, you know what they do with them? They sell them. It's just a business, and I don't like them because they thought they had the right to interrupt my process and to challenge me when I wanted to go into the hotel because they had to have their thing. Oh, golly, it just doesn't feel that good anymore. Every day, I get emails, "Please send me your autograph," and I ignore them all. That's their thing. Just imagine, what if you're really a movie star or something, and people are always all over you with their hands and their mitts and they're trying to get a piece of your body? I think that must be terrible!

WRIGHT: It must be.

MATHER: I'm glad I'm not that kind of a star. There's sort of this little worry about, am I going to do it right? It was still there with me up on the platform with the King [King Carl XVI Gustaf of Sweden], as all of us filed in, in front of the Nobel party and we were all going to get all awards. Of course, we have to remember what to do. We've been instructed that we're going to walk across the stage to talk to the King, and we're going to bow three times, I think first to the King, then to the committee behind him, and then to the audience. Then you accept your prize and then you go back and sit down. You're a performer now, and some people are good at this—and I was just nervous—but it all worked.

The other thing about the Nobel ceremony is that it's not just, "Here it is, go home," it's 10 days of parties and speeches, parties and speeches, go visit this, talk to those people, be interviewed on the radio. This is way far beyond what any of the other big prizes are about. They made a huge process out of it, and the Nobel Foundation's working very well and very hard to make the information available to the public. If you haven't seen it, they've got an archive of all of the Nobel events. My autobiography is over there, my slides that I used for my talk are there, there's a video of everything. There's a little video, I think, of me giving my two-minute dinner talk. Actually, I'm pretty proud of that little one. That's a long story about what it's like to be in the public eye now. Now, I'm pretty much back at Goddard, doing my work with the project and doing a lot of public outreach stuff.

WRIGHT: It's an amazing story. I did have an opportunity to read your book that you wrote with John Boslough that captured the amazing journey of the COBE [Cosmic Background Explorer] project. As you mentioned already here this morning, one of the choices that you made in that book is to mention so many names, about each person—and not just here—as you went through that 15-, 18-year journey of making that work. One of the people that you mentioned there, I believe, was Nancy Boggess.

MATHER: Nancy Boggess, yes.

WRIGHT: Which was an interesting name because it was one of the few female names. Did you have a lot of experience during this journey working with other female scientists, or was that a pretty rare event at the time?

MATHER: It's a changing phenomenon. Many more women are going into science now than were then. Times have changed a lot. Nancy is a fine scientist. She was among the first really well-known professional women astronomers. She made the choice to go work for NASA, so she stopped actually doing astronomy, and she has made the astronomy happen with other people. She found—this is sort of reporting on her behalf—that people tended to assume she wasn't a scientist because she was a woman.

Even our secretarial staff here, they would write "To Mrs. Boggess and Dr. John," so, she was pretty annoyed. She had every good reason to be annoyed, too, because she's good! People don't know because they didn't. Things have changed now. When I go see who's coming up in science now, quite often, more than half of the young people are women, so it's changing quickly. I think that's good; there's a lot of talent there, so I think we need the talent. I'm glad people can do it now.

WRIGHT: No matter if they're male or female, they'll still go through that wonderful or grueling bureaucratic process that you endured, going through all those years.

MATHER: I would change those words. Nothing was grueling about it. It was all fun.

WRIGHT: Was it fun?

MATHER: As far as I was concerned. I don't know whether other people find it grueling. It's long hours, but it's what you choose to do. Nobody says, "I don't want to do this; I'm doing it anyway." Once in a while, it's frightening, once in a while, it's tiring, but I don't know any scientist who regrets doing that. I haven't heard a single one say, "I'm sorry I went into science."

WRIGHT: I know you have opportunities to meet many students, as you mentioned, these up-and-coming researchers. What are some of the suggestions that you give them, or even some insight that you share with them, about the process that they're about to undertake? That it's possibly not going to have results in a hurry, it may take 15 or 18 years?

MATHER: I don't know. I don't feel very wise about what they need to know, but a few observations – number one is the perpetual state of scientists is not knowing, always working on something that's unknown. I have a funny feeling that the public thinks the opposite, they think we're so smart and we know everything. How it feels to me is we're always, "I don't know this, I don't know that, I can't figure this out, how am I going to do this one? I never saw that problem before." It's day-in and day-out, "I don't know how, but I'm going to figure it out." That's a different process.

The other thing I remind young people of is if you can't explain your idea to your mom, you probably don't really understand it. Try to understand how to explain in an intuitive way, so that there's a physical picture of what you're up to, and that'll help you. Then, that goes a little farther because if you want to do the work that's your own idea, you're going to have to explain to someone else why that's cool, you're going to have to write proposals, write reports, tell people in some way that inspires them to support you, that your work is exciting. Study a little bit about and practice a little bit giving presentations and reading good English, writing good English, because that's so important for us. That was a shock for me because, well, maybe it should have been obvious. When I finished my thesis I thought, "Thank goodness I don't have to write anything again." And I've spent the rest of my life writing.

WRIGHT: For many audiences.

MATHER: Yes. I did not really know how to write. I had to just practice and practice. That's something I urge students to think about, is take your chance while you're in school to find somebody who can help you learn. Another thing to tell them is the future's very unpredictable, it always is, and chances are low that you're going to just replace your professor. Here you are in a school full of professors and researchers, and in a more or less equilibrium state, one person retires and one person can have that job. The rest of you are going somewhere else, so don't just focus on one thing, be flexible, be open to opportunity, look around to pay attention to things that could be interesting, and say yes when opportunity turns up.

That's how I feel I got where I am. If somebody had said, "Well, do you want to write a proposal for a satellite, knowing that the odds are very low you'll ever be chosen?" I don't know, but I just said, "I'll try! It could work, it's a good idea, it could work. I might as well see what happens." As it turns out, we were supported well enough, we could take the time to write the proposal, and eventually, it was chosen. Here we are.

WRIGHT: At that time, NASA had opened up, I believe it was called, Announcements of Opportunity [AO]. They were looking at possibly going into new fields of study.

MATHER: Yes, that was in ’74. There was Announcement of Opportunity Six and Seven, for two different classes of rockets that you could be using. Scout launchers, which are small rockets, and Delta rockets, which are a little bigger. This was five years after the Moon landing, so what is NASA going to do? They’d closed the Moon program. As I heard the story, NASA was persuaded, “We should ask for scientific ideas,” and they expected few, and they got 150, of which about 12 were chosen for flight, and I think they all flew. The COBE was one of the 12.

WRIGHT: It had an interesting process along the way.

MATHER: Didn’t it, though? Yes.

WRIGHT: Which leads me to my next question because I remember reading that you talked about yourself as having some wild ideas, but you were able to contain that focus to this one project all that time. Is that a difficult challenge, or is that one, as you mentioned earlier, that it was fun, that you were able to keep working on just one project?

MATHER: Yes, I was able to keep on working on one project because it became pretty clear if I didn’t, that it might not work. That’s how it felt to me. It was a time when resources were short. You might remember Mr. [Jimmy] Carter was going to balance the federal budget by turning down the heat, and that was stupid, but it sort of made it clear that we are short of resources. How are we going to deal with our project, well, we're going to work harder. There was no thinking, "Well, I've got time to do something else."

For me, it also felt like, well, you're trying to steer the tiger, you're riding on the back of the tiger—you do not get off. You got where you should be; don't stop. I was full-time, every minute of every day, I was thinking about how to make this project go. I remember very clearly, when I first came to this area, I thought, "Oh, who am I going to meet? I'm going to have some fun." I started taking ballroom dancing lessons, and that was fun, but I couldn't remember for 10 seconds what my instructor had just told me because I was always thinking about the satellite project. So, it was really hard to learn. I enjoyed it, but I didn't get to be that great. I thought, "I just cannot concentrate on something else. I'm just always totally distracted with how am I going to do this?" That shows you how completely your mind can be taken over by a really demanding project. I think a lot of us were in that shape. Nobody said, "I think it's time to go to the beach."

WRIGHT: It sounded like you were busy all the time, that's for sure. As you were going through some of the plans that you made, on those first few years, changed, one definitely having impact on you was the [Space Shuttle] *Challenger* [STS-51L] accident.

MATHER: Yes, yes.

WRIGHT: Can you share with us? At the beginning, you were making plans and building this project based on a rocket, or a transportation system, that hadn't even been proven yet that was going to work.

MATHER: Actually, stepping back a further step, we mentioned the AO Six and Seven, where they had a standard Scout or Delta rocket available, so that's what we proposed in 1974. In '76, I was hired here at Goddard because it looked like we might really have a chance to do this project. Around '77 or '78, we had gotten into the engineering enough, and that was also the time that NASA was trying to get the Space Shuttle approved, and the deal with the devil was made, which was, "We are going to close down all other launch vehicles in order to get the money together into one heap so we could build the Space Shuttle. Whether it's a good idea or not, you are all going to use the Space Shuttle."

It was a vehicle that had never been flown, of course, but we were directed to use it. It was actually a wrong decision, but it turned out in the end, of course, and it was technically very hard to do. It was a very expensive way to go, and the Space Shuttle never did fly from the California launch site where we needed it to go. We would have been the first and only Space Shuttle launch from California.

Then, that was interrupted because of the *Challenger* explosion, so didn't even do that one. Yes, that was a complete change of plans. I don't think I knew anyone here who thought it was a good idea to put this satellite on the Space Shuttle, but we were directed to do it, so we did it, and it could have worked, but we were much better off the way we finally ended up.

WRIGHT: You went down one path, and then it was changed, and then again, you had to change again.

MATHER: Some of the story's in the book there, but there were a few people here on the engineering side, the management, who figured out that we were this close to being able to stuff it back into the Delta rocket, and it needed a certain kind of major surgery, but the hard parts about the instruments didn't have to be changed much at all. Which was almost a miracle—we were within a few pounds of not being able to fit, but we fit. There were a lot of behind-the-scenes maneuvers that went into getting that Delta rocket, and many people that you've heard of, like Mike [Michael D.] Griffin, were involved in that. He wasn't even at NASA then, but he was on the other side of the fence, and he knew about all that process. He told me once that he had something to do with it.

WRIGHT: That was kind.

MATHER: As it happened, his wife was a thermal engineer here at Goddard, and she worked on the COBE project, so it's a small world.

WRIGHT: Yes, so there's a little inside information there.

MATHER: Yes, her name's Becky [Rebecca Griffin].

WRIGHT: Talk about the working relationship between engineers and scientists, and how that works well and then how the two different sides communicate.

MATHER: It doesn't always work well. I would observe that a typical engineering personality is very different from the typical science personality, and we have two very different jobs. The science personality is, "I've got to imagine something that's never been done before and imagine a way to do this, and so I'm all about imagination."

The engineer's got the job of, "Well, I see your imagination, but I got to make this thing work. We've got a whole different methodology for making that happen. " They're imaginative, but they have a different process to do it, and so it doesn't always work well.

Where it worked well for us, in this project, was that the engineers and scientists are very close together, physically, so I spent quite a lot of my time in engineering offices and labs. They would say, "Well, you asked us to do this, but I don't know how to do that. Can you back off on your requirement?" We'd have to all consider and discuss and talk for a while and find a path that would come close enough to what we needed to do and still accomplish something amazing, but maybe different from what we thought before.

There was a lot of back and forth in direction, and that part, I really enjoyed. I would say it didn't afflict me very often, but some of my colleagues had really big troubles with engineering teams because they'd say something was really important and the engineers didn't quite understand why it was important to them, or didn't agree that that was the right way to do something. When people really disagree, who's in charge? How is that resolved? The authority structure isn't always that clear in a big organization, and who has the right to decide something? Not easy, that part's not easy.

When two people that are both in charge of something can't agree, then you have to sort of elevate to a higher level, and one party's not going to like the answer, so that's tricky but interesting. I think our project never could have been done in a contract mode. You cannot write a little book that says, "Contractor A, this is what I want you to build," because we don't know how to say that. When we started off, there was no way to describe the hardware we needed to build. It all had to be invented. Engineering organizations are good at implementing stuff, but they have a hard time when you tell them, "I don't know what I need. Please build one anyway."

WRIGHT: So it was a definite plus for you to have an in-house operation at the time?

MATHER: Yes. I don't think we ever could have built this project in the contract mode. Maybe, but I couldn't see how.

WRIGHT: Some of the instruments you did, you did have to go to other areas.

MATHER: We bought stuff, we'd buy stuff. The big thing we bought was the tank, the helium cryostat, which came from Ball Aerospace in Boulder, Colorado. It was a more or less copy of the one they had just built for the IRAS [Infrared Astronomical] Satellite. They had experience, and they had mastered that. That part worked.

WRIGHT: That was a benefit for you, too, you didn't have to go through that.

MATHER: Oh, yes. If we had had to be the first ones to build that, too, I think we never could have gotten started.

WRIGHT: At the time when NASA was supporting this effort, to borrow a statement from your book, it mentions that NASA had a unique opportunity to advance humanity's knowledge about the beginning of the universe. From your experiences, can you share with the pros and cons of why you feel NASA moved forward with your project on something of this type?

MATHER: I'd say partly it's because of one person, Nancy Boggess. She was the astronomer at Headquarters in charge of infrared astronomy, and she saw there was opportunity here. She was a bulldog about it—she wouldn't let go—she made sure everybody there understood why it was important. She started not only the COBE project, but also the IRAS satellite happened under her leadership, and she got the Spitzer Space Telescope study started while she was at Headquarters, and that's still operating. I think she was behind also some of the studies for the SOFIA [Stratospheric Observatory for Infrared Astronomy] flying observatory, which we now still have.

There is one important factor, a single real human being made something important happen. To me, she's a great hero. There's also the fact that it was really a true opportunity. This work that we did couldn't have been done any other way, as far as I know, and you have to get your equipment up out into outer space because the Earth's atmosphere prevents you from seeing. Who's going to do it if not us, if not NASA? That's why NASA has the special opportunity in this particular area. The other things that we fly, we mostly do because it's also the only way to get that information.

Space stuff is so difficult, expensive, and time-consuming that if you could ever get it another way, somebody will before you ever build your project. Don't even think about it—if there's any other way to do it, somebody else will get there sooner. We could see that there was no alternative, in our case.

WRIGHT: At the time, right before you got re-launched, we mentioned about the Space Shuttle *Challenger* accident, and then now, all of a sudden, the space agency was looking for something to help redeem their credibility, and the focus became your project, that it became almost the centerpiece of the agency's work.

MATHER: It suddenly went from being the dog that got to wait until everybody else was done to being, "Well, this could be the next flight after the *Challenger*," and it was. It was the first science mission. It came before even the Hubble [Space Telescope, HST], and the Hubble, of course, had to go on the Shuttle, but the Hubble was the next spring after COBE launched.

Before that, our project was at the bottom of the totem pole. Whenever anybody else had an emergency, they got to get our best engineers. I thought, "Well, this is kind of slow going, this way." Everybody else had priority in the machine shop anyway because this was, "We're just going to do it our way here at home," and nobody else was pushing us to get there by a particular instant. Then, suddenly, yes, we could be the first, so then they said, "How fast could you possibly go if we give you everything you ask for?" We did it. It was a few months after what they asked, but we got it.

WRIGHT: That's a little change of pace, from getting whatever you could to being the first in line?

MATHER: Yes. There were a lot of nights and weekends for the staff, and the engineers and the technicians, they were in the clean rooms all the time, somebody was in there. There wasn't a single quiet moment.

WRIGHT: Also, I believe I remember reading that someone had a concern for burnout because you guys were just working almost non-stop to get this up and going.

MATHER: Yes, well, I don't know if anybody actually burned out, but I'm sure people were a little tired.

WRIGHT: Yes, and sometimes, there are mistakes that were made, but you scheduled in a lot of testing. Talk about the importance of the tests that you were able to do, and then actually, sometimes, the re-testing to make sure, thinking outside the box, make sure that when this went, it really worked.

MATHER: I guess this is pretty basic, and maybe I should step back to my thesis project, which failed. I think I told the story in the book there a little bit, but my thesis project failed. It was a balloon payload; it went up from a launch site in Texas, and the launch was fine, it went up, and up, and up, and then the commands were sent and it started to sort of function, and then nothing was right about it. The motor didn't turn, the signals from the amplifier were not right, so it became very clear to me immediately that I wasn't going to get any data for my thesis out of that.

The sort of lifelong lesson from it was if you don't test something, it's not going to work. People talk about taking risks and figuring out your chances and stuff like that. Nature hates you when you do that. It's going to function the way you built it, and the way you built it is probably not what you meant. If you do not test it, it will not work. It's not a matter of chance.

That's my personal learning experience about that, and then our engineers here all know that. That's how they're brought up, and it's the profession, is to know that if you don't test it, it won't work. The management's always got the job of pushing back to say, "Well, are you done testing yet, are you done testing yet, are you sure we can't go to the next test?" There's a huge tension about that because you're spending time and money, things you almost don't have enough of, to make sure that it will work.

We did a number of tests that some people thought wouldn't have been necessary, but there's one really particularly important one that's probably mentioned in there, about the calibrator body for the FIRAS [Far Infrared Absolute Spectrophotometer] instrument. It's on a pivot and it's supposed to go in and out of the aperture of the instrument, so some of our engineers here determined that they better test that it really would do that. Most of the time, we were testing it with the pivot axis horizontal, so the weight of the device held it in place no matter what. They said, "Well, what if not?" They set it up for a test with the pivot axis vertical, so the weight doesn't matter, and sure enough, the calibrator body would not stay in place.

We were very lucky to find that, lucky that our engineers, number one, insisted that they had to make that test, and number two, we were lucky because it turned out we could fix it.

There was a relatively simple thing that had to be changed, and we had access to the part without having to take the whole thing apart.

WRIGHT: That was lucky.

MATHER: It's one of the few times I got to go into the clean room, was to see what they were doing that day. Mostly, I stayed out of the clean room because I knew that I'm just a kibitzer, I'm just getting in their way. They fixed it, and if we had not done that, we wouldn't be here telling this story. It was so important to the mission. That's where I have to say, the engineers know what they're doing.

WRIGHT: That was good you had dedicated people from that side as well.

MATHER: Oh, yes.

WRIGHT: I thought it was an interesting statement in your book, too, about "we were lucky also in our bad luck." I think right before, just a few weeks or so before you got ready to launch and they were supposed to be doing some testing, but then the [Loma Prieta] earthquake happened? Can you tell that story? I found that was very interesting, how that happened.

MATHER: I wasn't there in person, but it happened. There were just a few months before the actual launch, and they were putting the observatory together in California. It had already been put together here, but they had to do final tests out there, and connect it up to the rocket. Last tests, and it turned out, that was the day when two of our engineers went off to get married to each other, so the whole observatory was buttoned up. They were the quality control people, so if they're not there, we're not doing anything.

That was the day of the earthquake in California—it was summer of '89. It was a big deal. Things shook around, and if our equipment had not been buttoned down tight inside, it might have hurt itself. It might not have, but what would you do? You'd have to think and talk and argue about could it have hurt itself, is it still okay, how would you know, do you have to open it up to find out? It could have cost a vast fortune to figure that out. We were lucky about that.

WRIGHT: Yes, I thought that was pretty interesting.

MATHER: Then, there was another lucky about our unluckiness event. I don't know if I called it that, but after launch, did you see that thing about the gyro that failed?

WRIGHT: Share that with us.

MATHER: Our engineers knew that gyros could easily fail, so we had two sets of four, I think, and we could function with three. It was two or three days after the launch, one of the gyros failed right away. I'd been here until like 3:00 in the morning, doing what we're supposed to do, and I went home to sleep. Then, I got home and the phone rang, "Better come back in, we have just lost a gyro."

As it happened, the engineers had done a wonderful job and the thing failed gracefully, as they say, so it just kept on going, just slightly different pointing, and everything was perfectly safe. After we argued and thought about what to do, we decided to just make some adjustments to that one, where it had three good gyros all functioning properly together, and then it was already set up so that if one of those failed, it would automatically switch over to the other set.

We were very lucky about that because nothing bad really happened as a result of this one failure because they anticipated. This is one of the most common failures. The gyros are little miracles themselves because they're a little ball about that big [about an inch across] that spins, I think, 40,000 rpm. Can you imagine something that big spinning 40,000 rpm? It's actually got bearings and it runs on bearings for years and years and years, and little tiny, as tiny as possible, wires that go to motors inside there. I don't know how they ever invented them, but anyway, they were invented for other people and we just get some off the production line. That was a similar technology to what we had to keep replacing on the Hubble. Now for JWST we've got a new technology there that won't wear out, we hope.

WRIGHT: Yes, we hope. The launch was such a special day for you, and you were able to be there.

MATHER: I went to the launch, yes. Everyone was totally wiped out and exhausted because there's just so many things to think about, and the night of the launch, everybody's having parties and giving speeches, and talking about how wonderful it was to build this and how important it was, what we were about to do. Then, they get you up at about three o'clock in the morning to go get ready to the launch site. The launch is about dawn, so everybody's standing out in the cold field in California, it's about 40 or 50 degrees in the wintertime, almost winter, and anyway, it finally goes up.

It's a spectacular event. It was magnificent to watch in a curious kind of way because you're very far away. You've got to be far away, otherwise you're not safe. We're about two miles away from the launch site, and we're waiting for the time that it might finally go up. The worry is, what if it's too windy out there? If the rocket goes up and suddenly the wind changes as it's going, it'll have to steer to compensate, and it can hurt itself trying to compensate for the change of the wind. So they launch weather balloons and they watch them go up, and they measure and they say it's safe or it's not safe.

They concluded it was just about safe, and so we waited a long time. Finally, they pushed the button and it went up, and it all looked perfectly beautiful, but then afterwards, you could see the contrail from the engines and the contrail went up and up and up, and it made a sharp loop and it went off horizontally after that. That showed us that there was a huge change of the wind velocity at a certain altitude, and so the rocket had passed through without hurting itself, but that's a scary moment. You realize, this is like hearing the bullet go by, you know they missed and you're okay, but whew! It's a little scary, and you say, "Okay, I'm glad I'm still here." It worked.

WRIGHT: Then, you pretty much immediately came back here to begin the other parts.

MATHER: Came back right away, near as possible. You can't get back immediately. I had a rental car, I was with my wife, and we stopped by a little mission [La Purisima Mission] right near Lompoc, which is where the launch site was. It was a very quiet, peaceful place; nobody's there that day. We spent about an hour looking at the mission, and then drive to the airport to get on the plane. Of course, the people who were actually operating the equipment, they've been home all the time. They didn't get to go to the launch site anyway.

WRIGHT: The important part of their job had just begun, hasn't it, or the next important part, I guess?

MATHER: Yes.

WRIGHT: Give us your thoughts, as you knew that the data coming in was data that you had hoped to receive.

MATHER: Of course, at first, you don't know whether it's good. You know it came, and your first question is, is the equipment functioning correctly? To tell you the truth, it wasn't right away. We had made an error in one of our designs. There's a motor that runs the mirror back and forth in the spectrometer, and it turned out every time we flew through the Van Allen belts, that there was a glitch that was getting into the equipment, and the motor would run up to the end of this track and stop, and keep on pushing. It was using up a lot of energy, boiling away the liquid helium and wrecking the temperature. We were getting data, but it wasn't right, so we had to diagnose this as quickly as we could.

We were also lucky about that because we had just barely enough control over this equipment that we could turn it off when it was going to get hit, and then turn it back on again. It had a self-timer circuit, so it could recognize that it should stop doing what it was doing, but we didn't want it to do that, either. All of this had to be figured out, and anyway, after we got control of it, then the data were pretty good. We started to get some good data. We knew fairly soon it was what we expected, more or less. That was pretty amazing, too. We knew we had good data, and within about six weeks after launch, we had a date with the Astronomical Society to tell them what was happening.

That was another stay up all night sort of struggle because we had a deal among the scientists that we wouldn't announce anything until we'd submitted a manuscript for publication because that means your work has done enough and you trust it. That's the other all-nighter sort of thing. You're writing and getting the whole team to agree that this is what we all mean to say. How it turned out was we got this done, analyzed, and down at the Astronomical Society meeting, I had the manuscript in an envelope and I slipped it into the mailbox and then went over to give the presentation.

We had done our process. This was a manuscript based on nine minutes of good data, when the mirror wasn't doing its bad thing. We were already able to draw a spectrum of the Big Bang radiation and say that it was what everybody said it should be. I put up my graph and I got a standing ovation for that little graph, and I've been showing it ever since. That was in 1989, so it's 24 years of showing a graph, just about, and it's still a wonderful graph.

WRIGHT: I'm sure it is. I'm sure the scientists shared with you a feeling of satisfaction of knowing that you had gone through that journey, and the ups and downs, and made it.

MATHER: Yes. The funny thing was, I didn't know how important it really was because I always knew that that was the answer we should get. I couldn't imagine a universe in which it was going to do anything else. It would have been a wonderful discovery, but I couldn't imagine how it could happen, so if we had not seen that, we would have had to be extraordinarily cautious because it would have been a major revolution in our understanding. We did see it this way, and so, as predicted, everybody was greatly relieved. It took me a while to appreciate why they were cheering. I think they were cheering the design, they were cheering the result, and they were cheering that all the bad measurements that all of us had made beforehand were incorrect, so we didn't have to ditch the Big Bang idea.

WRIGHT: Stephen Hawking was quoted as calling it "the most important scientific discovery of the century, if not of all time." What are your thoughts on that statement?

MATHER: That was a later statement, by the way. That was when we discovered and published the hot and cold spots map. At first, I didn't understand why he said that either because I thought, "Well, it's just one thing—gravity, that was pretty important. How about gravity, huh?" How about the discovery of the expansion of the universe? That was back in 1929. That should be important, right? Now, I can see that there are some important factors about that. Number one, it confirms the Big Bang idea. Number two, it shows that there is actually a process where we could exist. In other words, if the universe had been totally uniform and there were no spots in that map, we have no idea how it could have produced us. The prediction was very firm that there had to be hot and cold spots, at least by the time we made the measurement.

When we originally proposed the satellite, there was no theory of whatever. It was pretty startling. We were experimenters really going way out on a limb and saying, "This is all there is to measure; we had better go and measure it. That's all there is, and we're going to measure it as well as the universe allows us to do." It took a lot of nerve for us and took a lot of nerve for NASA to say they were going to invest this huge effort in something that might or might not be there. That was important.

Then, there's another story to emphasize there, which is, we were that close to not being able to see it, in the sense that the equipment was just barely sensitive enough. The project had been delayed while we were waiting for Hubble and all kinds of other things, so we said, at a certain point, "We have time to jump to a slightly better technology and better receivers for that map." They were about twice as good as they would have been the first shot. That was just enough to be sure that what we saw was real, and if we hadn't, it would have been an argument for a long time—did they really see anything? It was just enough. That's why we could say we were sure, and so much luck in this process. It's a reminder, it's not always good to get what you ask for.

WRIGHT: That is an interesting way of looking at it, because I think you had mentioned too that you measured it really, really, really well. It wasn't just the fact that you could produce the data, it was just done so well.

MATHER: Yes.

WRIGHT: From the outside looking in, you did survive this process of funding going up and down, priorities being rearranged, and you also did it during a time that was prior to the faster, better, cheaper type, and you were able to do it as a process that moved its way through and was able to evolve and change as a fiscal environment helped it.

MATHER: Yes, and it's interesting that you say we survived, but I think in many ways, we should say people protected and defended the project, and that's why we survived. It wasn't only because we did good work; people saw that it was important and they made sure that we got what we needed.

WRIGHT: You had a champion to take you through?

MATHER: We had champions at Headquarters. Nancy, among many, but people would see the importance of this project. They didn't all, by the way. Astronomers mostly weren't interested, that's what I've heard, because they didn't get to use the data. They didn't get to point the telescope at their subject. It was just our little team of 19 scientists and a project, and it was our job to take the data and give it to them. They didn't know they were about to start a revolution. They didn't know that thousands and thousands and thousands of papers would be published about those little bumps. Nobody could know that. Astronomers mostly weren't that interested. Physicists were interested, but most physicists aren't NASA astronomers, so there were advisory committees that told NASA this was a good idea. That's one of the reasons.

There was even an advisory committee that worked for NASA that came around to visit [University of California] Berkeley when I was a graduate student. I hadn't really paid much attention at the time, but I got to tell them about the balloon payload that I was working on at the time, and I'm pretty sure somebody on that committee said, "Why aren't you putting this up on a satellite?"

Who, me? I'm just a graduate student; I don't do that stuff. Then, after my thesis project failed, I thought, "I'm never going to do this stuff again, that's much too hard." I got a job to become a radio astronomer, but it turned out I went from the frying pan into the fire, in a way, because I ended up working at NASA to become a radio astronomer and my advisor there was Pat [Patrick] Thaddeus, and he knew about the cosmic background radiation, and when NASA said, "Here's this opportunity," he said, "John," and everybody in our lab, "what's your idea?" We got this idea, so let's write it up. That became my life. I tried to escape my fate, but it came.

WRIGHT: Your destiny, it sounds like.

MATHER: It feels like it.

WRIGHT: Watching projects go through a 15-, 18-year process, like you mentioned, you didn't survive as much as you were championed and helped along the way. In mentoring these new scientists coming up, do you have suggestions for them on how best to work their way through this new fiscal environment, or an environment that the quality of the work is not what is driving the project as much as the cost and scheduling aspect?

MATHER: I don't think that's actually any different than it was. We just all try to do the best we can and see a way forward. There's no general answer.

WRIGHT: You do see similarities?

MATHER: Oh, yes. My view of science is sort of like, how do the ants find the sugar in your house? They look everywhere. How does the water get through the flat roof? It goes everywhere, it tries everything. If you're persistent, you'll find a way, and it'll be a different way every time, but you'll get there. The main thing is just don't give up if you've got a good idea. Eventually somebody will help you find the way. The other ants will find the sugar, and then you'll all get some. That's my version of persistence.

WRIGHT: I like that.

MATHER: There's nothing noble about it; you just want to do it, and let's find a way, and eventually it'll turn up. How do you solve a giant crossword puzzle? One letter at a time.

WRIGHT: While you're giving your philosophy, I remember reading that you said your picture of good science begins with obtaining good hard data, with new and evermore ingenious instruments that will include Mother Nature to yield her secrets to us.

MATHER: Yes.

WRIGHT: That's a really good basis for any scientist, I guess, to move forward?

MATHER: Yes.

WRIGHT: Is it the hard part for scientists to figure out what they want to do when there's so much to choose from?

MATHER: I don't know. I think if you were all by yourself, you'd have a hard time thinking of what you could do because you have to find a problem that you can do yourself and that's still worth doing. In the modern world, we're so totally connected. Non-scientists might think we're wearing lab coats, carrying off our great thoughts all in our minds by ourselves, but it's totally social. It's much more like the two football teams signaling and communicating and making plans and strategies, and try this, and try that, and, well, we didn't get the ball across this time, we'll try another one next time. We choose our problems that way.

We have chats, we sit around the table, we draw things on the wall, we say, "Oh, what if we tried this? What if we tried that? Could we do this, could we do that? If we built this, could we solve that?" It's very conversational, and maybe it's a conversation with yourself, but often, it's a conversation with somebody else who is prompting you to a new question. That's part of how it happens. Sometimes there's a general agreement already in the community that this is what we all see we need to do and work on, and so, then really big things have committees. Really big things.

For instance, the James Webb Telescope has a science team that helped us define what we thought was important and call for the right hardware to be built. Before that, there was a National Academy of Sciences committee that reviewed what they thought all astronomers wanted to have, and they wrote books. They do this every 10 years, write a little book about, "This is our idea about the top priority for big projects." When the Congress and NASA see that, they say, "Oh, they know what they want, we can trust them to get the right answer on this so we'll send some money." It's one of the ways that we've succeeded in astronomy, is to have a process that leads to agreement about what's the number one thing to do. Congress, private funding organizations, they all respect that.

WRIGHT: In the case of the James Webb Space Telescope, it was number one priority.

MATHER: They put it at number one.

WRIGHT: Share with us how you had the opportunity to begin working with that?

MATHER: It was a surprise. I don't know if it's in the book, but that was, let's see, it was the fall of '95. I think it was just the day before Halloween, maybe, of '95. I'd been finishing up writing my book and thinking about what to do next, and I'm thinking, "NASA's never going to do anything as exciting as the COBE again, and something like Hubble, that's fantastic, we're never going to get to do one of those either because they're too big and expensive. What's next? Maybe I should think about going somewhere else."

Then, I got this phone message from Ed [Edward J.] Weiler, who was newly made—I forget the exact position he had—at NASA Headquarters, in charge of that certain area of astronomy. It's like the end of the fiscal year, and he finds that his predecessor has a few hundred thousand dollars that he hasn't spent yet, so what's he going to do? He knows that he wants to start a new project, so I get this phone message that says, "Send me a proposal tomorrow if you want to work on the next telescope. Call up John Campbell, he knows what this is all about." John was the project manager for the Hubble. It doesn't take me very long to figure out I'm going to answer yes to this one, so that's how it got started. Somebody asked.

There was a little bit of precursor work that I had been doing because I had already started dreaming about a new telescope that would be in-between what the Spitzer Telescope is and what the James Webb Telescope is. I thought, "Spitzer isn't big enough—how about something twice as big that unfolds in space?" I was working on that idea. My friends made fun of me for that, too. They said, "We'll never do that, either. It's way too complicated." That's how we got started.

It turned out there was a committee that had already been appointed and was working to define what NASA needed to do. It's called the HST and Beyond Report, and you probably have seen it. Alan [M.] Dressler was the chair of the committee, and it's a wonderful report. If you read that report, you'll say, "I want to do that. This is so enchanting, it gives me goose bumps to think about, we could do that." He was an inspiring writer, they were an inspiring committee, and eventually, it happened partly because he got to go see Dan [Daniel S.] Goldin and explain why this was wonderful and he liked it. That's partly how we got to go forward.

When you talk about, "What do you advise young people to do," clearly one of them is to learn how to read, write, and communicate excitement because we only get to do what we want to do because somebody else is willing to support it. How are they going to be willing to support it? They've got to love it, too.

WRIGHT: Your new telescope project has become something of an almost international collaboration, would you agree?

MATHER: It was immediately defined as one.

WRIGHT: Would you share that with us, and how that's all evolved and came together?

MATHER: Ed Weiler knew immediately we should make it an international partnership because the Hubble was one, and it's been successful that way. Some really important reasons. Number one is we open the telescope up for international use, so wouldn't it be cool if they'd help build it? About 20 percent of the Hubble observers are Europeans or Canadians, so Hubble was built with a significant European participation. There's the model; do that again, it worked. This time, we said, "We'll also open it up to Canada, if they're interested." So they contributed one crucially-important part, the fine guidance system with an associated instrument.

Working out the partnership deal about who's going to do what, that's pretty hard, because what people want to do because it's fun is not necessarily what needs to be done. It took many years of discussions and proposals and ideas about who's going to do what. Then, we had an idea and the review committee said, "No, you can't do that. That's not possible." At that point then, finally, the only way that was left was the one we chose.

WRIGHT: I know that it's been delayed, as in all big projects, tend to have that opportunity, and I believe now the current date is 2018, is that correct?

MATHER: We're talking about the fall of 2018, and the launch date hasn't slipped an inch since two years ago, when we made the new plan. That's because the new plan asked for enough money and time. The old plan was based on the question that was asked every year, "What's the least amount of money you could have and still survive," which is a guarantee to go as slow as possible and to make the price as high as possible. This time, the question was different, it was, "What's the right answer to get there in the best, fastest, cheapest way?" It was a lot of money, but it was a different answer to a different question. Ever since then, we've been doing that.

The risk that we faced was that Congress could have said, "No, we don't want to send that much money." But they did. I wasn't there—I don't know who said what to whom—however, some people decided that this was the thing to do.

WRIGHT: What are your specific duties? I understand you're a senior scientist, but what does that entail on a project of this magnitude?

MATHER: It's evolved. Early on, my specific duties were more work with the scientists to help us figure out what we need to build, and so, a lot of science meetings. Then, it was write the requirements and make sure those are all written down so that the project engineers can build that. There was also, for a fair amount of time, we hadn't yet chosen a contractor, so we were working with two different engineering firms to say, "How would you build it? What's your idea?" That was pretty tricky, but we needed to work with both engineering firms and not tell either one what the other one was doing. We had that process, that was mostly engineering, but the scientists needed to work with those folks to say, "Yes, they're doing about the right thing for what we asked for." That was through about 2002, so developing the requirements, making sure everybody knew what we needed. Then, we chose the contractor in 2002 and we chose our official team of scientists, also.

Now, I work with those people to make sure we are still doing the right thing. At this point, our science team has grown so I mostly talk—I talk to you, I talk to reporters, I talk to other scientists, mostly, talk to engineers about what it is we have to do and why we have to do it that way. We have, I think, 11 of us—scientists—right here, mostly in this building, who go to all the meetings and understand all the technical content and make sure that we do it right. Yesterday, for instance, our observatory scientist was sitting right where you are and he was telling me all the things that they found out at the contractor's that needed to be changed. Of course, that's why we have people go to visit the contractors, to make sure they do the right thing and that we fix them before they're broken.

This is part of what we do, and it turns out, scientists and engineers look at things enough differently that it's sometimes really important for a scientist to go talk to an engineer. We'll just think differently. People talk about diversity in the workforce? It's not what you look like, it's how you think that matters the most. We really need the diverse viewpoints, that people say, "I can do that," and that people say, "No you can't, it's too hard, and we've got to have a discussion about how you're going to really do this." "I can do that." "It would cost too much money." "How am I going to get the money?" There's many really radically different mental viewpoints, emotional viewpoints, that have to come together to make a project really work.

If you want to read more about that, there's a wonderful book by Charlie Pellerin that you might have seen, it's called *How NASA Builds Teams*. He was the Associate Administrator at NASA Headquarters that we worked for when we were building COBE, and he was the guy in charge when they had to go service the Hubble Telescope. When he left, he decided there was a lot to learn about management, and he studied it, and he wrote a book. He started a company to make management training available, and it's good. You learn a lot from him and you learn a lot from his book, even.

WRIGHT: I'll look for that. I was curious of whether or not lots of lessons that were learned in Hubble were applied for this telescope project as well.

MATHER: Yes and no. The technical lessons, I don't know how much you learn a technical lesson, but you develop a skill and an ability to see. A lot of our top people are people who grew up on the COBE project, so they've been through the mill, they've learned from personal hard knocks university, so, they can do stuff. I don't know if you could say I learned a lesson about how to ride a bicycle, but I can ride a bicycle.

WRIGHT: I recall that you were going to become the Chief Scientist of the Science Mission Directorate.

MATHER: I was, for a year. I was part-time, and I did that two days a week, yes, it was interesting. I worked with Alan Stern.

WRIGHT: You had mentioned that you had wanted to provide a proper balance of scientific programs. Is there a challenge of doing that; does NASA have a big challenge in trying to provide a balance from Earth science to cosmology?

MATHER: I don't know what I was thinking when I said that. As it turns out, NASA already has a fine balance and nothing was needed for me to make sure that it was continuing. The job of the Chief Scientist was a little fuzzy. It wasn't that clear what I was supposed to do, and to tell you the truth, it was a relief to get back to Goddard where I could tell more what I needed to do. The other challenge is anything that's a part-time job isn't really. Your name is on the job, and so you're supposed to do stuff, and you say, "I'm only there two days a week, what do you need me to do?" And nobody can quite tell you. I'm against part-time jobs, mostly. I find it too confusing.

WRIGHT: You spent that little bit of time at Headquarters, and we were talking about the James Webb Space Telescope. It's, of course, named for NASA's second Administrator, who's known for certainly ensuring the success of the Apollo Program, but also at that time, he insisted that NASA have science. If you could reflect back on your years here, but also what you would like to see where the science should go, or do you feel like it's going on the right path for NASA at this point in time?

MATHER: Good question. Things have changed with time. The science program is very strong, very robust. We continue to make the most marvelous equipment and the most marvelous discoveries, and so, if the public will support us, we'll continue to do that. We are full of ideas and full of projects that we know how to do. Our ambitions are increasing as our technological base is improving. Moore's Law is working for everything electronic, and so, 10 or 20 years from now, you can imagine building something that's almost completely unimaginable today. Stuff is happening. We can explore Mars with robots; we don't have to go there in person—

although people want to go—we've got a wonderful robot there. Downstairs in this building, we've got the equipment that prepares us to use that robot.

If you want to dig up a piece of dirt and analyze it in the chemical lab on the Mars Science Lander, on the rover up there, well, we can rehearse right downstairs. We've got equipment that's similar enough to say, "I picked up the soil and I put it in the equipment and I tried it out, and if it's alive, we'll find it, or if it's got perchlorates in it, we'll find it." Or whatever it is that they want to know, we can practice right here in this building. This is kind of clearly a growth area for science's increased ability to do robotic stuff. I don't think there's any limit to how far you can get with robot stuff. Robots are just growing better and better every year, hundreds and thousands of them are trotting around on the bottom of the ocean as we speak, trying to find oil and drilling for oil, and for all I know, they're going to have robot wars at the bottom of the ocean.

If you want to know more about it, read Robert [B.] Laughlin's book, called *Powering the Future*. Also talk to Bob [Robert D.] Ballard, who's an underwater explorer. I've been on stage now with him and seen him a couple of times, and he's just full of intensity and all the stuff you can do with robots. Robotics exploring is really powerful, it's coming more and more, and robots are getting smarter every year and we're not. We're just as vulnerable to cosmic rays as we were 100,000 years ago when the first people were walking the Earth.

We've got a very wonderful future in science and exploration, and I think, personally, the manned program can be tied into that because everything the scientists need has an application in the manned program. If we need a bigger rocket to put up a bigger telescope, well, the manned program needs a bigger rocket to put people farther away, and vice-versa. If they build the bigger rocket for the people, then yes, we've got a telescope for you. I think there can be a lot of synergy there, and it should continue if possible. That's my hope.

WRIGHT: This is kind of a strange question, but at the same time, it was interesting that you were noted as one of the most influential people in the world in 2007, and then one of 25 most influential people in space in 2012. If you could apply your influence, what would you like to see accomplished in the field of science?

MATHER: I don't know. I think the way I like to do my influence is to make sure what I'm doing works. I don't try to convince people to do something they don't want to do. I like to demonstrate that what we are doing is great, and then another one, that's sort of my indirect influence strategy. I don't want to convince you to go dancing, I just want to go dancing, you know? Then, when we're dancing, they'll say, "Let's do that some more." That's how I do my influence. I don't call people up and say, "You know what we ought to do?" I've got a different method.

WRIGHT: Do you feel that the interest in science over the last, let's say, 25 years, or during your lifetime, has grown, where more of the people who need to support it—as you mentioned, you've got to have the people, you have to have the public, and you have to have the Congress—do you feel like the science interest is at the point where more young people will become interested in it?

MATHER: It's hard for me to tell about historical trends because the world is so much more connected, that we can't tell what it was like before. These days, if I type something on, say, Google Hangout or Twitter or Facebook or something, hundreds and thousands and millions of people can see it in a flash, if they want to. The people that are interested in what we do are avid. They just are so thrilled that we're doing what we do.

A couple of years ago, when our project was in danger, a group of young people spontaneously got together and made a project to save the telescope. I had nothing to do with it, but they came by to see us a few weeks ago, and they had never met each other in person but they'd made this website, *Save the Telescope* or something, and this just sort of tells you how our world has completely restructured itself in a way that you don't necessarily see. People didn't travel to do that, they didn't have a meeting, they got on their computer in some way that only young people know how to do. The people that really want something can organize so well now.

I think science is still inspiring to those folks, and I, personally, I read science news all the time. I'm so thrilled to see what people are doing in so many areas. It's just a miracle every week. People are getting at artificial intelligence. I saw Watson [IBM artificially intelligent computer] beat people on TV, and Watson is going to be commercial. He's going to be your doctor's assistant, and that means artificial intelligence has access to a $1 trillion annual budget. Can you imagine having $1 trillion to spend on fundamental scientific research? Some fraction of that $1 trillion is going into Watson, so, do you need artificial intelligence? It's coming because people are paying. Do we need artificial intelligence on Mars? Yes, so, we'll send Watson or send his brother, or something. Do we need to explore the stars? It'll take us a while, but when the robots want to go, they'll go.

There was a Smithsonian event, I guess, two weeks ago, a week ago, called The Future is Here. It was on June 1st. I spoke at it, and they're about to make the videos online, I think, but that's part of what I was telling people, "When the robots want to go, they'll go." I think there's a tremendous, tremendous public interest in the revolutionary nature of technology and science and they're participating. It's not everybody, but a lot of people. If one percent of the world is doing it, that's still 70 million people, right? That's a lot of people.

WRIGHT: That's a lot of people. As you mentioned, the connection that we have now through the internet and other ways of communicating.

MATHER: Yes. About five times a year, I give a talk to India by Internet. The Indian Institutes of Technology have their Technology-Fests every year, and I'm always negotiating when I am going to talk to them because they're doing it all the time. They're eager, so millions of people who are in India want to do what we do. Of course, many people from India came here to work at NASA. I've got lots of friends from India who are right here, one of the reasons they're on my mind.

WRIGHT: It's an interesting result of the work that you've been able to do, that it can reach so many people, and then they take that and build from it. Have you seen, as I think you alluded to that earlier, about seeing so much more papers and presentations based on the foundation of what your team was able to do?

MATHER: Yes, I had no idea what we had started. When we started off, I said, "We just have to measure because that's all there is to do." We didn't know that there would be a huge industry. There are many hundreds of people, maybe a thousand people, around the world that are personally, every day, working on the cosmic background radiation and its meaning. We never knew, you could never have guessed that, because you hadn't got the result yet.

WRIGHT: When you thought you were possibly ending your project just started many, many more, didn't it?

MATHER: Since COBE, there have been two more satellite missions flown, the WMAP [Wilkinson Microwave Anisotropy Probe], which was ours here at Goddard, with Princeton University [New Jersey], and then the Planck mission, which is the European [Space Agency] one, with some American participation. They have pushed the subject so far, and there's more yet to go. We have a proposal here at Goddard for yet the successor for that, and other people are working on their other ideas. I think there's going to be yet a fourth cosmology satellite. That may or may not come to the end of what you can do with that.

I feel very privileged to have been there at the beginning. I was a person whose luck just went that way, and I cannot say that that was because I was smart or had good strategy because I actually tried to go some other direction.

WRIGHT: You were drawn into that way.

MATHER: I got drawn in. This is an example of how it's a very social phenomenon that we're in. We do it because our friends are doing it.

WRIGHT: Very interesting. Share with us, before we close, what are your expectations for the James Webb Space Telescope?

MATHER: I'm expecting wonderful surprises, and I don't know what they'll be. I know what people have said they wanted to try, and we've designed the observatory so that it can observe the first stars and objects that formed after the early universe. We call it the Big Bang, which is, by the way, a really rotten name for something completely spectacular. Big Bang just isn't big enough to explain that—how about an infinite and expanding universe?

WRIGHT: I like that.

MATHER: How did the galaxies assemble and grow? We know that we can see them far back in time, we can see them as they were when they were a lot younger. They're pretty different already; we know that from Hubble, but we know that Hubble doesn't see far enough to tell what really happened. We hope to see some surprises there. One of the big, open questions is, what about the black holes? Every big galaxy has a super-massive black hole in the middle, with a mass of millions to billions of times the mass of the sun, so how did that happen? How did the first black hole form, how did it grow to be so big? How did they all fall into the middle? It's a pretty big mystery; lots of ideas and no answers at the moment. How did the stars grow, and how are they made?

The sun is a latecomer—our sun is only one-third as old as the whole universe—and it comes with a batch of planets that, as far as we can tell, our material is very recycled. Our Solar System atoms have been out of the galaxy and back in, and what we're made out of, the chemical elements, did not exist in the early universe. It was only hydrogen and helium. You're not mostly hydrogen and helium—you're a lot of hydrogen, but not much helium, and there was no carbon, oxygen, nitrogen, sulfur, iron, phosphorous, all that stuff. We're totally recycled, well, let's find out how that happened. How did the planetary systems grow? We've got one that we're in, so we can begin to learn about that. So, we're making a lot of progress locally, but also, we have the chance now to observe others.

The Kepler mission gave us about 3,000 candidate planets around other stars, and we've got the TESS [Transiting Exoplanet Survey Satellite] mission has been chosen to go find many, many thousands more—closer ones—and this is all done with the transit technique, where a planet goes between us and the star and it blocks the light, so you can tell it's there. When that happens, we can point our telescope there and analyze the light that went through the planetary atmosphere on the way to the telescope, and so we'd be able to tell you, is that Earth-like planet over there wet? Does it have enough water to be wet?

Beginning to answer, are we alone? I think probably we're not alone and I think probably we won't find the others, but we might be able to tell, in the future generation of observatories, that that planet is alive. I don't think we'll be able to tell that they're sending us signals for a while. Why would they bother, among other things?

Then, the final mystery, of course, people really want to get at is, how does life occur, and we've got our one example to look at close to home. Our own planet is pretty fascinating and there's life everywhere there's water, pretty nearly, including way underground. We could—not probably with Webb—but, with a future telescope, we'd be able to see signs of oxygen in a planetary atmosphere, and that would be a sign of photosynthesis. Eventually, we might be able to say is life rare or not, and it's a much harder step to see how does it work, but we've got our own example here which we can pry apart. Biologists have a wonderful challenge there, but I think they're getting the most amazing technology, too.

The same reason that we can build Watson and have access to a [piece of a] $1 trillion budget for stuff, medical research has access to the same $1 trillion. Everybody wants to be healthy a little longer, please, so can't you please find out something more? Let's try. Then, because there's so much money there and we all love to be entertained, there's the electronic industry, and they've got their $1 trillion budget, and so, some of that goes into the research. You can have that [cell phone], I can have that [iPhone], and I can have that [computer], and so, I don't see that there's really much limitation on how far we can get with this. We're going to know one heck of a lot more in a big hurry, and so I'm pretty sure we're going to find wonderful things with the telescope, but I don't know what they are.

WRIGHT: You're already planning the telescope to follow the Webb?

MATHER: We are, actually. People are already having a committee. We started meeting last week on the phone to think what is it that we would recommend we prepare? It's too soon to tell you really what we need because you should decide what you need after you get a little farther. But we know in basically ideas, for build a bigger telescope, we could build a bigger one, that could do more about planets around other stars. Then, there are the other mysteries. What is the dark matter, the dark energy, and other things that will turn up? You don't necessarily need the same telescope for all these problems. There will be surprises. Somebody might actually find dark matter in the lab. They're working on that, too, and with technology that some of us here at NASA started to build.

Harvey [Samuel H.] Moseley, who was here in my office when you first arrived, is one of the inventors of this technology of really, really, really sensitive low-temperature equipment that can maybe tell is a dark matter particle occurs in your equipment. A lot of ideas, so there are a lot of pathways to answers, and who knows? We'll have ideas for next committees to consider and recommend our future in the next generations of telescopes.

WRIGHT: That's amazing.

MATHER: It is, it really is.

WRIGHT: Do you have anything else you'd like to add, or is there more things you'd like to share?

MATHER: I could talk forever, but I probably shouldn't.

WRIGHT: We don't want to miss anything, but we certainly don't want to take all your morning. We know you have lots to do.

MATHER: Sure.

WRIGHT: Are you going to write another book?

MATHER: I'm thinking about it, but I'm thinking about what book to write because I've gotten to retirement age, if I feel like it. I'm thinking, what else do I want to tell people, and is it worth telling them? Right now, I'm in the research phase. I'm saying, "I'm going to read all the coolest science books I can find and see if there's anything they're not saying." I'm enjoying that part.

WRIGHT: It is fun for you to have the time, at this point, to be able to do that.

MATHER: I do and I don't, but it's a possibility. I don't think I just want to write another book. I want to write a book about something that interests me, and what would it be? It's probably the stuff I don't know about.

WRIGHT: Then that's a lot, isn't it?

MATHER: Yes, there's plenty of that. When you came, we were talking about whether there's really an ether underneath all the particles that we're in, that we have. The Higgs Boson [particle] and all these wonderful discoveries now complete a wonderful picture of the elementary particles, but where do they come from? Why are they like that? There's string theory, and there's this idea that maybe this is what's called an emergent phenomenon, growing on top of something else. A long time ago, people thought there was an ether, because something had to wiggle in order for it to have waves. Then, we couldn't find it—there's no sign there was a real ether—and that was the Michelson-Morley experiment in 1887.

That idea went away, but it didn't completely because now we have ways of thinking about the ether that are different. For instance, if you cool a material like aluminum or mercury or something down to very low temperature, it suddenly becomes a superconductor, so it has a completely new property, it conducts electricity without resistance.

A new phenomenon can occur spontaneously, if you cool something down, so the idea is what if, as the universe cools down, it spontaneously creates these particles that we see and consider to be real, but it creates them based on something underlying. The question is, does something underlie what we call the vacuum? We call it a vacuum, like it's empty, but what if it's not? What if there's something under all that stuff? We now know of this Higgs Field, which seems to fill all of space, and it's really hard to make evidence of it appear—we had to build a huge accelerator—but it probably fills all of space. Where did that come from? How did that get there? Why is space structured so it has this Higgs Field all over? I don't know.

WRIGHT: I wouldn't know.

MATHER: This is an example of something it would be fun to write about, if I could figure out what to write. Just to try to convey the wonderfulness of the challenge that we all are facing, and the imagination that people have, to consider the wildest stories you can imagine.

WRIGHT: You could be setting another foundation for more discovery.

MATHER: You never know. The reason this one comes up is not only superconduction, but every other quantum system that engineers and scientists find out about is worth considering this way. The stuff that makes this work is quantum mechanics. The deep understanding that people have about that, because we have a real thing in front of us, we can make every possible experiment, people are saying, "Can you apply that to the universe?" Maybe.

WRIGHT: Maybe.

MATHER: That was fun talking with you. Thanks for coming to ask all these wonderful questions.

WRIGHT: We'll look forward to hear more about the discoveries of the unknown that you do, because we know you're just starting.

[End of interview]