Science, Art, Beauty, the Meaning of Life, and the James Webb Space Telescope

John C. Mather
Code 665
NASA Goddard Space Flight Center
Greenbelt, MD 20771

Abstract

As an astronomer I ponder the mysteries of the universe, and I think about how to understand them a little better. Astronomers have measured the Big Bang and we have an idea of how the primordial material could leave to life here on Earth – but is the idea right? We have powerful telescopes reaching far out in space and far back in time, and looking inside clouds of dust and gas where stars and planets are forming right now. The James Webb Space Telescope is the most ambitious space telescope ever built, and progress is excellent toward a planned launch in 2018.

As an Introduction

I have a thirst for discovery and understanding, and I'm a scientist. The art that I like feeds that thirst – the surprise of seeing how a line or a form can evoke a world of thought and feeling and action. My wish is to understand how we got here; I asked my father when I was 6, but he didn't know. And, are we alone? Are we the only ones asking these questions? The universe is large, but we could still be the only ones.

So now I am working on the great James Webb Space Telescope, the planned successor to the Hubble Space Telescope, and I fervently hope that its images will fill our coffee tables with beautiful questions, just as the Hubble has done.

Jefferson wrote for us, in the Declaration of Independence, one of the most challenging questions, though for him it was not a question. How is it, that "the Laws of Nature, and of Nature's God", as he put it, can lead to this: "We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty and the pursuit of Happiness." He was disappointed by what happened later: democracy was pretty raw, not the activity of selfless men of high character. But he was also the President who launched the first scientific expedition of the young United States, the Lewis and Clark search for a water route to the Pacific. He would be thrilled to know what science and engineering have given us in its place. Lewis and Clark set off in 1804, just 99 years before the Wright brothers flew their first plane, and 165 years before astronauts Armstrong and Aldrin walked on the Moon.

How Did We Get Here?

So that is the great mystery before us: how did we get here? Darwin was the first to understand how biological variation and natural selection could produce new species, and he was well aware that the competition for survival would produce chaotic change and unpredictable results. He would have been a fine economist, for the same principles seem to apply very well to the modern world of work and trade, and even politics and government. Of course, many have misused his insight to say that what is, is what ought to be. But that underestimates the creative power of the mind, and misses the essential point that nothing in nature is stable forever.

So I am engaged in the search for evidence about the physical universe, and especially the preconditions that enable life to survive here on our planet Earth. After Edwin Hubble discovered that the Universe is expanding, we knew there was some kind of cataclysmic history, and we built more and more great telescopes to see the evidence, up to the great Hubble telescope itself. In 1965, it was found that the universe is also filled with the heat radiation of that primordial condition, now called the cosmic microwave background radiation. I did my PhD thesis on an initially unsuccessful attempt to measure this radiation better, and thought I would give up on this difficult topic. But that was not my fate. NASA asked for proposals for new satellite missions, I told my new postdoctoral advisor that my thesis project should have been done in outer space, and we formed a team to propose a mission, the Cosmic Background Explorer (COBE). It flew in 1989, and in 1992 it provided a stunning confirmation of predictions: the early universe was not quite uniform. Instead, there were some spots that were denser than average, enough that gravity could pull them back together despite their rate of expansion, and in those spots, galaxies and stars and planets would form. When Stephen Hawking saw our maps, he said that it was the most important scientific discovery of the century, if not of all time. I think he meant that if those cosmic lumps did not exist, we could not exist either. If our understanding of physics is correct, then these lumps must have existed from the very first moments, and they would grow under the influence of gravitation to form galaxies and stars and planets. No lumps, no people.

Maps of the Temperature of the Radiation

We made maps of the temperature of the radiation, and we tried different color schemes to illustrate the most important parts of the results. In Figure 1 we have a picture of the entire sky, the result of a team of altogether 1500 people working for years, compressed into an oval map of pink and blue blobs.

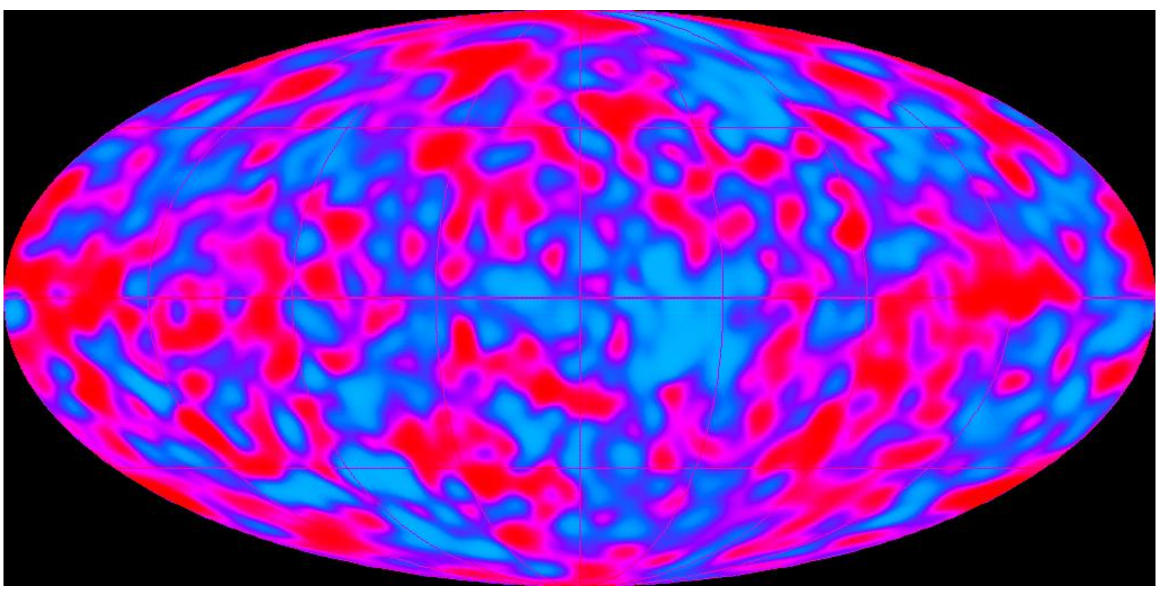

Figure 1: *Map of the entire sky, the universe as it was at the age of 400,000 years when the universe became transparent, measured at millimeter wavelengths with the DMR instrument on the COBE satellite. Foreground interference from our own Milky Way galaxy has been removed. Red spots are up to 100 microkelvin warmer than average, blue spots fainter. The average temperature of the map is 2.725 Kelvin so these differences are very hard to measure. Cold regions are denser than average and will eventually grow to become clusters of galaxies. Warm regions will empty out. Courtesy NASA and the COBE Science Working Group.*

Then in 2001, a successor mission was launched, called the WMAP (Wilkinson Microwave Anisotropy Probe), and after the team analyzed 7 years of data, they made a new and much better map, in Figure 2. This time they chose a different color scale including green and yellow as well as red and blue, but the meaning is the same: one color (red) means hotter than average, one color (blue) means colder.

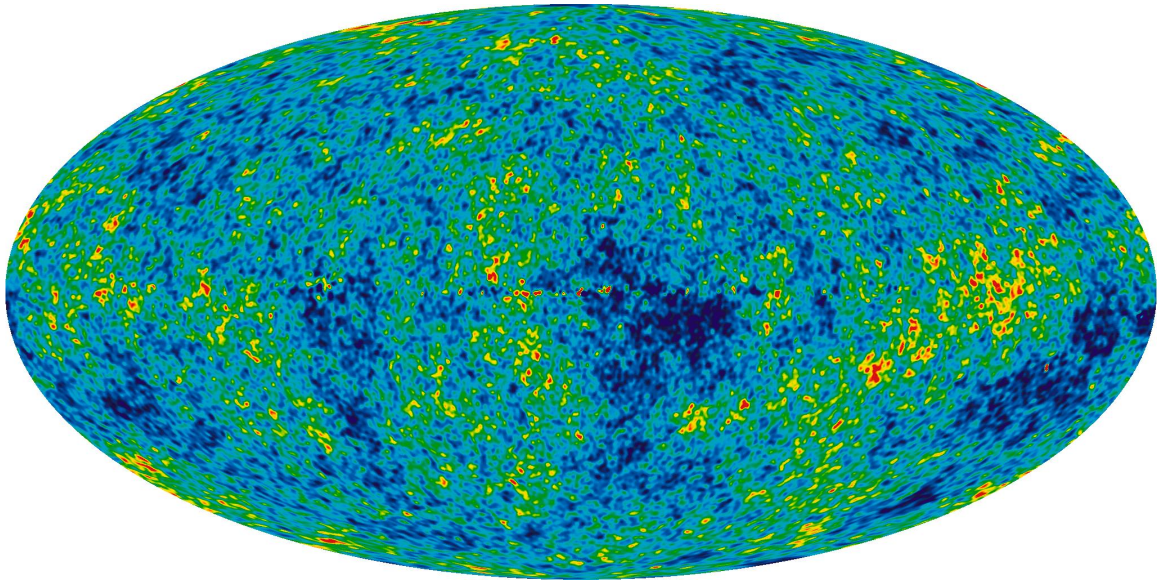

Figure 2: *Map of the entire sky, similar to COBE map, but made with data from the WMAP satellite. Fine detail confirms that the early universe had sound waves caused by differences in density in the Big Bang material. Large scale features agree with the COBE map but provide much more detail, with intermediate colors (green and yellow) between the red and blue. Red is a few hundred microkelvin warmer than average, dark blue a few hundred microkelvin cooler.*

So to the scientist, these two maps are extraordinarily beautiful. The little spots appear to be random, but not quite, because there is a preferred size for the spots: about a degree (of angle) across. The mathematicians have measured the statistics of the spots, and the physicists have drawn amazing conclusions. They tell us that the spots are (or at least might be) arranged like this because: 1. The early universe was so hot and dense that quantum fluctuations made hot and cold spots, 2. The universe expanded so rapidly that tiny regions of space, maybe the size of a ping pong ball, blew up to be as large as the whole part of space we can see, 3. Gravity acted on the primordial material to make stars and galaxies, 4. There are mysterious things like dark matter and dark energy that must exist, or the patterns don't work out right. There are also many mysteries that cannot be answered yet: 1. What is the dark matter that makes the spots and controls the growth of galaxies? 2. What is the dark energy, that makes the universe accelerate every day? 3. Will it stop expanding and turn around? (Probably not, but how would we know?) 4. Are there other universes like ours? 5. Are there gravitational waves in the early universe? New experiments are being planned to get even more details about these hot and cold spots.

There are a lot of kinds of art in this. There is the art you see, of the images of the sky, and their mysterious random patterns. There is the art of the artist, who took the numbers and made the beautiful pictures. He or she had to find a way to make the patterns visible so they could be appreciated by the scientists; we tried many color schemes to see what the eye could see in the data. There is the art of the engineer, who took the scientific requirements and found a way to build the hardware to make the measurements. There is the art of the scientists, who had questions and strategies and sketches on napkins. When you read about the great discoveries, you may think it is all Science, in the sense of

Knowledge received on stone tablets. But I want you to think of the people, embarked on a voyage of discovery, with skill and talent to build what had never been built before, to find what had never been known before.

The James Webb Space Telescope

Now a few words about the new telescope, the **James Webb Space Telescope,** shown in Figure 3. James Webb was not a scientist, but he did as much for science as almost anyone you can name. He was leading NASA when he told J. F. Kennedy what it would take to get a man to the Moon, and he got it right. In less than a decade, it was done. Kennedy said we would do it, not because it was easy, but because it was hard. (Or as he said, “haad”.) And Webb was the man who coordinated the efforts of a half million people to do the job in time. He was an incredible force, and President Kennedy entrusted him with a project that would determine the future of the nation and much of the world. You can read about him in the book “Powering Apollo” by Henry Lambright.

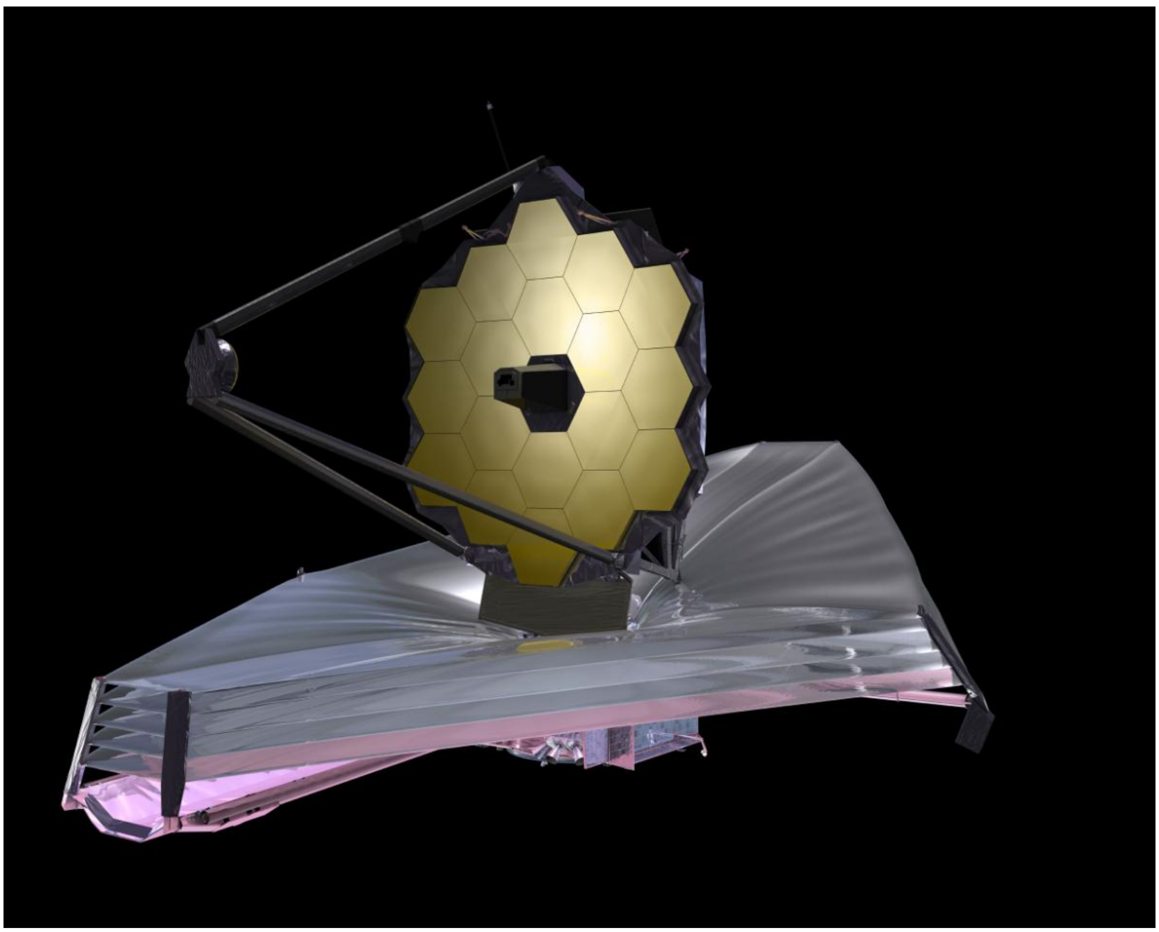

Figure 3: *James Webb Space Telescope, artist's concept. JWST will be launched in 2018 to examine the first object to form after the big bang in the most distant universe, as well as the clouds of dust and gas where stars and planets are forming nearby today. JWST can observe planets around other stars when the pass between the star and the telescope and block starlight.*

The telescope is also amazing. It is far larger and more powerful than the Hubble telescope, and it will open up new scientific territories. It will observe at wavelengths from 0.6 to 28 micrometers, including red light and infrared light that Hubble cannot see, because the Hubble telescope is warm and emits its own infrared. The Webb telescope will be cold, only 45 Kelvin. The Hubble showed us that Nature has many secrets just beyond our reach: the distant universe is receding from us so fast that the light we receive has been stretched to longer wavelengths, so that the Hubble can not see it. And near to home, stars and planets are forming inside dust clouds, that visible light cannot penetrate, and when they are young they are too cold to emit visible light. The Webb telescope will be so sensitive that it can detect the heat emitted by a bumblebee at the distance of the Moon. So we are pretty sure it will find something surprising!

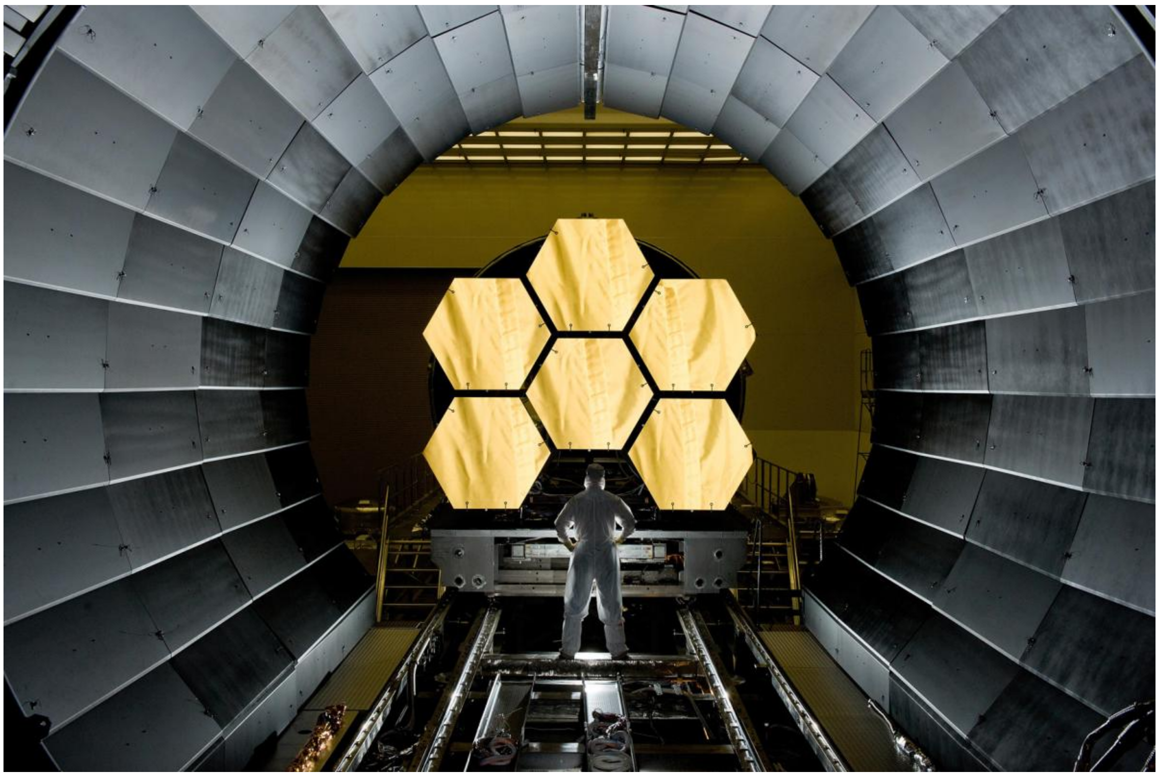

Figure 4: *Six of the segments of the primary mirror for the JWST, in the test chamber at Marshall Space Flight Center. All the mirrors have been polished, coated with gold for improved infrared reflectance, and tested at their operating temperature.*

Figure 3 is an artist's concept, but much of the hardware is real. Figure 4 is a picture of 6 of the 18 primary mirrors being prepared for testing in the cold tank at Marshall Space Flight Center.

The telescope is also the result of extraordinary efforts by engineers to meet the requirements of scientists. The Webb has to be far larger than the rocket that carries it, so it will be folded up like a ship in a bottle, and after launch motors will unfold the hinges and pull on cords to unfold the giant umbrella protecting the telescope from the Sun. The engineering of this marvel is one of the highest forms of creativity. There are so many ways to put it together, that we made a catalog of 50 different ways to fold it up.

And if organized human activity can be a creative activity, then the organization of over a thousand engineers worldwide, across the US, Canada, and about 14 European countries is certainly such an art form. NASA is leading the effort, with major contributions from Europe including two instruments and the launch vehicle, and Canada is providing another instrument and the fine guidance system.

What the James Webb Telescope Could See

When the great telescope flies in 2018, we hope to see many things that have only been imagined or predicted. So we don't have a good picture yet! But the Hubble Space Telescope gives us a hint. The Hubble was pointed at a single spot on the sky for weeks on end, to give the most sensitivity possible, and the resulting map shows literally thousands of beautiful and far-away galaxies.

Figure 5: *The Hubble Ultra-Deep Field shows thousands of galaxies at the limit of Hubble's capabilities. If Hubble could observe the entire sky it would see 100 billion galaxies like these. But Hubble also tells us that there are more galaxies beyond where we can see.*

Figure 5's beautiful image shows many tiny specks, little reddish smudges, that we think are the most distant objects ever discovered. That means that they are also seen as they were when the universe was very young – we see them as they were when they emitted the light we are now receiving, because astronomers literally do see back in time. When we truly understand how these little smudges work, we may begin to understand how our own history came about.

To put this in perspective, if the Hubble could take pictures of the entire sky, it would find about 100 billion galaxies. And each galaxy has about 100 billion stars. And at least in our own Milky Way galaxy, there are as many planets as there are stars. So someplace out there, there is a planet a lot like Earth. But so far, as far as we know, Earth is the only planet with people asking questions like ours.

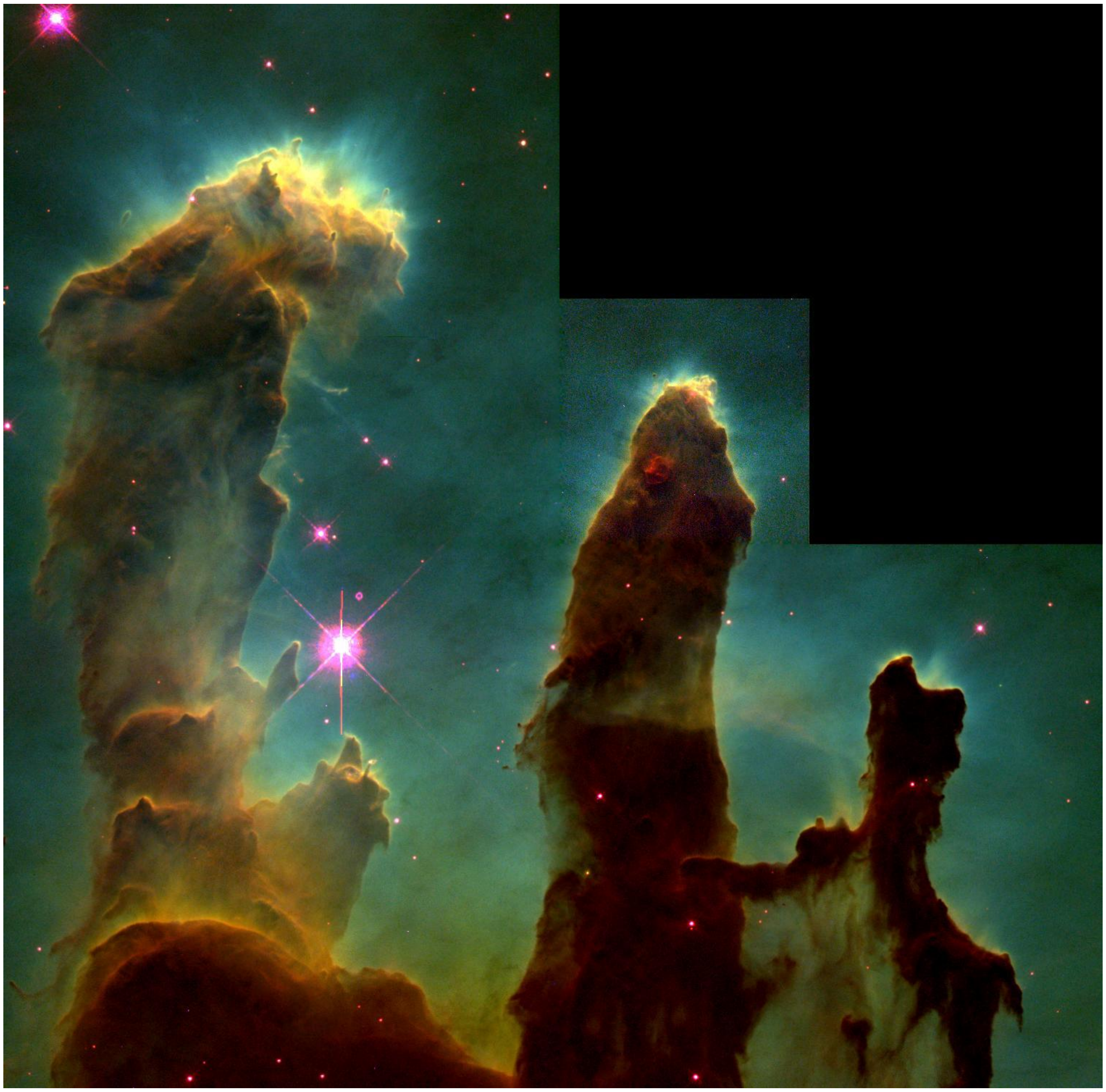

Figure 6: *The Eagle Nebula, as seen by Hubble. A spot where stars have just been born from clouds of dust and gas. JWST will be able to see through the dust to find out how stars are born.*

How are stars and planets made?
Figure 6, the Eagle nebula, is a place where stars have just been born, hidden by dust and gas. The general idea of how this nebula works to make stars has been known for decades, but getting the details right is still a huge challenge, because we can't see inside.

How common are planets like Earth? The Kepler mission has been observing the sky for three years, to find planets that pass between our telescope and their parent stars. The Kepler team has released a catalog of over 2000 potential planets, and a few of them are about the right size and the right distance from their stars to be like Earth, not too hot, not too cold, not too large, not too small, in the Goldilocks zone for what we think Life might require. The next challenge is to find out more about them: what is in their atmospheres? Are they wet enough to have oceans? Could there be oxygen in their atmospheres, which would be a sign of plant life? The JWST will tackle this question by looking at the starlight that passes through the planetary atmospheres on the way to the telescope.

Conclusion: It's too soon to say that the question I asked my father when I was 6 is answered, but we are well started to give some understanding. We have the basic outline of the history of the universe, and we have an idea of how evolution works to produce spectacular complexity. But no matter what we learn, it will still be mysterious, terrifying in a way, inspiring perhaps, and beautiful.

Acknowledgments: The work I have described was supported by the American public through their representatives and NASA. They should be proud! My special thanks go to my mentors Paul Richards, Pat Thaddeus, and Mike Hauser, and to my many colleagues and team members for both COBE and JWST. It is a great pleasure to say that we have done, we have done together.

More references:

1. "The Very First Light", by John Mather and John Boslough, Basic Books. The story of the universe and how we found out about it with the COBE satellite. Updated with stories of the Nobel Prize.
2. Prof. Ned Wright's cosmology tutorial online at UCLA. Ned was a member of the COBE and WMAP teams and is the Principal Investigator for the WISE mission that surveyed the entire infrared sky. http://www.astro.ucla.edu/~wright/cosmolog.htm
3. The JWST web site: http://www.jwst.nasa.gov
4. The Hubble images web site: http://hubblesite.org/gallery/
5. The WMAP web site: http://map.gsfc.nasa.gov/
6. The Kepler mission web site: http://kepler.nasa.gov/
7. The Nobel Prize web site, with stories about all the prizes. The prizes in Physics in 1978, 2006 and 2011 were about cosmology. http://www.nobelprize.org/nobel_prizes/physics/laureates/