CULTURAL PROGRAMS OF
THE NATIONAL ACADEMY OF SCIENCES

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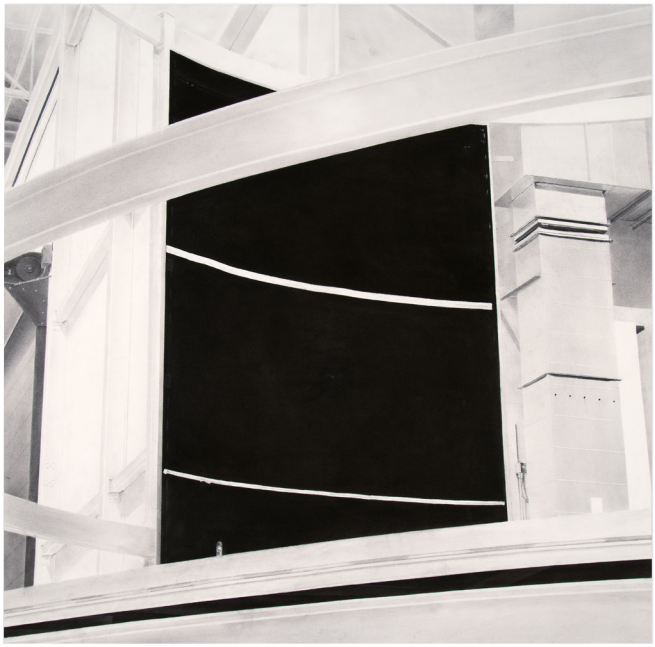


Reflections on a Tool of Observation

Artwork Inspired by the James Webb Space Telescope by Tim Makepeace

Introduction

In 2017, Tim Makepeace was one of several artists selected by NASA to create artwork inspired by the construction of the new James Webb Space Telescope (JWST). The most powerful space telescope ever built, it will succeed the Hubble Space Telescope when it launches in late 2021. Makepeace has continued working on a series of drawings inspired by JWST over the past four years.

"Since 2017, I have continued working on a series of drawings based on the photographs I took during my visits, trying to convey some of the awe evoked by this engineering marvel," he writes. "I have been thinking about the telescope's intended purpose, once it reaches its location orbiting the sun, as a break-through tool for imaging objects which we have never seen, or knew existed, and events that happened at the beginning of time."

Seeing the instrument in the terrestrial environment where it was being constructed set up a dichotomy with its exquisite engineering, as well as with the transcendent knowledge of the universe that it will eventually help us gain. This contrast of the mundane and sublime is a theme that guides Makepeace's resulting work.

The drawings, rather surprisingly, are rendered in charcoal and pastel. "One thing I have come to enjoy about this process is the counterintuitive idea, and the technique, of using a very imprecise medium, like soft charcoal, to render the image of one of the most technically advanced and precise objects ever devised and constructed by mankind," Makepeace explains. "Charcoal is also one of the most ancient tools for drawing, and I'm using it to describe an extremely advanced tool for science that will be shot a million miles into space to help unlock some of the mysteries of our galaxy and the universe. It's an interesting juxtaposition."

Makepeace is a Washington, D.C.-based artist who explores the interaction of engineering, science, architecture, and nature. His subjects range from decaying industrial structures in the natural landscape to the newest NASA space telescope bound for solar orbit.

#JWSTArt I @CPNAS

Installation photos by Kevin Allen.

Cover: (left) *Cryogenic Test Structure*, 2018, charcoal on paper, 49 x 49 inches
(right) *JWST Vertical Primary Mirror*, 2017, charcoal and pastel on paper, 49 x 49 inches

CULTURAL PROGRAMS OF THE NATIONAL ACADEMY OF SCIENCES

Art Meets Engineering
Tim Makepeace and the James Webb Space Telescope

To look at the James Webb Space Telescope is to wonder, "What IS that?" There is no classical telescope tube. The large mirror, made up of golden hexagons, sits atop what seems like a large silver sail. Though it looks much different than the Hubble Space Telescope, Webb is its scientific successor. Its design is a function of the science it will do, and the science has pushed the engineering to new heights. Science and engineering are often symbiotic. Science asks the question, and engineering enables the answers, which pushes the science even further. Sometimes when we build a telescope to answer questions, what results are new mysteries to solve. This was the case with the Hubble Space Telescope – it revealed things we had never seen before, but it also had its limits.

Hubble sees primarily visible light – the light our eyes see – though it has some capability in the infrared and the ultraviolet parts of the spectrum. It was originally deployed by the space shuttle, so its size and the diameter of its mirror were constrained by the dimensions of the payload bay. Despite this, Hubble was able to peer to the very distant past to see some of the earliest galaxies. Famously, it captured "deep fields" wherein astronomers pointed it at one spot in space for a very long time, curious what it might see if it peered long enough. It was a gamble to use that much observing time, but it paid off. Hubble saw galaxies over 13.2 billion light years away, gave us new clues as to what the early universe looked like, and has helped us understand how the universe has evolved over time.

The current known age of the universe is over 13.8 billion years. A couple hundred million years after the Big Bang, stars and galaxies started forming out of the darkness. These were the first luminous objects to exist – but we don't know exactly when or how they formed. These objects are so distant that as the universe expands, the light traveling towards us from over 13.5 billion light years away is also stretched, from the visible to the infrared. Hubble can't see these objects. Enter the James Webb Space Telescope and its odd design.

Most space hardware might be generously described as "something only an engineer could love." The James Webb Space Telescope is an exception to that rule, with its gold-coated, 6.5-meter (over 21-foot) diameter primary mirror. The mirror's beautiful golden face is a part of its function. Gold is an excellent reflector of infrared light. And with the size of Webb's mirror and its optimization for reflecting infrared light, it was built to see these first galaxies.

Creating a telescope this size came with challenges. How does one fit such a large mirror in a rocket? Just as Hubble was constrained by the size of the shuttle, Webb is constrained by the size of its rocket fairing. (It will fly aboard an ArianeSpace Ariane 5 rocket, which is quite large, very reliable, and the only rocket that fit NASA's requirements for launching a mission like Webb.) The answer was to build Webb with a segmented mirror that could fold to fit into a rocket. Its primary mirror consists of 18 hexagons, a shape chosen because hexagons fit together without gaps, are symmetrical, and when put together, give the mirror a roughly circular shape. The "wings" on each side of the primary mirror, which consist of three stacked hexagons each, fold backwards like a drop-leaf table. Why does the mirror not have a tube to protect it? It doesn't need one.

Unlike Hubble, which orbits the Earth, Webb will be going a million miles away where it will orbit the Sun, in line with the Earth. There is no debris out there to damage the mirror, and Webb's sunshield will block the light and heat from the Sun, Earth, and Moon, keeping the mirror and instruments in the dark and cold. If you want to detect faint heat signals from things far away, you need to keep your telescope very cold.

The sunshield is the size of a tennis court, so it too must fold to fit in the rocket. After launch, Webb will take two weeks to deploy as it travels to its orbital home. Then it must cool down before it can do science.

Besides the first galaxies, Webb will also be able to use its infrared vision to peer through clouds of dust and gas that obscure the objects inside from the view of visible-light telescopes. Webb will see planetary systems forming in these stellar nurseries. Webb will also be able to view objects close to home – it can see all the planets from Mars outward (it must never point in the direction of the Sun, so it won't be able to see Earth or the inner planets) as well as smaller objects like asteroids and comets.

Since Webb's inception, we have also learned that our solar system is not an exception, that planets orbit many (or even most) stars. Webb's instrument suite is perfectly suited for examining the atmospheres of these "exoplanets."

Webb will rewrite science books. Webb will help us answer questions we don't yet know how to ask. And Webb, like Hubble, will find new mysteries for future scientists and engineers to solve.

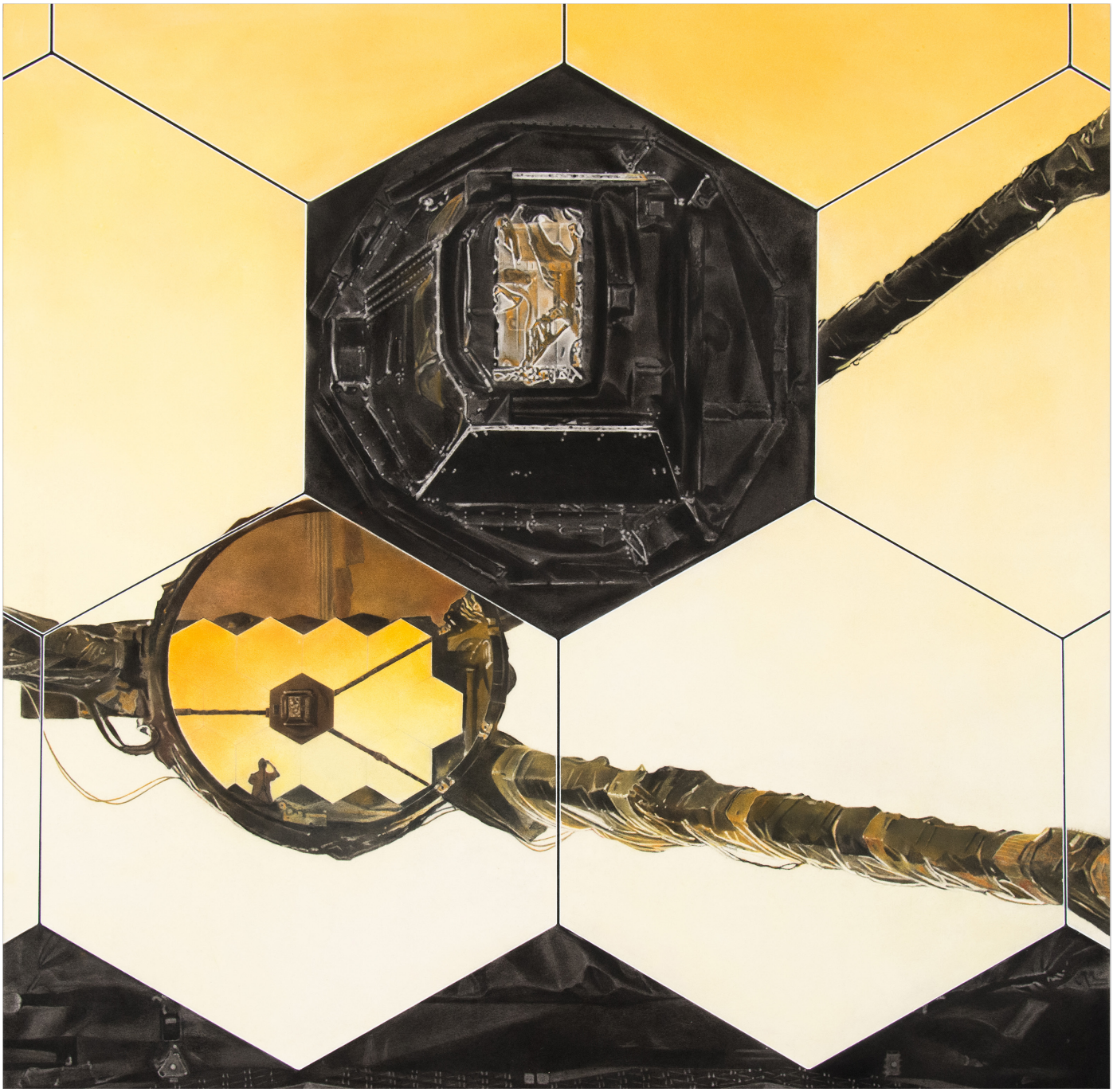
Webb is an international collaboration, with Canadian Space Agency and the European Space Agency contributions. The telescope and its parts were mainly constructed, tested, and assembled all over the US. For a time, it was at NASA's Goddard Space Flight Center, which is where the mirror was assembled.

I was lucky enough to watch it come together and the day I first saw its golden eye turned upon myself and a whole room of other eager viewers was one I will never forget. I was lucky enough to be able to share that view with other people over the years the telescope was at Goddard, but most impactful personally was being able to have artists visit. Having artists be inspired by the telescope resulted in the creation of a whole slew of artwork, from a range of different media – everything from watercolor to fabric art, tattoos, jewelry, and music.

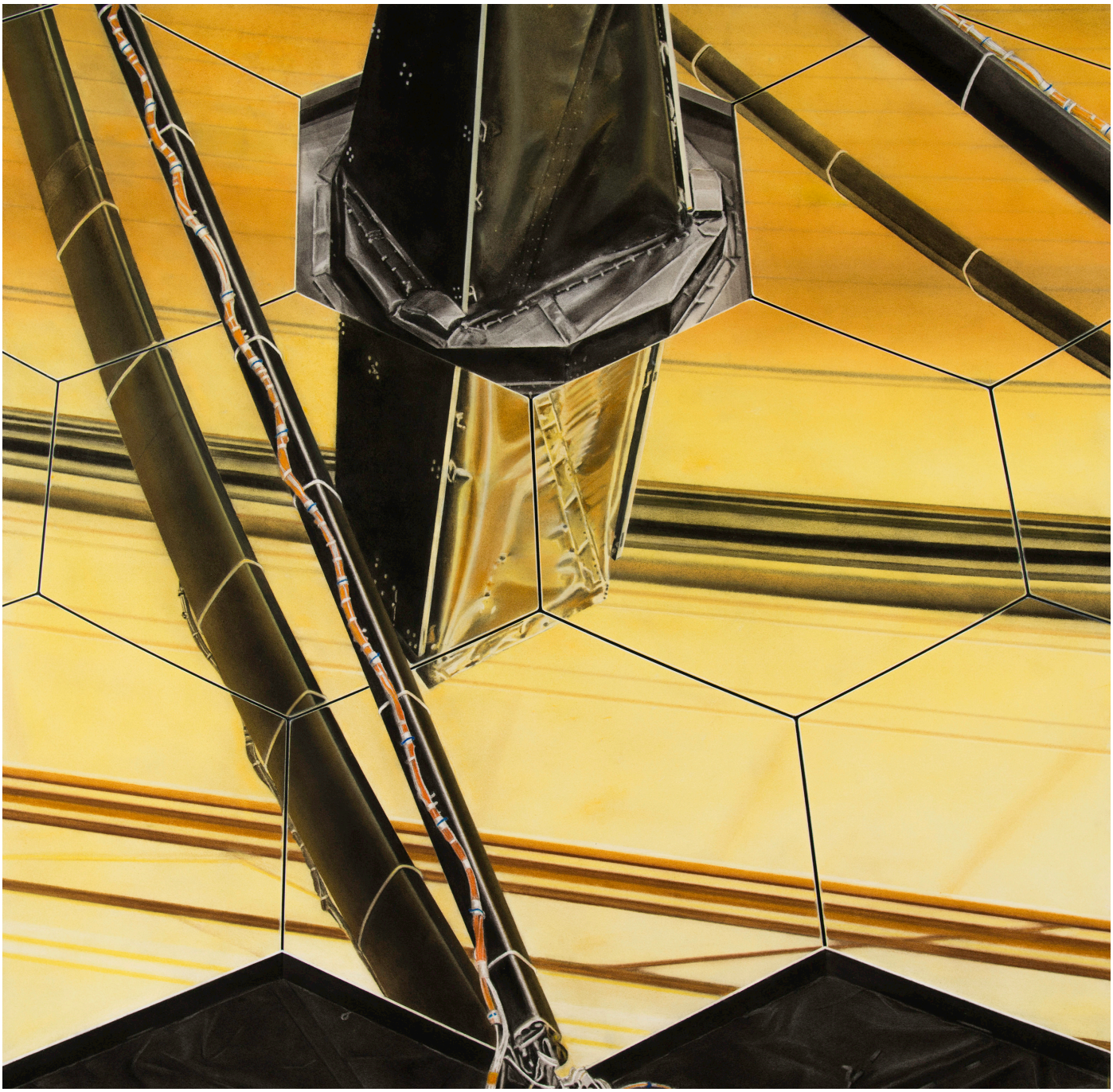
I gave Tim Makepeace a tour of NASA Goddard back in 2017, and I was there when he got his first look at Webb. I didn't understand then what an impact it had on Tim until he started creating work after work based on the telescope. He exhibited his first two pieces in our Art + Science exhibit at the NASA Goddard Visitors Center – and then kept creating. It has been an honor and a privilege to have witnessed his beautiful, meticulous, photo-realistic work come to life over and over again. Some of his pieces show the golden mirror, but some focus, for example, on a close-up of a section of strut and the wiring that runs over it. The details, the reflections – seemingly every aspect of the telescope's design has been translated by Tim onto paper, and by doing so, he transforms the engineering into art. The mission has photographers that have documented every nut and bolt of the telescope – but they also have Tim Makepeace.

Clearly this is a telescope that artists can love as much as engineers do. Through Tim's work, the viewer, I hope, will come to love every inch of this telescope as well.

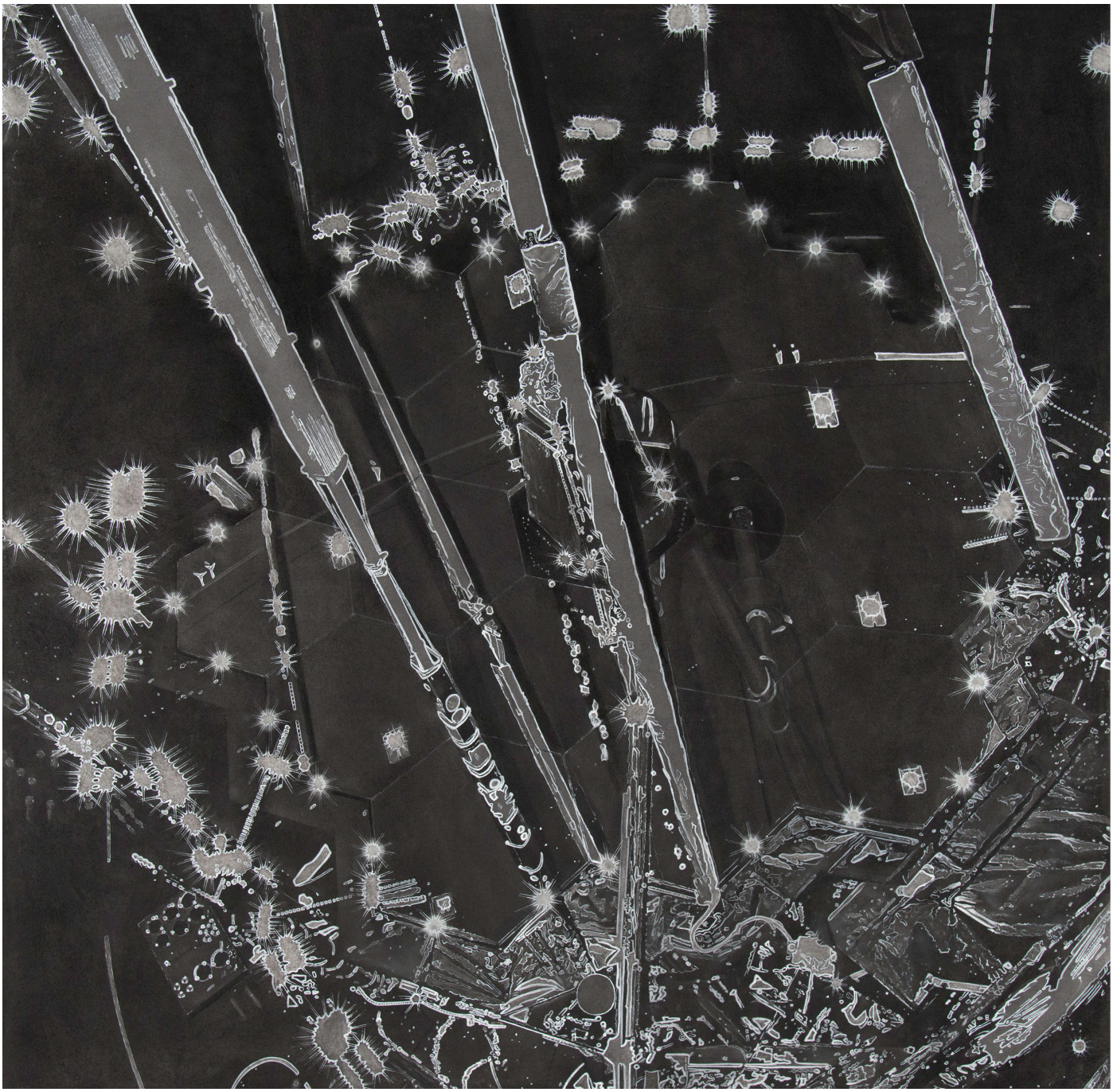
By Maggie Masetti
NASA James Webb Space Telescope
Social Media Lead & Web Site Manager



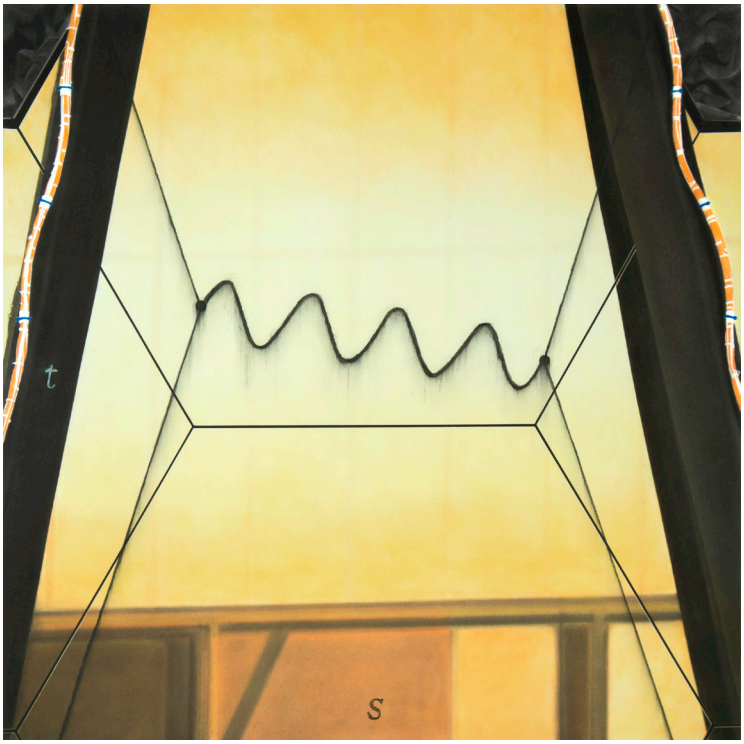
Primary Mirror Reflecting Secondary Mirror
Reflecting Primary Mirror
2019
charcoal and pastel on paper
49 x 49 inches



Central Baffle Detail
2019
charcoal and pastel on paper
49 x 49 inches



JWST Cryo Testing
2019
charcoal, ink, and graphite on paper
49 x 49 inches



JWST vs. QED v. 1
2021
charcoal on digital print
30 x 30 inches
Collection of the National Academy of Sciences

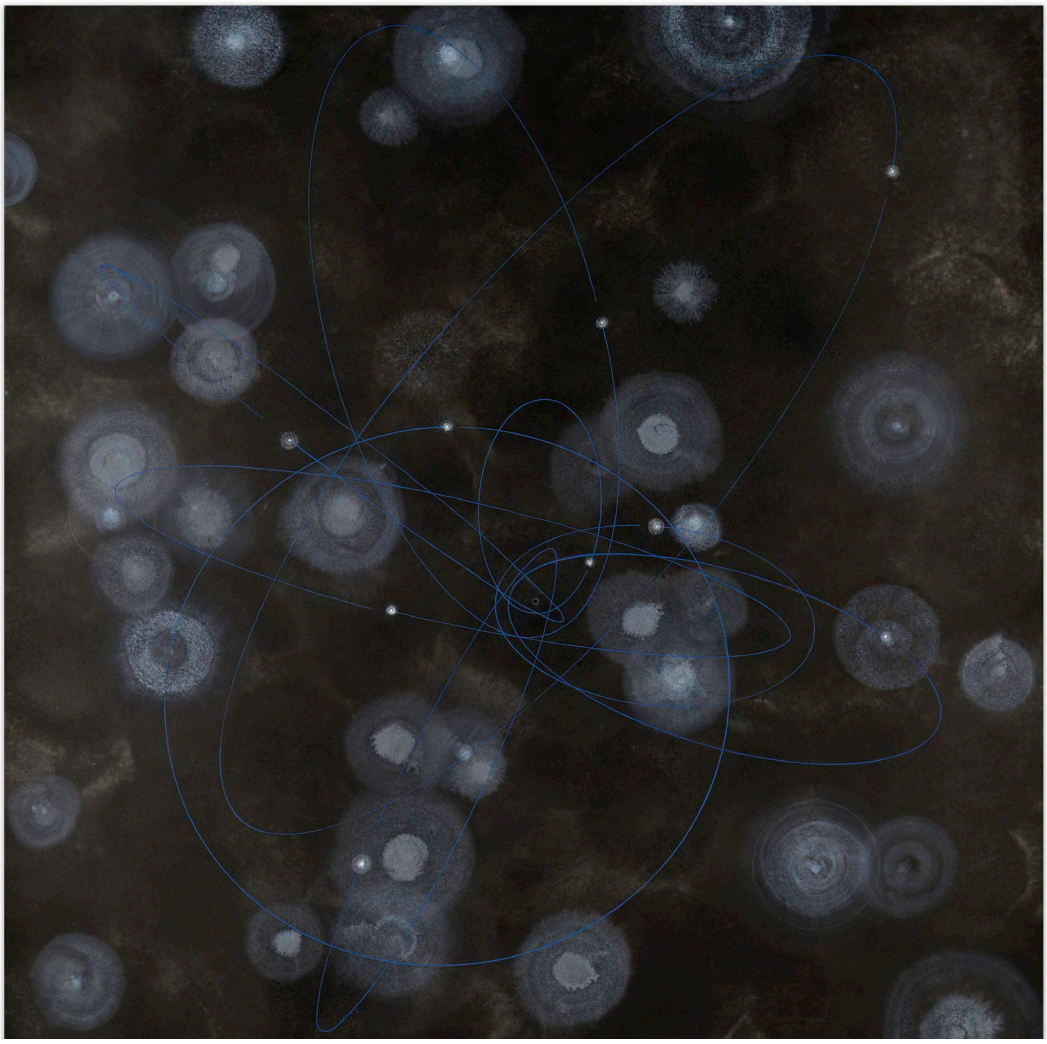
Tim Makepeace's drawings, JWST vs. QED, are about space, time, and light. They are close-up views of the James Webb Space Telescope (JWST) depicting part of the telescope's primary hexagonal gold-plated mirror, with an overlay of a graphic illustration of a Feynman diagram.

This particular diagram is a representation of quantum electrodynamics that describes how an electron can emit a charge-carrying photon, which can be absorbed slightly later, or slightly earlier, by another electron. The wiggly line represents the photon moving to the right, forward in space, after being emitted from an electron. The photon is also moving down in this diagram, indicating that it can travel back in time. Effectively, the photon is absorbed by one electron before it was emitted from the other electron, seemingly violating laws of physics and running backwards in time. This is a difficult aspect of quantum physics that uses retrocausality and quantum entanglement to explain the phenomenon. This theory attempts to show that space and time are effectively interchangeable and are facets of the same thing, depending on one's relative point of view.

JWST vs. QED v. 2
2021
charcoal on digital print
30 x 30 inches

The James Webb Space Telescope can also be seen as a time-machine of sorts; the more distant the objects it images, the further back in time it sees. This is possible because the light emitted by distant objects takes time to reach our eyes. So, what we see has already happened sometime in the past.

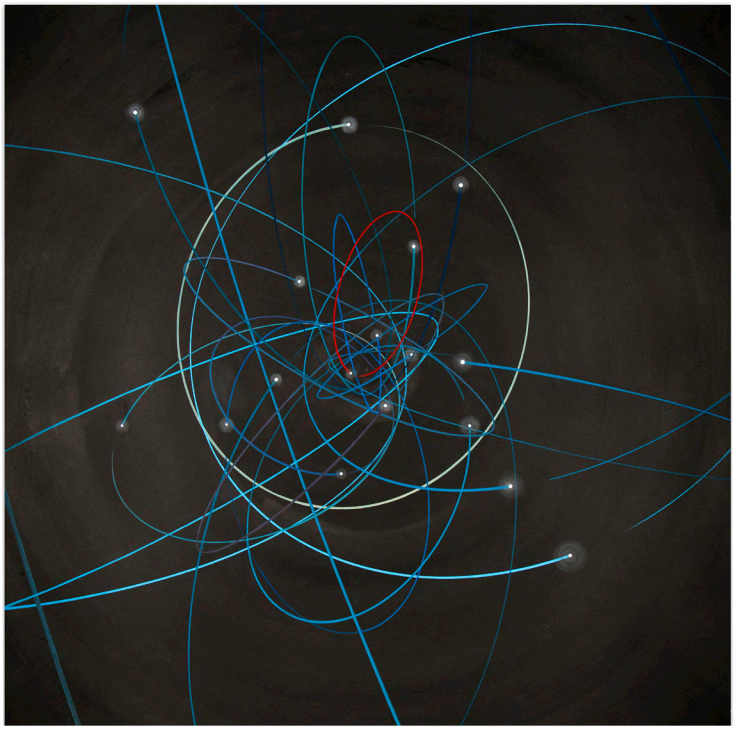
The challenge Makepeace set for this artwork was to juxtapose a rendering of the JWST's large light reflecting mirror (and its ability to see back in time), with a Feynman diagram describing quantum particles and the fluidity of time and our perception of light — the large and the small, the classic and the quantum, and the mutability of time.



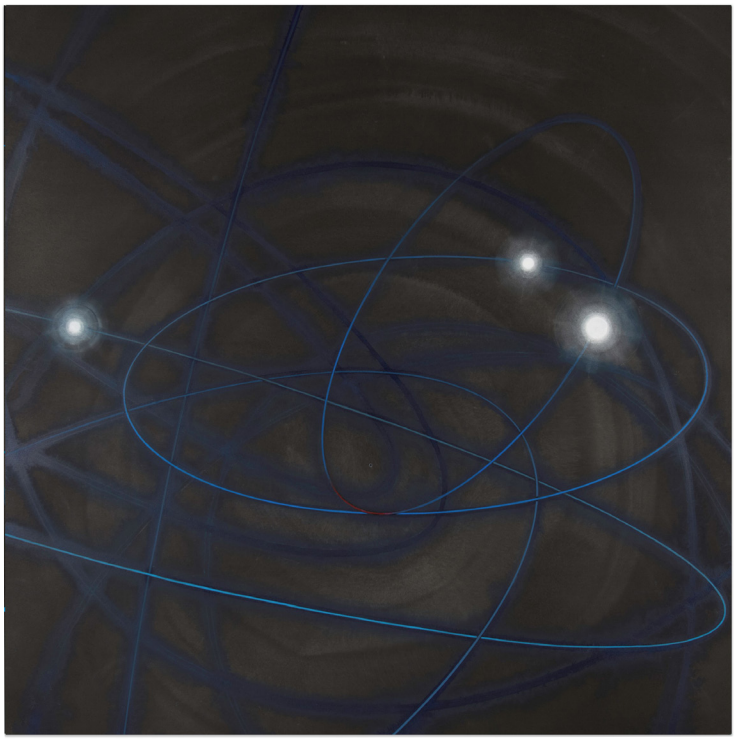
Galactic Center of Mass- 9 stars v.1
2020
acrylic paint and sumi ink on paper
49 x 49 inches
Collection of the National Academy of Sciences

In his *Galactic Center* series, Tim Makepeace has drawn elliptical shapes that represent the paths of the closest stars orbiting the supermassive black hole that resides at the center of our galaxy 26,000 light years away. These works are based on a 3D mathematical model made from the data collected by the UCLA Galactic Center Group over ten years, using the Keck Telescope in Hawaii and the Very Large Telescope facility operated by the European Southern Observatory in the Atacama Desert in Chile.

Although the art that Makepeace creates is data-driven, its quality of abstraction is influenced by Constructivism's vocabulary of geometry, proportion, and optical play. He writes that the *Galactic Center* works are meant to illuminate a fundamental curiosity of mankind: To find order in the cosmos. To know where we are, and in relation to what. Where are we on this Earth? In this solar system? And, where are we in relation to the center of our galaxy, around which we revolve?



Galactic Center of Mass #2, 2019, acrylic paint, sumi ink on paper, 49 x 49 inches



Sag A with 3 Stars*, 2020, acrylic paint, sumi ink on paper, 49 x 49 inches

The Marvelous and the Mundane

Art and the James Webb Space Telescope

The following transcript is derived from a recording for *Issues in Science and Technology*'s podcast The Ongoing Transformation recorded on November 30, 2021. Artist Tim Makepeace was joined in conversation by Anne Collins Goodyear, co-director of the Bowdoin College Museum of Art, Brunswick, Maine. The conversation was facilitated by JD Talasek, director of Cultural Programs of the National Academy of Sciences.

Talasek: Tim and Anne, I'm so glad to have this conversation with you. Tim, your most recent work as an artist has been based upon your interest in the James Webb Space Telescope, which is a highly advanced instrument, developed by NASA, that will allow us to observe parts of the universe that we've never seen before. How did you become interested in the telescope? And what drew you to that as a subject for your art and for inspiration?

Makepeace: Well, I happened to see a call for artists. It was a contest run by Goddard Space Flight Center/ NASA outside of Washington, D.C. They were looking for artists to make artwork about this new telescope. I had never heard anything about it, and the more I looked into it, the more I recognized out how amazing it is, and I thought, well, I've just got to be a part of this. In the end, I was one of a handful of artists who were invited to come to the space center where the telescope was under construction in one of the world's largest "clean rooms." And from there, I made a couple of drawings that were exhibited at Goddard, and then I just kept going with this series of work.

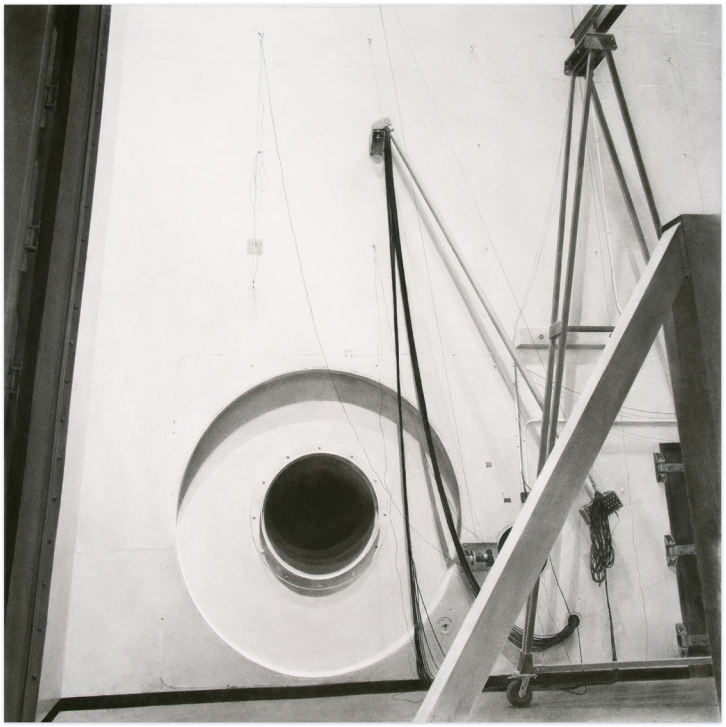
Talasek: Tim, that's fantastic. Thank you. Anne, the relationship of art and technology has long been an interest for you as an art historian. What drew you into this terrain between art and technology as an area of research?

Goodyear: Absolutely, J.D. It's a pleasure to be able to be part of this conversation. As you mentioned, this interest of mine in the interconnection between art, science, and technology is a very deep-seated one. In fact, I recall having done a term paper in high school about Leonardo da Vinci, who, of course, is somebody who is understood as a consummate unifier of art and science. And in many ways, I think the type of curiosity that we associate with Leonardo da Vinci continues to motivate the artists, scientists, and technologists today. Across their work, I see a core principle of creativity that is helping us to see the world and perhaps to see the future in new ways. I like looking at this question through the eyes of an art historian, because visual artists quite literally picture our world, and often distill and pick up on themes the significance of which may not yet be obvious. And that's one of the reasons that I'm so interested in how Tim Makepeace has chosen to show us the James Webb Space Telescope.

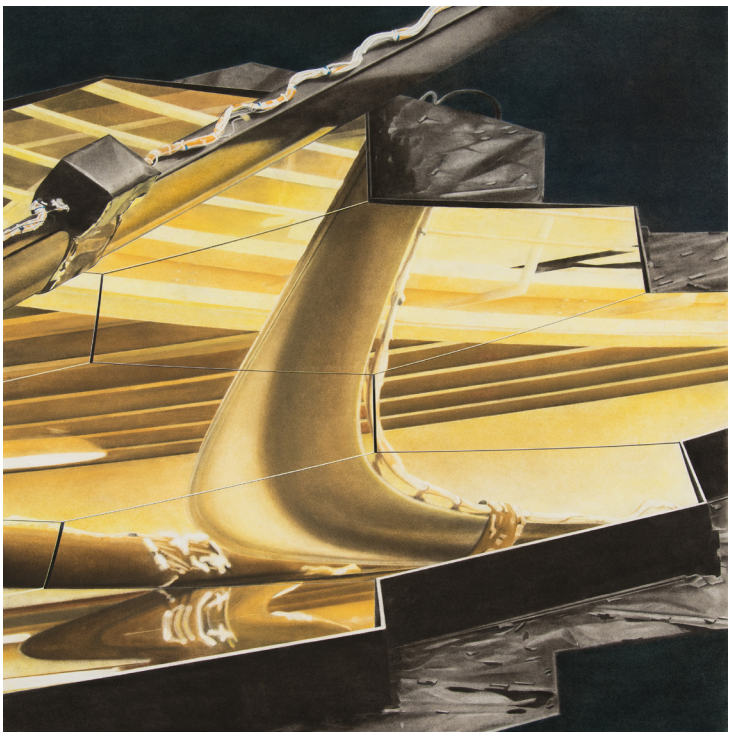
I think it's very special to depict a telescope in the sense that once it is in orbit and in action we will see the images that are gathered by this telescope, but this may be our one opportunity to actually view the instrument itself. So I think it is a very suitable and exciting topic for an artist. But I think it's also an invaluable subject for us as human beings, enabling us to reflect on the instrument that is reflecting back to us the universe that we inhabit.

Talasek: I think that's a really great observation, Anne. Tim, I wonder if we could go back to what you were saying about this large clean room and what it was like being there with the telescope. How did you go about representing it in your work?

Makepeace: Sure. There are two parts. There's the science and then there's the art. The art is always hard to describe. So I'll start with the science – the science of this beast that NASA engineers came up with. They spent over 30 years developing this telescope. Its purpose is, some say, to replace Hubble, and it's going to be much better than Hubble even though the Hubble Telescope



Acoustic Test Chamber, 2018, charcoal on paper, 49 x 49 inches



JWST Recumbant Primary Mirror, 2017, charcoal and pastel on paper, 49 x 49 inches

itself is an amazing instrument. So it's very expensive, very technologically advanced, right on the edge of what is possible. When they first designed the telescope, they didn't even know how to build it. It was so advanced that they had to invent certain technologies just to fabricate it. Every part of this thing is tricky, from the creative design, to how it was fabricated, to where it orbits, and how they get it there.

It's so big, it doesn't even fit in the rocket, so it has to fold. Anytime you have moving parts, you've got complications. And because it's an infrared telescope, it images heat. To image heat, you have to be in a cold environment, you have to have cold instruments, and, by cold, they mean really cold. It's like 40 degrees above Kelvin or minus 400 degrees Fahrenheit. So they have this enormous sunshade the size of a tennis court, and that has to unfold. It's just wild!

I got to see this thing under construction, and I took a lot of photographs of it. And what inspired me was its very abstract quality. I was less interested in an iconic image of a telescope. I wasn't interested in capturing the whole thing and just illustrating it. I was interested in focusing in on tighter elements that highlighted the geometry, the materials and the architectural elements of it. One of the founding principles of modernist architecture is "form follows function." So the forms that I was able to see and focus on all derived from the very specialized functions for which they've invented this machine.

Talasek: These beautiful, large, pastel and charcoal drawings are quite stunning. I would like to talk a little bit about your choice of material. I find it wonderful that you think of charcoal and pastel as early simple forms of imaging technology. To represent such a high-tech, newly engineered piece of technology with something very, very basic, is, in my mind, quite marvelous.

Goodyear: JD, I think the question of medium is really important and interesting, Tim, could you comment further? You are an experienced photographer. And yet you have chosen not to present photographs. You've made a very deliberate decision to interpret photographic material and to make particular choices about what you what you include in an image, how you center an image, and so forth.

For example, there's a beautiful drawing of yours now on view at the National Academy of Sciences titled, "Acoustic Test Chamber." It's stunning visually, and, at the center, is a big, circular element. But it's no accident that you placed that circular element so prominently in this composition. Another thing that I find exciting is your decision to use a square format, a format that evades the traditional use of a horizon line in landscape painting. So you defy some of our expectations about how these images might be intrinsically oriented. I think that's fascinating, given the fact that space is one of the things that you're evoking. JD's point about your use of charcoal—one of the most ancient of human mediums—to depict one of the most sophisticated tools of our era—this telescope—is also quite intriguing.

This becomes even more exciting when we realize that one of the explicit purposes of this telescope is in fact to allow us to peer back into the origins of the universe. Your choice of the medium in and of itself provides this really beautiful connection between history, the present, and perhaps even the future.

Makepeace: The drawing that Anne's referring to is a drawing of the acoustic test chamber, where they tested the telescope for vibrations, higher frequency vibrations. It's just a tool. It's boring in a sense. But I liked it. I'm interested in the working elements and finding beauty in everyday things, and particularly in structural and mechanical things. And so this was a perfect subject. The picture has a large circular tweeter in the center left and then it has a bunch of other structural or gantry-like elements. The net result is a composition of lines and triangles that is very classical. One of the intentions is to glorify the mundane, the work-a-day. And I just love the architectural elements, the geometry, the purity of it, and the Euclidean geometry of it.

This work is an exploration of the relationship between sculpture, photography, and abstraction, finding abstraction in the real world. In the early 1900s, the Russian constructivists were doing something similar. They were glorifying the purity of architecture and design. I'm sort of carrying on that tradition. Not that I was so much inspired by them, but I'm inspired by some of the same sorts of things that inspired them.

It is the combination of the exquisite and the mundane. This telescope is as exquisite an object as you can imagine. And yet I've included in the image reflections of the telescope and some of the structural elements of the room, things that the telescope was not intended to image. JWST is designed to image the infinite, but I liked this composition because it showed the architectural elements of the telescope's terrestrial environment. It's an odd but interesting contrast.

Why did I use charcoal? Why didn't I just leave it as a photograph? Well, whenever you draw something, there's always an element of simplification, amplification, and streamlining. You're able to emphasize the point of the image. You can magnify those elements and reduce others. So that's one reason I draw them.

And then, why charcoal? Why not pencil? Only a fool would use charcoal to try and draw something so precise. Charcoal is much harder to control than pencil. But a pencil is really designed for making lines, and I'm not really interested in that as much. As a photographer, I'm more interested in tones, and particularly black and white tones. And so I like charcoal because you can smudge it, smear it, and achieve graded tones very easily. The same goes for pastel when I need to add color. It's sort of inherent in the medium of charcoal to get tones from black to dark gray just by smearing it. The trick is to control it. And there's also the idea that people have been using charcoal to describe their environment for thousands of years. So here I am describing one of the most advanced feats in engineering with one of the most primitive mediums. So that's kind of fun too.

Goodyear: I love hearing you talk specifically about what it means to depict a mirror. Some of the greatest works of art are both literally and visually connected with the mirror. One thinks about Narcissus, for example, and about the origins of self-portraiture. Jan van Eyck, Parmigianino, and Velázquez immediately come to mind. I think the presence of the mirror has been an important one in the visual arts because it seems to provide an affirmation of the presence of the artist or the viewer in a particular place and time. This is to say that it provides an affirmation of the reality of the image itself. So, as you picture this extraordinary new instrument, charged with picturing new realities for its human audience, I love the fact that you depict this extraordinarily fine-tuned mirror and include some reflections of human presence in doing so. It's like you're once again connecting this incredible new technology with a deeper history of human aspirations and affirming for us the very reality of this somewhat mind-boggling instrument.

As I reflect--if you'll pardon the pun—on what you are doing in providing a human perspective on this remarkable tool of space exploration, I find it exciting as an art historian who has looked at the history of the emergence of the NASA art program in the 1960s that we are talking about a telescope that is named for James Webb, the second Administrator of NASA. James Webb was the initiator of the NASA art program in 1962, almost exactly sixty years ago. I think Webb recognized, as did some of his contemporaries, the important ways in which artists could capture the sense of wonder implicit in the technology of space exploration.

It is exciting to imagine what it will be like to see those first images that come back from the Webb telescope. Tim, I love that you've given us an opportunity to think about that instrument as an object in itself engineered and manufactured by other creative individuals. When we see those pictures for the first time your work will serve as a reminder that it's not a divine force that's sending these images back to us—it's an apparatus made by human beings. And of course, along with being human comes the mundane, and we hope, from time to time, also the marvelous. I just love the way in which, through the drawings you've created, you do help us to be mindful of those juxtapositions.

Makepeace: Part of the excitement I felt when I first saw the telescope was knowing that I was standing 30 feet from something that would soon will be a million miles from Earth for eternity. And for a very brief moment in time it was available to see here on Earth. It was very special to be a part of that. I found that acute awareness of this moment in time to be super inspirational.

Goodyear: I wonder if I could ask you to expand on your comment about this moment in time, Tim. One of the explicit aspirations of the telescope, according to NASA, is to observe a part of space and time never seen before. I know that this relationship between space and time is of special interest to you.

Makepeace: Sure. I made a few drawings in a series I called the JWST vs. QED. QED stands for quantum electrodynamics. It's a little bit of a stretch, but the telescope itself is, in a way, a time machine. And by that, I mean, when you image anything with your eye or the camera, you are seeing light that is scattered off an object at some distance. And the further that distance is from you, the longer it takes for the scattered light to reach your eye. So the further out you look, the older that light is.

When you are able to look deep into space, like with the JWST, you're also looking deep into time. Scientists want to use this telescope to look at the very edge of the visible universe, which is somewhere between 13.5 and 13.9 billion light years away. So you're not just seeing something that's very far away, you're also seeing something that happened a very long time ago. This is the macro, or classical, way of describing how light scatters and travels.

In the JWST vs QED series, I juxtapose the telescope with a Feynman diagram. Richard Feynman was a Nobel Prize winning physicist who contributed to the development of quantum electrodynamics, explaining how fundamental particles interact with each other at the micro, or quantum, level. He was able to describe this very complicated thing with simple line drawings which showed electrons traveling through space and time as straight arrows, and photons traveling along as wiggly curvy lines. These kind of diagrams describe how light scatters, at a fundamental level, which is of interest to any visual artist who uses their eyes. And that was his genius. He was able to take extremely complicated ideas and simplify them so that most people could readily understand them. I always liked that idea, and I liked the graphic simplicity of the diagrams.
I had taken a photograph of a detail of the telescope's primary mirror that happen to resemble a bowtie shape. And that shape reminded me of a similarly shaped Feynman diagram. But I didn't know how to incorporate these two disparate ideas. I kept thinking about it and then eventually came up with these compositions where I placed the Feynman diagrams on top of the drawing that I had made based on that photograph. There were two reasons for doing this. One was the graphic and compositional similarity. But the other was that his diagrams illuminate the mutability of time and space, by showing it could be mathematically possible for particles to go backwards in time. Scientists don't really think time goes backward, but the math works that way. The drawings in this series combine these two ways of looking at time, at the universal level and at the quantum level.

Goodyear: And as we think about that interrelationship between time and space, Tim, we are reminded that the JWST itself functions as a sort of time machine—as you have put it— in terms of its vast voyage to compile images that will help us to peer—literally and figuratively—far back in time towards the origins of the universe. So your drawing puts into dialogue the magnitude of space travel with the quantum dynamics of particle physics. It's a dizzying but fascinating comparison. Another thing that I love, Tim, about your description of the JWST vs. QED drawings is that it brings to mind a parallel between the conventions of mathematics and art making. Both art and math provide us with systems of representation to describe the world around us. But, at the same time, these might introduce their own blind spots. Perhaps any such shortcomings will in turn provide the impetus for future generations to pierce the boundaries of these systems of representation to see still further. These are just some of the really interesting philosophical implications that I see rising out of the ways in which you have pictured the telescope itself.

Talasek: And going back to the purpose of the Cultural Programs at National Academy of Sciences, maybe scientists and others had thought in some of these ways about the telescope before, maybe not. But there's a chance that this is of interest to someone who studies this field. And ideally, I've brought something to the scientific community through art that has real intellectual value.

Goodyear: You know, it's interesting, when the NASA art program was developed back in the early 60s, thanks to James Webb, the goal really was to go above and beyond the mere mechanical photographic documentation of advancements in space technology. Webb recognized that artists would respond to those achievements that captivated their imagination. What does it mean to float a telescope millions of miles

above us? This is a question that Tim Makepeace takes on through his drawings. And, in so doing, Tim's work promises to transmit something of the spirit behind our technological and scientific innovations and in turn to further stimulate that passion, that curiosity, in other creative visionaries.

Makepeace: The way that artists look at it, one of the goals is to animate these achievements and to humanize them. Because it makes it more personal, like this is something that you could touch.

Tim Makepeace leading a tour of his exhibition at the National Academy of Sciences, December 2021. Photo by James Wisnieski.