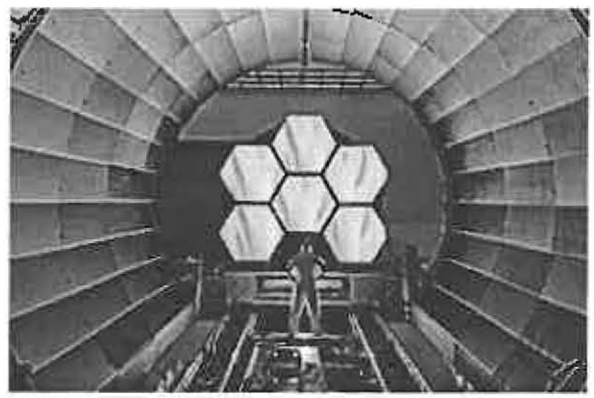
**Our History in the Stars**
***John C. Mather WF '68 on space science and the next generation space telescope***

Nobel Laureate and astrophysicist John C. Mather WF '68 is senior project director of NASA's James Webb Space Telescope (JWST), successor to the Hubble Telescope. Nearly cancelled in summer 2011 during a flurry of federal budget cuts, the project was fully funded by Congress in November 2011. *Fellowship* spoke with Dr. Mather about his thoughts on the importance of funding space science and the JWST.

"The government is the only organization large enough to invest funds on the scale that it takes to maintain our national position," says Dr. Mather. "We don't just do space projects because it's cool; we do them because it's important for the whole nation's economic and intellectual future." On an international scale, he adds, "We know other [countries] are doing it. They feel that their national interests are at stake the way that, I think, ours are."

Through space science, Dr. Mather says, "We learn about our own origins—and as far as I can tell the public really cares about things like that." His example: when the first Hubble pictures were released, the number of people trying to view them online all but crashed the Internet. "To me, it seems that the public is very strongly supportive of both the emotional part of people in space and the technical part of what we discover about ourselves and our history."



Scheduled for launch in 2018, the JWST is based on the development of ten new technologies and four scientific instruments. While the instruments are in various stages of completion in Europe, Canada, and America, the telescope's primary mirror is finished—a great achievement, according to Dr. Mather, requiring the perfect polishing and testing of eighteen smaller pieces. "That was just accomplished late last year. We're really pleased with that."

Once the telescope is completed, it will undergo a thorough test program in the same chamber the Apollo astronauts used to prepare for the first moon landing. "We cannot actually go out and fix the observatory if it's not working properly because it's too far away from Earth," explains Dr. Mather. "We've become more cautious and realized that if you're going to invest all this work, then you need to be sure that it *will* work. I think we've come to appreciate that nature doesn't forgive you when you screw that one up!"

The JWST is not a replacement for the Hubble but an extension, says Dr. Mather. "They really do different science," as the Hubble observes ultraviolet and visible light wavelengths, while the JWST will observe infrared wavelengths. "Hubble has discovered [things that] tell us there are mysteries just beyond where it can see. Hubble says, 'See all these beautiful galaxies from the earliest times of the universe? We can tell that there are more beyond that and we can't see them.' We need something that's able to look at longer wavelengths."

In addition to being able to see these "first galaxies," the JWST will also "see inside the birthplaces of new stars and planets," says Dr. Mather. "It's happening as we speak...but they're mostly hidden from us because they're inside dusty clouds of gas. The infrared light will go through the dust, or around the dust, and we can see in.

"To me this is really exciting because it's part of working out our own history—the history of how we got here from the Big Bang. It's a long story. The biologists have a part to play, they need to figure out the life part; but we on the astronomy side can tell them about the physics part." For example: "How does the earth come to have the right temperature and pressure and chemistry to support life here?"

As amazing as the astronomical discoveries have been and will be, the "practical arm of NASA is really important too," Dr. Mather points out. "We can tell very clearly, from Earth observations from space, that we have a big problem here—where climate is changing, rainfall patterns are changing, the oceans are warming up, the oceans are getting more acidic...It might not be as surprising to people as what we discover with astronomy, but it's absolutely critical to our future." (705)

*Read the full transcript of* Fellowship's *interview with Dr. Mather at http://www.woodrow.org/newsletters .*

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***FELLOWSHIP:*** *It's been 40 years since the last manned moon mission and spending federal money on space programs has become a subject of debate in the current economic climate. Why do you think it's important to continue to fund these projects?*

**MATHER:** That's an infinitely large subject—I think partly because the importance is infinite! The way I look at it is: the government is the only organization large enough to invest funds of the scale that it takes to maintain our national position. We don't just do space projects because it's cool; we do it because it's important for the whole nation's economic and intellectual future.

For instance, everybody in the world now, practically, can have a GPS, and that was part of federally funded research—it had a military origin. But the national budget for GPS systems is actually comparable to the national budget for NASA, just as a point of comparison. This is a pretty amazing situation where we think it's big money that we're spending on space and it's still a pretty small portion of the national economy. But it's really important because it keeps on maintaining the leadership that we have to have to continue our prosperous economy.

From a purely intellectual point of view, we have continued to discover the most amazing things and we're really on a roll: the Hubble Space Telescope finds things; we land on Mars, we drive around, we pick up rocks and drill holes in them. We learn about our own origins—and as far as I can tell the public really cares about things like that. I remember when the first batch of Hubble pictures came out, and the Internet was new, it crashed the Internet, practically, because everyone was trying to look at the pictures. So there's a tremendous public interest in the scientific results that we do. There's also an awful lot of folks that personally want to go into space—even though that's really hard, difficult, dangerous and expensive—they still want to go. Something like a million people came to Florida to watch John Glenn go into outer space, because he was a hero, and they wanted to go too and that was the closest they could get. To me, it seems that the public is very strongly supportive of both the emotional part of people in space and the technical part of what we discover about ourselves and our history.

And on the international scale, we know other people are doing it and it's not just because it's fun either. They feel that their national interests are at stake the way that, I think, ours are. So that's the short answer to a very big question.

***FELLOWSHIP:*** *It's been a rocky path keeping the JWST project going. Can you give some insight as to what the process has been like? How does it compare to your experiences on other projects?*

**MATHER:** Well, this one is different in degree because the previous one I worked on [the Cosmic Background Explorer (COBE)], although it won a Nobel Prize, was much smaller. I can tell you about both of the processes.

The James Webb Telescope, for me, started off with a phone call from NASA headquarters in 1995 and it said something like "We'd like you to work with [a team] and send a proposal for how to study the next generation space telescope—because we know that the Hubble is doing great things but, on the other hand, some time it will be old. So what's the next thing?" A strategic decision was made that we should think about that. It only took a few months before we knew what we needed to do. The head of NASA got very excited about it so he announced to the Astronomical Society that we were going to do it. Given that kind of endorsement, a tremendous number of brilliant engineers and scientists volunteered that they wanted to work on it and within a year we had the basic concept down pretty well. Our head of NASA in those days was Dan Goldin and he urged us to find ways to do things that were faster, better, and cheaper than we had ever done them before. That did turn out to be difficult. I can't say that they're faster and cheaper, but I can sure say they're better. What we ended up deciding to do was to invest in ten new technologies that would enable this new, wonderful telescope to be built, and then gradually, over the next, roughly ten years, we got to figure them out and polish them off and have them ready for use. So that's what enabled this amazing and wonderful telescope to be built, the new inventions.

Then there's the question of "how much is it going to cost?"—which has turned out to be very interesting to people. We have gradually grown away from Mr. Goldin's "faster, better, cheaper" mantra because the experience that we had with it was that it didn't work. We lost a couple of missions to Mars and some other smaller missions here close to Earth. We said: "You can't just say it's going to be cheaper. You have to do something smarter and better." So we've been becoming more and more cautious and realized that, if you're going to invest all this work, then you need to be sure that it *will* work. I think we've come to appreciate that nature doesn't forgive you when you screw that one up! We cannot actually go out and fix the observatory if it's not working properly because it's too far away from Earth and so that means we *will* be careful. We will prove it works before we launch it. We don't get to take chances. We now have a very large and complete and difficult test program which includes even, this is the final part, cooling the telescope down to the temperature it will have in outer space and focusing it up in the test chamber. This will be down at Johnson Space Center, in the same chamber that the Apollo astronauts used to rehearse for their moon landing, so it's pretty amazing. But we have to upgrade and update the chamber to do it.

That's some of what it's been like. And, of course, nobody likes to hear that the number gets bigger as you go along. On the other hand, we think this is the right plan and we think it's worth it. I'm very pleased to see that Congress and the Senate has agreed on a budget for all of NASA and the President signed it this year, so now we have a plan.

The COBE was a very different scale of project. It was still a pretty big project but nothing like a great observatory like James Webb. The COBE started out back in 1974, just 5 years after the moon landing—the first one. NASA was saying "Well, what are we going to do now that the moon program is just about over?" They cast about for ideas, and I think they got about 150 proposals, including one from the team I helped organize. I was just a youngster in those days. I was 28 years old, just out of graduate school. I thought we should do my thesis project, only better, and other people agreed. We got together a team and actually proposed four instruments to measure the cosmic background radiation from the Big Bang, and anything else that might have happened afterwards. It was proposed in 1974, selected for further study in 1976, and finally flew 13 years after that in 1989. And then it did wonderful things.

***FELLOWSHIP:*** *As a scientist, what is your role in the political processes like securing funding?*

**MATHER:** My role is as a civil servant scientist so my role is entirely within the project—doing the technical part; talking to other scientists; talking to engineers; making sure we're doing the right thing. Most of the time, I don't talk to a politician. I think most of the hard work of "securing the funding," as your question puts it, relates to making sure the plan is correct; that we have the budget and the schedule and all the details down correctly—the government scientists work on that part. The managers and engineers have a much bigger part too because they actually know what it would take to build a giant test chamber/test setup and make it go; what's it take to grind and polish the mirrors. Scientists don't know that to begin with and we work with the engineers to make sure they know what is needed; but mostly it's the managers and engineers that figure this all out.

***FELLOWSHIP:*** *How is the James Webb different from the Hubble? What is the importance of having both?*

**MATHER:** This is the really interesting question! The new telescope is far more powerful and can see much farther, and much better in many ways, than the Hubble. It does this by observing at infrared wavelengths. Hubble observes ultraviolet—which is shorter waves than what your eye can see—and it observes visible light, and a little bit of near-infrared. It can't observe longer wavelengths, like infrared, because the telescope itself glows. The James Webb Telescope is much bigger but it's also much colder so that it can observe these waves. Scientifically that's important because of several things: One is the things that Hubble has discovered for us tell us that there are mysteries just beyond where they can see. The Hubble says "See all these beautiful galaxies from the earliest times of the universe? We can tell that there are more beyond that and we can't see them. So what do we need to see them? We need something that's able to look at longer wavelengths." The expanding universe shifts the wavelengths of the most distant galaxies into infrared—it starts out as visible light and then it ends up as infrared—so if you want to see them, you have to have a telescope that can do that.

There are several other scientific objectives that we also are pursuing. One is to see into the places where planets and stars are being born today. It's happening as we speak, in nebulae like the one in Orion, and other places where new stars are being born; but they're mostly hidden from us because they're inside dusty clouds of gas. The dust stops the light so we can't get it, but infrared light will go through the dust, or around the dust, and we can see in. Those are two of the more exciting things we could be looking at: the first galaxies, the first things that light up after the Big Bang—and we'll see them with James Webb but you can't see them with anything else—and to see inside the birth places of new stars and planets. James Webb can see in there too.

To me, this is really exciting because it's part of working out our own history. The history of how did we get here from the Big Bang? It's a long story. The biologists have another part to play, they need to figure out the life part; but we on the astronomy side can tell them about the physics part: how does the earth come to have the right temperature and pressure and chemistry to support life here?

You also asked why do we need both? They really do different science. The Hubble sees things that James Webb cannot see, because it studies physical and ultraviolet light; and James Webb studies things that Hubble can't see because Hubble doesn't do all the infrared. We don't know which one is going to be more surprising but I know for sure the Hubble is not done yet. Every year they keep making more amazing discoveries, and seeing farther, so I think we're not about to run out of things for Hubble to do, even when we have a new telescope that's more powerful in some ways.

***FELLOWSHIP:*** *So the James Webb is not a replacement for the Hubble?*

**MATHER:** It's not a replacement at all—it's an extension.

***FELLOWSHIP:*** *What are some of the contributions of the Hubble so far?*

**MATHER:** There are so many but let me give you a couple that really excited me! One is that Hubble was the key tool to enable discovering the accelerating universe, which got the Nobel Prize last fall. People using the Hubble discovered some really really distant supernovae, which are exploding stars and, if they're far enough away, you can use them to tell that the universe has been accelerating, going faster all the time. For many generations, astronomers have been pretty sure that the universe would be slowing down because of the effect of gravity pulling everything back together—and it probably did for the first five, ten billion years but it's not now—it's going faster.

In completely different areas: people using the Hubble discovered that there's a black hole in the middle of almost every galaxy—and that's a big surprise. We have a fairly small one in the middle of the Milky Way, but others in other galaxies are a thousand or ten thousand times more massive than ours and that's pretty spectacular. We've even been able to take pictures of planets around other stars. There's a star called Fomalhaut—it's a bright star in the southern sky—and you can actually see this little thing move around the star in orbit. That's a pretty spectacular discovery.

With the Hubble, we've also been able to start learning about the chemistry of planets around other stars—exoplanets. Sometimes a planet goes between us and the star, and some of the starlight goes through the planetary atmosphere on the way to the Hubble telescope; so then you can begin to do the chemical analysis of that planetary atmosphere. It's now a pretty well-established technique but was pretty startling the first time! To follow that up, by the way, we've got the Kepler mission up there, which is observing these transits when the planet blocks starlight, and they've got a little over a thousand candidate objects that I think are mostly going to turn out to be real planets. This is a handful of some of the contributions of the Hubble, there are plenty more.

***FELLOWSHIP:*** *So the way it works with these telescopes is that different groups of scientists can apply to use them?*

**MATHER:** Yes, for big, ground-based telescopes and space telescopes you usually get your friends together and you write a proposal. You say why your science idea and your team are so good that they should give you the time. And if you're chosen then you get to do it.

Hubble is what we call oversubscribed—the proposals received would occupy eight times as much time as what we actually have in a year. So we know there's a huge variety of ideas that are good and worth pursuing.

***FELLOWSHIP:*** *Are there already proposals for using the James Webb?*

**MATHER:** Well, we have a general idea. We wrote ourselves lots of proposals ten, twelve years ago, when we were trying to figure out what did we really want to plan it to do, but the real proposals won't be due until about a year before launch.

***FELLOWSHIP:*** *What do you hope to learn from the work with the James Webb Telescope?*

**MATHER:** I hope to get a great surprise! What are some of the surprises that I hope to get? I would think if we were really lucky, we'd find a planet a lot like Earth around a star a lot like the sun, and we'd be able to learn a lot about it. Now, Webb is probably not the search tool for that but we would be the ones to follow it up in observation. So if another mission, another observing program, can find it in a star, we would definitely want to follow that up. That would be a wonderful surprise if we could do that.

On the other end, if we were able to learn about how stars and galaxies were formed way back in the earliest times of the universe, that would spectacular too—and it's possible.

***FELLOWSHIP:** Is the telescope on target for completion in 2018?*

**MATHER:** Yes, it definitely is. Since we made our new plan, we set out a monthly calendar of events that we would have to achieve, to prove we knew what we were doing, and we're achieving them. Nobody's saying we need to change the launch date and we're pretty pleased with that. We're actually doing a few things ahead of schedule.

***FELLOWSHIP:** Where are you in the process? Is it ready for testing?*

**MATHER:** Oh no, we have not yet started to put it together, really. The things that are closest to finished are the instruments. There are four instruments that take pictures and make the spectra, basically spread out the starlight into rainbows so you can tell what's happening. And of those four: one of them is finished and in Europe and soon to be delivered here. One of them was finished in Europe but there was a crack they had to fix, so they had to take it apart and put it together again. So that's been delayed for a while. The other two, one is Canadian and one is American, and they're coming along. Also something that is finished, that was very nearly impossible, is that all the mirrors are made and we're really pleased with that. The great primary mirror that actually collects the starlight is actually made out of eighteen smaller pieces and all eighteen are polished and coated and meet the requirements. That was just accomplished late last year.

***FELLOWSHIP:** How did you become interested in your field? What was the trajectory of your career?*

**MATHER:** As Bill Cosby said: "I started out as a child." In my case, I remember back to about eight years old and my parents took me and my sister to the Museum of Natural History in New York. We saw the planetarium show which was spectacular. In the early 1950s, not too much was known—there was no space program. It seemed exciting. Mars was going to come close by and people were very excited to see if the Palomar Telescope could see canals on the surface. (Now we know there weren't any but it was a great hope anyway.)

My dad was a scientist. My parents would read to me and to my sister from the biographies of Galileo and Darwin so it was pretty clear that it was exciting to be a scientist—and maybe even a little dangerous, but clearly important. These people had changed the world, changed the history of the planet, in ways that who would have ever guessed. They were heroes to me. And although my dad was a scientist, I didn't want to do what he was doing because he was studying dairy cows (we lived on a farm).

I read everything I could get about physics and astronomy and electronics—that's what was hot when I was kid. Then I got to college and wanted to do physics. The most exciting thing in those days, to me, was elementary particles because they had been discovered but they didn't know how they worked. Now we think we know, but it sure was a total mystery then! In graduate school, I thought I wanted to do that. I wanted to be like Richard Feynman and they said "There's already Richard Feynman and besides there are no jobs in that area." So I started looking around for a thesis project and interviewed some faculty. I found Paul Richards and Charles Townes and they were working on a measurement of cosmic microwave radiation from the Big Bang (it had been discovered only five years before). I ended up doing a thesis project that included a balloon payload, an instrument to go up and to measure this cosmic microwave background radiation. That first flight the instrument failed. It did not function correctly so we didn't get any useful scientific data. My advisor let me write a thesis about the instrument design and helped me get a job in radio astronomy. After I'd been a postdoc in that position, learning radio astronomy for six months or so, NASA announced this opportunity in 1974 to propose new satellites that would do science: "What are we going to do after the Apollo program?" I said to my advisor, "Well, you know, my thesis project didn't work but it would've been better if we could do it in outer space." That was right, so he said "call up these people, we'll make a team and we'll propose it" and, you know, it all worked. That's how I got into it.

This is an extremely chaotic process. If somebody had said: "What are you going to do so you could achieve a great objective and earn a Nobel Prize?" nobody would have ever thought to do *this*, as far as I could tell. I ended up in Berkeley because my friend sent me a picture of himself in short sleeves in January and said "Why don't you come out to Berkeley? It's nice out here." So I did. There are lots of stories to tell that basically emphasize that you cannot predict this kind of thing.

***FELLOWSHIP:*** *Can you talk a little bit about winning the Nobel Prize?*

**MATHER:** For a long time after we flew our COBE mission, and even before, people would say to me "We think this is a Nobel Prize project." I thought well that's nice of them to say but it has to work and we have to find something. We just have to be lucky. So I just didn't think about it but thought it'd be nice if it happened. I was pretty nicely surprised when I got a phone call one morning; I think it was October 3 of 2006, about 6:00 in the morning, or a little before. It was the people from Stockholm wanting to know if I was the right John Mather because they had something to tell me. When the call came, I realized that my life had just changed completely because now I would be on call to do a lot of public speaking, even more than before, and that this would be something where my daily life would be completely changed.

***FELLOWSHIP:*** *Is there anything I have not asked about that you'd like our readers to know?*

**MATHER:** I would say that space science is only one of many areas where spectacular discoveries are about to occur. Many areas need to continue with a rigorous research program. Pretty clearly, we can't plan all of these things. From what NASA does for earth science, we can tell very clearly, from Earth observations from space, that we have a big problem here—where climate is changing, rainfall patterns are changing, the oceans are warming up, the oceans are getting more acidic—all these kinds of things we can measure from space. So the practical arm of NASA is really important too. It might not be as surprising to people as what we discover with astronomy, but it's absolutely critical to our future that we should do that.

Another thing, I guess I mentioned already, people really love when the Mars rovers rove around and discover things out there—I do too! There was a time when I heard some public talks about what the Mars people had found and I thought "I wish I could be born over as a Mars expert!" because it's so exciting. It's partly a measure of how completely impossible it seemed before we went there. "Oh we'll never know anything about that. It's only going to be fuzzy pictures taken from Earth." And now we've got little critters roaming around, under our control, drilling holes in rocks and doing chemical analysis and looking for life. It is most spectacular! There is actually a genuine hope that we will detect life there on Mars. And if we don't find it right away, it's not that it's not there, it's just that it's in hiding, which is how I think about it. I think it's going to be very exciting to learn about the life we find elsewhere. I'm fairly confident that it's there.