ASTRONOMY BEAT

Giving Birth to the James Webb Space Telescope: Part 1

John Mather (*NASA Goddard Space Flight Center*)

In late October 1995, I found a remarkable message on my answering machine from Ed Weiler, then the Program Scientist for the Hubble Space Telescope. Would I work on the next generation space telescope, the successor to the beautiful HST? It took me mere moments to work out the answer: Of course! At the time, my work on the COsmic Background Explorer (COBE) was finished, I was writing a book about it (*The Very First Light,* with John Boslough), and I thought NASA might never do anything nearly as spectacular again. Wow, was I happy to be surprised by that call!

The context was that Hubble had been repaired and was sending back brilliant images, and the universe was again surprising us. In particular, Hubble showed us that the galaxies formed far earlier than theorists had told us, but Hubble couldn't see the first galaxies because they are too faint and too red-shifted.

To deal with this issue, Alan Dressler was chairing a committee and writing a report called "HST and Beyond: Exploration and the Search for Origins," which called on NASA to build a new infrared-optimized telescope to cover the one to five μm (micron) range (extending to shorter and longer wavelengths if possible) with an aperture of four meters or more. I still get goose bumps remembering the poetic power of that little report.

Called the eXtreme Deep Field (XDF), the photo was assembled by combining 10 years of HST photographs taken of a patch of sky at the center of the original Hubble Ultra Deep Field. While the XDF reveals galaxies that span back 13.2 billion years in time, the very first galaxies remain invisible to Hubble because they are too faint and too red-shifted. Courtesy NASA, ESA, University of California Santa Cruz, Leiden University, and the HUDF09 Team.

Early Days

Dressler got to meet NASA Administrator Dan Goldin, who became a very enthusiastic supporter of the idea. Most NASA Administrators don't go to the American Astronomical Society meetings, but Goldin went more than once, and at the January 1996 meeting, he announced that NASA would build the telescope Alan was asking for, but that it was too small! (Implicit in this was the fact that Goldin knew that larger telescopes had already been studied for the military, and that the needed technology for folding, deployment, and in-flight focusing was available.) Needless to say, he got a standing ovation from the audience.

Dressler's little report laid out a huge variety of wonderful things that could be studied by the new telescope. The topics ranged from our solar system and extra-solar planetary materials (even though the rich subject of exoplanets had yet to develop) to the birth and death of stars, infrared and active galaxies, galaxies in the early universe, and cosmology. The innovative infrared technology available for a cold telescope in space would open up new territory for discovery, with unimaginable riches to be found. Moreover, the report also called for the development of technology for an even more powerful observatory capable of finding and studying Earth-like planets around other stars. The HST had led the way, showing that NASA could build an incredibly powerful observatory despite tremendous challenges. But Hubble couldn't possibly do what the new missions could — it's too small, and it's warm, so it glows at infrared wavelengths.

Budget Crunch

Within NASA we were thrilled, and talented engineers were soon lining up to work on this new project that was going to fly as soon as possible. But Goldin asked us to find a way to launch the project "Faster, Better, Cheaper" and set a budget and schedule target that

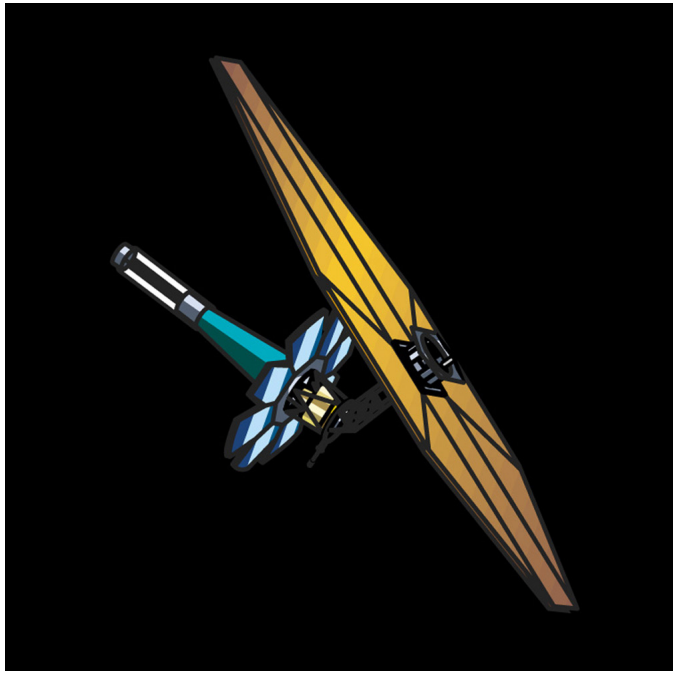
Two images of the ever-popular "Pillars of Creation" in the Eagle Nebula (M16). The HST image on the left is in visible light. On the right is a near-infrared image of the same scene taken with the 8.2-meter-diameter ANTU telescope at Paranal, Chile. Using infrared, astronomers can penetrate the obscuring dust to detect newly formed stars; the tips of the pillars contain stars and nebulosity not seen in the Hubble image. *Left:* Courtesy NASA, ESA, STScI, Arizona State University. *Right:* Courtesy VLT, ISAAC, AIP, ESO.

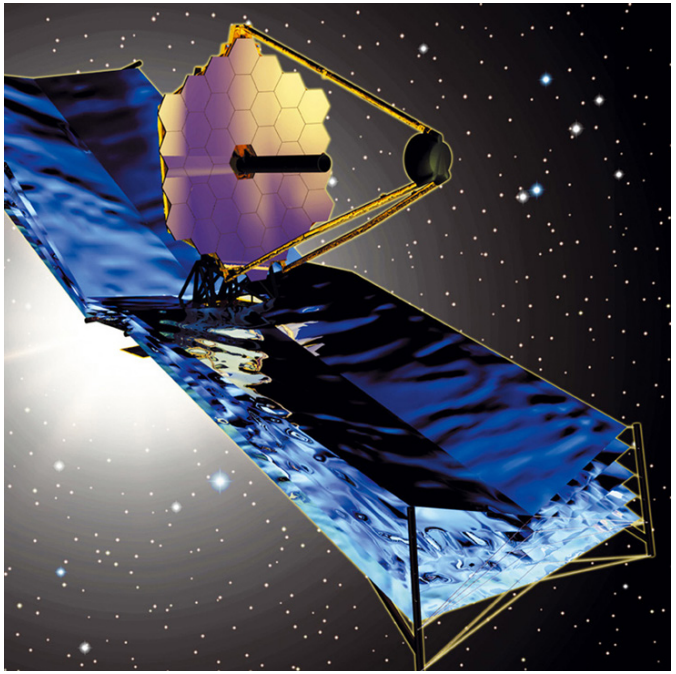
turned out to be impossible to meet. It was good to get going and have the support of the Administrator, but people used to laugh at me when I told them how we could do the mission. They knew what Goddard engineers also knew — it came down to which two of the F/B/C tripo do you really want?

As it turned out, we designed an observatory that was completely impossible to build with old technologies, and so we have developed many new inventions to make it possible. We had to invent ways to make the mirrors and ways to focus them after launch; we had to develop bigger and better infrared detectors; we needed cryogenic amplifier chips (ASICs, application-specific integrated circuits); we needed an active cooler to get the mid-IR instrument down to 7 kelvin; and we needed new material for the sunshield.

The budget target ultimately caused us a lot of grief. But we did learn several important lessons from the HST project, which was

behind schedule and over budget for a long time. First, we knew we had to get those new inventions finished before we designed an observatory around them. Second, we knew we'd better prove that the telescope would focus in orbit — the end-to-end test for Hubble had been omitted for cost reasons. So Webb will indeed have an end-to-end test in a giant cryogenic vacuum tank. To generalize the Hubble lesson: anything that matters a lot had better be proven in two different and independent ways, and if the results don't agree, then the reason for the difference had better be proven too. That degree of rigor and certainty is hard to come by, and it takes time, money, and giant test chambers.





Two early designs (*left:* Goddard Space Flight Center, *right:* TRW & Ball Aerospace) for what would become the James Webb Space Telescope.

Building the Spacecraft

One of our early challenges was developing international cooperation. We knew that cooperation between the US and Europe had been successful for Hubble, and that European scientists were winning a lot of observing time on the telescope. So we were instructed to find a plan for doing this and to be open to involving other countries. After rejecting a variety of ideas, we agreed to divvy up the work in the following manner.

The European Space Agency (ESA) would buy the launch vehicle (an Ariane 5) and one of the scientific instruments, the Near-Infrared Spectrometer (NIRSpec), covering 0.6 to 5 µm wavelengths. ESA would also sponsor a consortium of European institutions to produce the cold part of the Mid-Infrared Instrument (MIRI), covering 5 to 28 µm. The Canadian Space Agency would produce the Fine Guidance Sensor (FGS) and a Tunable Filter Imager (TFI) covering 0.6 to 5 µm as a scientific instrument. NASA would deal with everything else: the telescope, the sunshield, the spacecraft bus, the Near-Infrared Camera (NIRCam) covering 0.6 to 5 µm, the warm part of MIRI and its cooler, all the infrared detectors, microshutters for the NIRSpec, all the integration, test, and flight operations, and data reduction and distribution through the Space Telescope Science Institute. (Whew!)

Skipping ahead in time (and past plenty of details), we ran a lot of competitions, and in 2002, we finally chose TRW as the prime contractor over Lockheed Martin. Shortly thereafter, Northrop Grumman acquired that part of TRW.

James Webb, NASA Administrator from February 14, 1961 to October 7, 1968. Courtesy NASA.

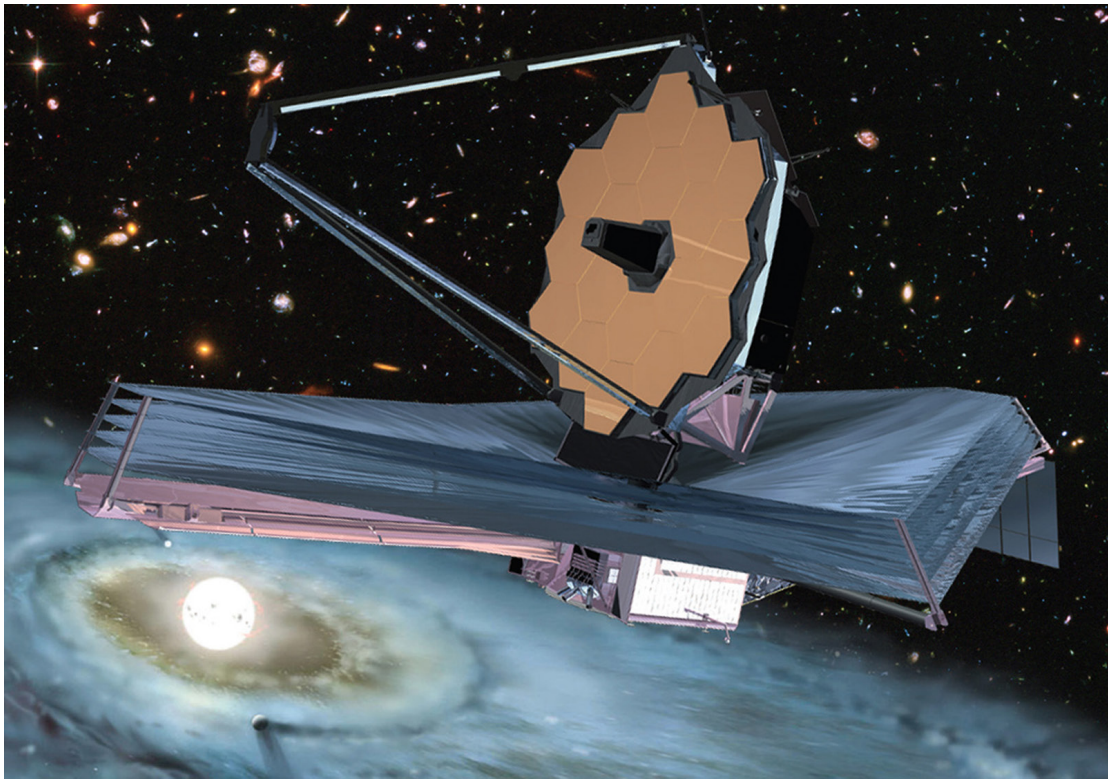
At about the same time NASA Headquarters decided to name the telescope after James E. Webb, the NASA administrator who went to President Kennedy with a plan to go to the Moon. Webb got it right, partly by asking for enough money right up front. He knew that the greatest risk the program could face would be running out of money, just as Lindbergh knew he'd better have enough gas to get across the Atlantic. The story goes that Webb doubled the budget in the taxicab on the way to see the President, and *then* it was enough.

Of course, things changed as time passed. The James Webb Space Telescope (JWST) is smaller now than we had planned in 2000 — the 8-meter version turned out to be impossible to build. The mirrors could not be made light enough, would take too long and cost too much to build, and there wasn't enough space to fold an 8-meter telescope inside the launch vehicle. So now it's a 6.5-meter scope. To save money we also backed off on the number of detectors. That was a good thing, but there was much gnashing of teeth in the process.

A decade later, our JWST budget has also increased a lot, albeit after a very difficult process. In June 2010, Senator Barbara Mikulski (D-Maryland) wrote a letter to NASA asking for a technical and management review, so that NASA would not have continuing cost growth on the JWST.

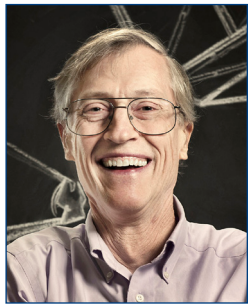
Though it was extremely nerve-wracking to have the reviews, the answers that came back from the independent committees were pretty clear. The technical plan was about right but would take longer and cost more than we said; the engineering was good to excellent and sometimes brilliant; and the greatest management fault was not asking for enough money. Needless to say there were many very human reasons that all those things had happened, but NASA responded with a new plan and new leadership, Congress passed the budget that NASA submitted, and since that time the JWST has stayed on its plan very well.

[To be concluded in *Astronomy Beat* #111, May 2013.]



An artist's concept of the current configuration of the JWST once in orbit, surrounded by a number of objects astronomers hope to study using the space telescope. Courtesy NASA.

About the Author



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Resources

- NASA's website for the JWST: www.jwst.nasa.gov. The Space Telescope Science Institute also has a JWST website: www.stsci.edu/jwst, as does the European Space Agency: http://sci.esa.int/science-e/www/area/index.cfm?fareaid=29.
- At NASA's JWST News Archive www.jwst.nasa.gov/news_archive.html you can instantly access all the Webb news releases.
- "Behind the Webb" is an ongoing video series about the telescope: http://webbtelescope.org/webb_telescope/behind_the_webb/archive.
- Here is a webpage with materials for educators: www.jwst.nasa.gov/teachers.html.
- Of course the JWST is on Facebook www.facebook.com/webbtelescope, Twitter https://twitter.com/NASAWebbTelescp, and it has its own YouTube channel http://www.youtube.com/user/NASAWebbTelescope.
- "The James Webb Space Telescope" by Jonathan P. Gardner and Heidi B. Hammel. *Mercury,* Spring 2013: http://astrosociety.org/publications/mercury-magazine. This article is an overview of the JWST project by two scientists who have been intimately involved in the project for many years.
- *James Webb Space Telescope Science Guide.* This free e-book features video, image galleries and more to tell the story of the Webb Telescope (also available as a non-interactive PDF) www.nasa.gov/topics/nasalife/features/e-books.html.✦

Astronomy Beat

Number 110 • April 9, 2013

Publisher: Astronomical Society of the Pacific
Editor: Paul Deans
Designer: Leslie Proudfit