contents

departments

navigation tips

- To go directly to an article from here, click on its title.
- Within each article click on the underlined text for additional resources.
- To visit one of our advertisers, click on their website URL.
- On your computer, navigate from page to page, go back to the table of contents, or toggle the full-screen version by clicking the buttons at the bottom of each page. (These buttons are not available on tablets.)

on the cover

Front: The stars in the Trapezium cluster glow in this infrared view, a composite of 81 images. The Very Large Telescope in Chile captured these images of the center of the Orion Nebula, and the James Webb Space Telescope will do the same. *[ESO/M.McCaughrean, et al. (AIP)]*

Back: The Ukrainians call it *Bily slon* (Білий слон). In English, it translates to "White Elephant." The University of Warsaw built it in the 1940s, and the Polish named it *Biały Słoń*. By the time the USSR claimed the land after World War II, all the valuable pieces of the instruments inside were gone and the building was essentially abandoned. It is on Ukrainian land, and efforts have been made to resurrect it as an astronomical observatory. You can find more information here and here. *[Taras Dut/Wikimedia Commons]*

From Waiting to Wonder

A much-delayed telescope is finally in space. Now it's time to reveal a new view of the universe .

By Steve Murray

The James Webb Space Telescope, illustrated here among the stars, will begin observations this summer. *[Northrop Grumman]*

After 25 years of development, including 10 years of launch delays, the James Webb Space Telescope is now on station with its mirror open and its operational checks underway. The Christmas launch of the telescope was a long-awaited gift to science, one that will be opened later in 2022 to yield our deepest views into the cosmos. Astronomers are gearing up for a new era of discovery.

A monumental mirror

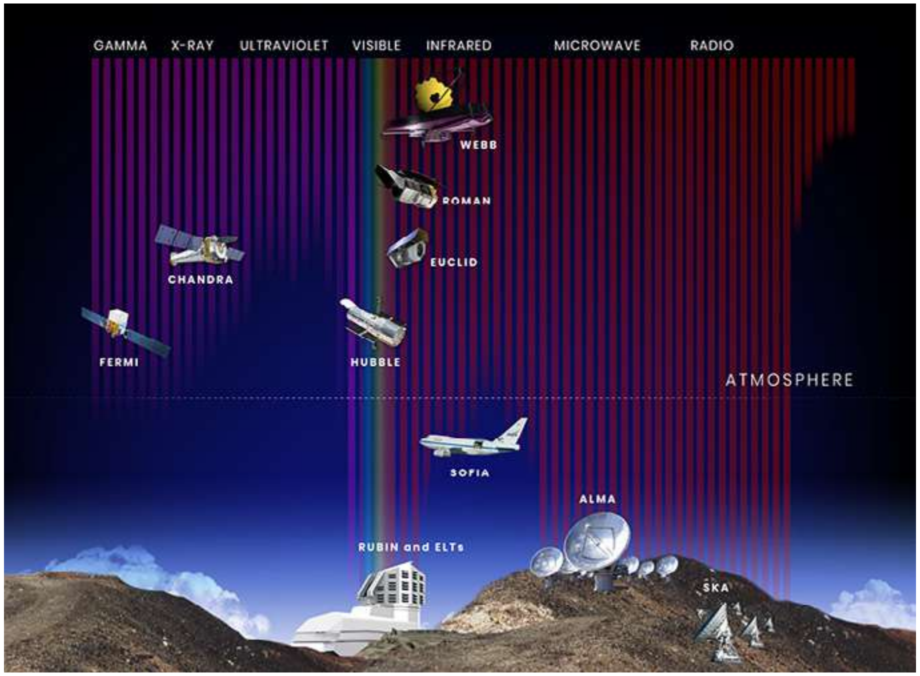
Webb's primary mirror is the biggest ever put into space, and its deployment was the most complex ever attempted. With over 6 times the collecting area of Hubble, Webb's 21-feet-wide (6.5 meters) mirror can detect objects up to 100 times fainter, and search for some of the oldest objects in the universe.

"The primary driver [for Webb's design] was the search for the first stars and galaxies after the Big Bang," says Eric Smith, the Program Scientist for the James Webb Space Telescope Program at NASA Headquarters. The older an astronomical object is, the faster it recedes and the farther its emitted light is stretched toward the red end of the spectrum. To see those first stars and galaxies, astronomers must detect redder-than-red light. "So Webb is an infrared telescope."

Design requirements for Webb were based on experience with previous space telescopes, says Smith. "In particular, the Hubble Space Telescope deep field images told us something about the wave band we wanted to look at and the size of the mirror we needed.

"Still," he adds, "the core science requirements were codified in the early 2000s, so we had to invent some things to make Webb possible."

Webb will operate about a million miles (1.5 million kilometers) from Earth in a halo pattern around Lagrange Point L2, where gravity from the Sun and Earth balance the centripetal force needed for the telescope to move with them through space. This will reduce the fuel required to maintain Webb's position during its mission lifetime.



Because Earth's atmosphere blocks much of the infrared part of the spectrum, the telescopes that capture it, like the James Webb Space Telescope, must go to space to do so. *[NASA/STScI]*

Webb's orbit will also keep it positioned with its five-layer sunshield facing the Sun, Earth, and the Moon, protecting its sensitive instruments from damaging sources of heat. Part of its post-launch preparation time is needed to lower the mirror's temperature below –370° F (–223° C), which will amplify its infrared sensitivity. Once in operation, temperatures on its Sun-facing side can reach 600 degrees higher.

With a price tag of $10 billion, Webb is the most expensive space telescope in history. According to NASA, about 40 million hours went into its construction. But if budgeteers had reservations during its development, scientists didn't.

"It gives us the broadest view of the universe that we've ever had," says Mercedes López-Morales, an astrophysicist with the Smithsonian

Astrophysical Observatory at the Center for Astrophysics | Harvard & Smithsonian (CfA).

"This isn't just a NASA effort," adds Néstor Espinoza, an Assistant Astronomer at the Space Telescope Science Institute (STScI). "It wouldn't be the big mission that it is without international partners." In fact, Webb is a collaboration between NASA, the European Space Agency (ESA), the Canadian Space Agency (CSA), and several industry participants. STScI serves as the science and operations center for the Webb mission.

A high-tech toolbox

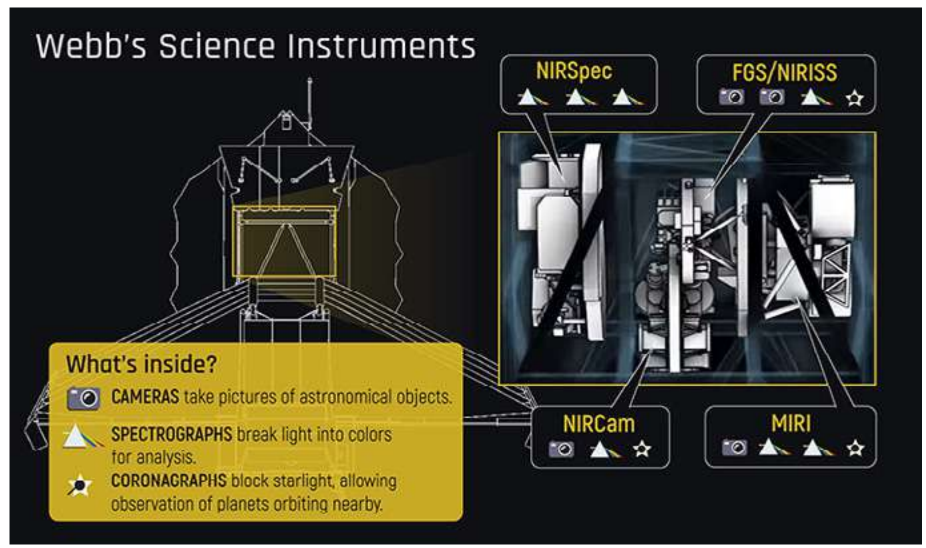
The Webb telescope carries four major instruments, housed in the Integrated Science Instrument Module (ISIM) behind the primary mirror. "Each opens a new window to do things that we couldn't do before," says López-Morales. "Every single one of them is going to yield major breakthroughs."

Webb's primary imager is the Near-Infrared Camera (NIRCam). Like all of the instruments, NIRCam is equipped with a spectrograph, as well as coronagraphs to study faint objects that orbit around much brighter stars by blocking the star's light.

The Webb Near-Infrared Imager and Slitless Spectrograph (NIRISS) covers the same 0.6 to 5 micron band as NIRCam but, because it can perform aperture mask interferometry, it can image bright objects at higher resolution. The camera-based Fine Guidance Sensor (FGS) that provides stable pointing for all telescope observations is housed together with NIRISS.

Imaging and spectroscopy at longer wavelengths are handled by the Mid-Infrared Instrument (MIRI), which can operate across a wider wavelength range than NIRCam and NIRISS. Its longer 5-to-28-micron detection band makes it the most effective instrument for studying cooler objects such as distant galaxies and stars,

A five-layer sunshield — where each layer spans the length of a tennis court but with a thickness less than 1/10 a millimeter — protects the sensitive instruments from external heat. *[NASA/Chris Gunn]*



The telescope's four science instruments sit behind the primary mirror and in what's called the Integrated Science Instrument Module. *[NASA/STScI]* as well as comets and Kuiper belt objects. To achieve that performance, however, MIRI needs to be kept at about 12° F (7° C) above absolute zero, even colder than the other Webb detectors. Like NIRCam, MIRI is also equipped with coronagraphs.

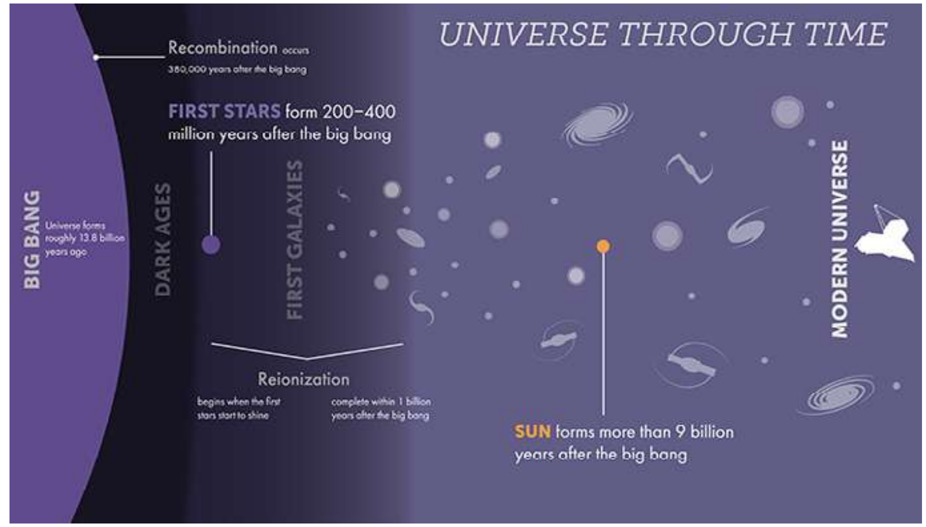
The Near-Infrared Spectrograph (NIRSpec) completes the telescope's suite. It is the first space instrument that can perform spectroscopy on up to 100 objects simultaneously. This unique capability is owed to a microshutter array of over 248,000 tiny doors, each smaller than a human hair, which can be individually controlled to admit or block light. This dramatically boosts NIRSpec's measurement efficiency, especially for very distant and faint objects.

Lou Strolger is the Deputy Head of the Instruments Division and Observatory Scientist at STScI. His job is to know the technologies aboard the Webb, and to ensure their calibration and maintenance. "Each instrument presented its own technological challenges," says Strolger, "but I would say that NIRSpec is by far the most challenging, because of its microshutter array. That's the one we have our fingers crossed for. It's complex and ambitious, just like the rest of the observatory, but I think we're all ready for it."

The red-shifted cosmos

The Webb telescope will gather light from stars and galaxies that formed more than 13.5 billion years ago, in a cosmic era known as the Epoch of Reionization, when the universe was less than five percent of its current age.

These early stars were formed with only hydrogen and helium as raw materials. "Those are pristine conditions," says Stolger. "They're radically different from younger generations of stars." And when many end their lives as supernovas, they create new types of atomic nuclei. "Such objects can tell astronomers how processed matter was



Infrared vision and a large primary mirror are crucial factors that enable the James Webb Space Telescope to detect the earliest stars and galaxies. *[STScI]*

spread into the universe," he adds. "They'd likely be most luminous explosions in the universe since the Big Bang."

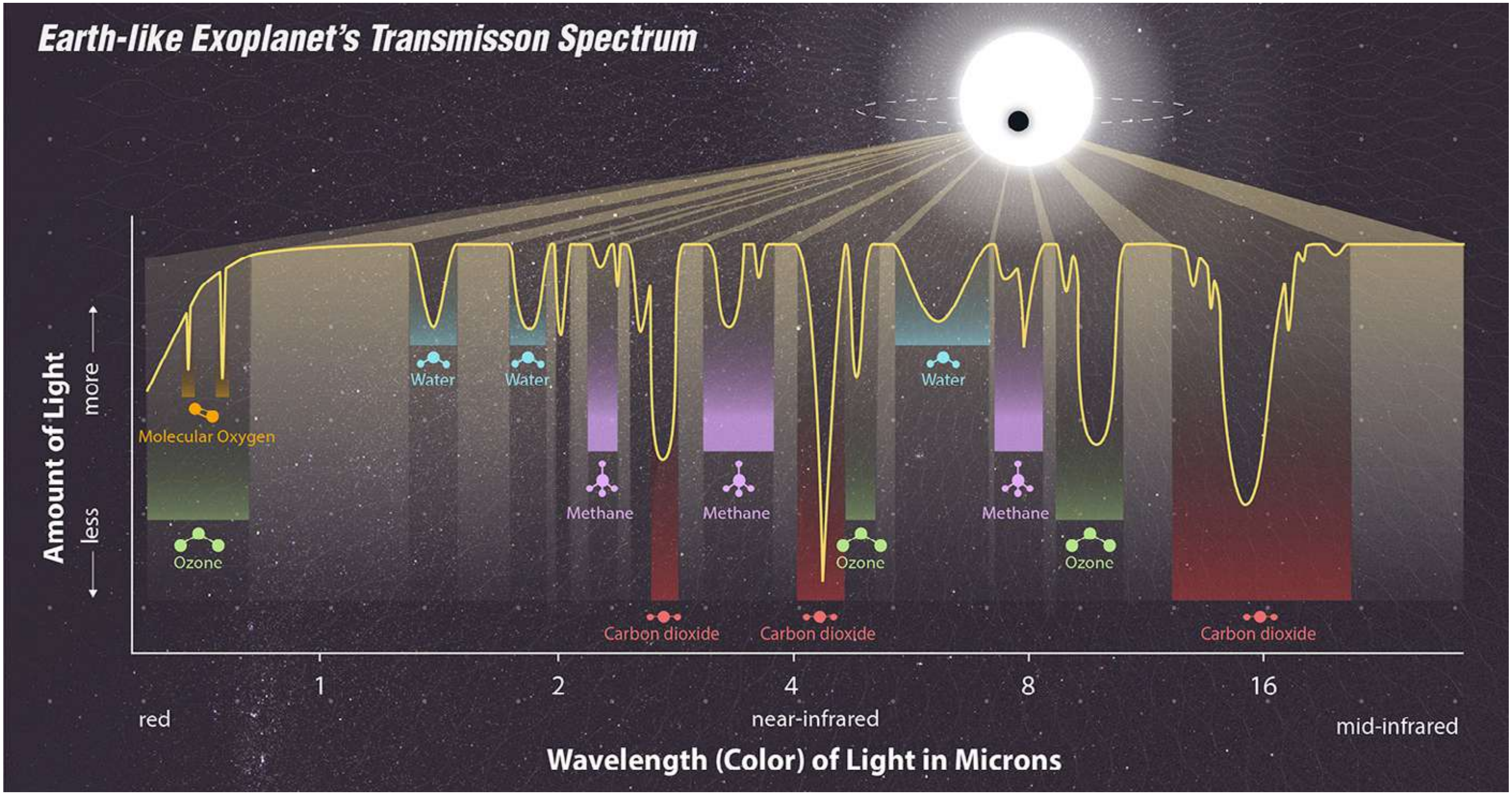
Reaching so far back in the history of the universe makes the Webb a cosmic time machine, as astronomers can view younger objects at closer ranges as well. "If you can see the first galaxies" says Smith, "you can also see every stage of galactic evolution in between those first ones and today, [and] watch galaxies and structures evolve over time."

Exoplanet excitement

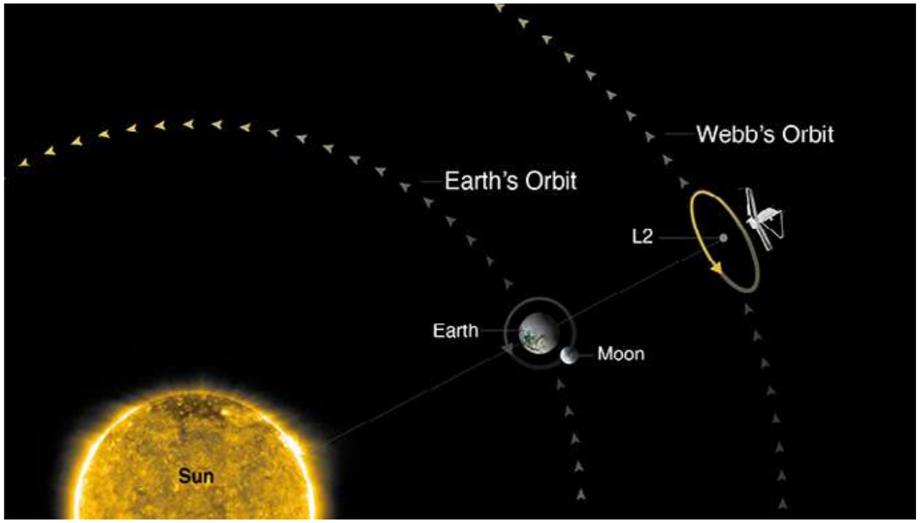
Webb instruments will also examine the physical and chemical characteristics of planetary systems using coronagraphs and transit spectroscopy, which makes it a premier instrument for the study of exoplanets. "It's miraculous," says Smith, "when you consider that when we began to design Webb, we really didn't know anything about exoplanets. The fact that we're using it for exoplanet observations is a credit to just how capable the telescope is."

Webb is sure to reveal new populations of exoplanets around other stars in the Milky Way, gathering light measurements to understand planet formation, evolution, and habitability.

"This is going to be a real revolution," says Espinoza. "We're only 20 years into this field [of exoplanet atmospheres] and we're just scratching the surface of what they're all about." Measures of atmosphere components for large exoplanets are highly uncertain, and detection of small-planet atmospheres has been out of reach with existing tools. "All that will change with Webb," he adds. Precise data would help refine models of planet formation. "Five years from now, we'll look back at our questions and think about them in whole new dimensions. We're going to find things that we're not even thinking about today."



The Webb telescope will be able to capture filtered starlight that passes through an extrasolar planet's atmosphere to learn about the atmosphere's chemical makeup. *[NASA/ESA/CSA/STScI/Joseph Olmsted (STScI)]*



To lessen the heat from the Sun and Earth, the James Webb Space Telescope is about a million miles (1.5 million kilometers) away, in a halo orbit around the second Lagrangian point. *[STScI]*

And it's then only a short scientific leap to using Webb to characterize more local objects like planets, moons, asteroids, and comets, which can be compared with other places in our galaxy to better establish how common or rare our own solar system is.

Observations out of the gate

Webb will provide 6,000 hours of initial General Observing (GO) time beginning this summer, after instrument testing is completed. Over a thousand proposals were winnowed down to 287 projects for this first round, most of them focused on early galaxies and exoplanets. Both Espinoza and López-Morales made the cut. "It's very exciting to be in the front row," says Espinoza. "It's setting the legacy from day one of year one."

Among other activities, these astronomers are collaborating on two projects to study super-Earths and hot-Jupiters. "Super-Earths are actually the most abundant type of planet discovered by Kepler," López-Morales notes of NASA's former exoplanet-hunting space telescope, "but we don't have them in our solar system, and we don't really know how they work."

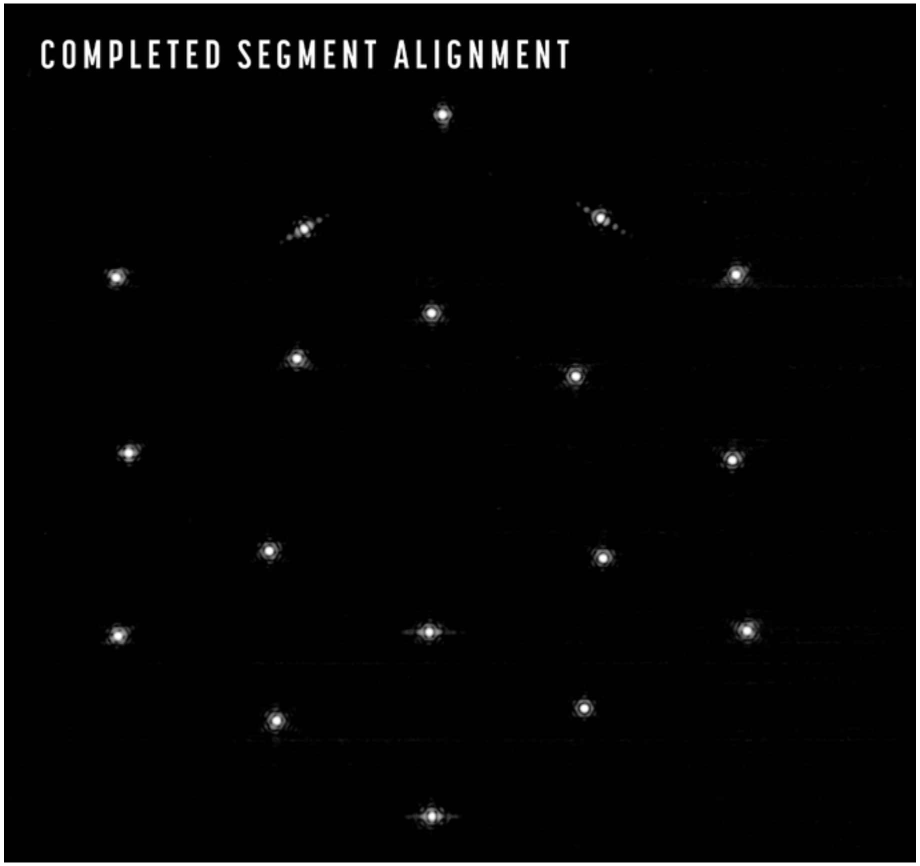
They'll also be applying new methods for examining hot-Jupiters with the new technologies that Webb affords. "We're trying to measure different sides of an exoplanet atmosphere," says Espinoza. "The composition from morning and evening limbs should be really different."

Like many other space missions, the Webb program also provides Director's Discretionary (DD) observing time for selected projects that tackle a unique objective. The Webb DD program, however, provides an innovative feature of 500 hours for Early Release Science — projects that will take place in the first 5 months of telescope operation — with data to be released immediately. "The purpose is to create some public data sets in the first year that the community can practice with," says Smith. New surprises could emerge from creative studies of this information. "Somebody could come along and say, 'Hey, I'm going to use those same data to do something completely different.'"

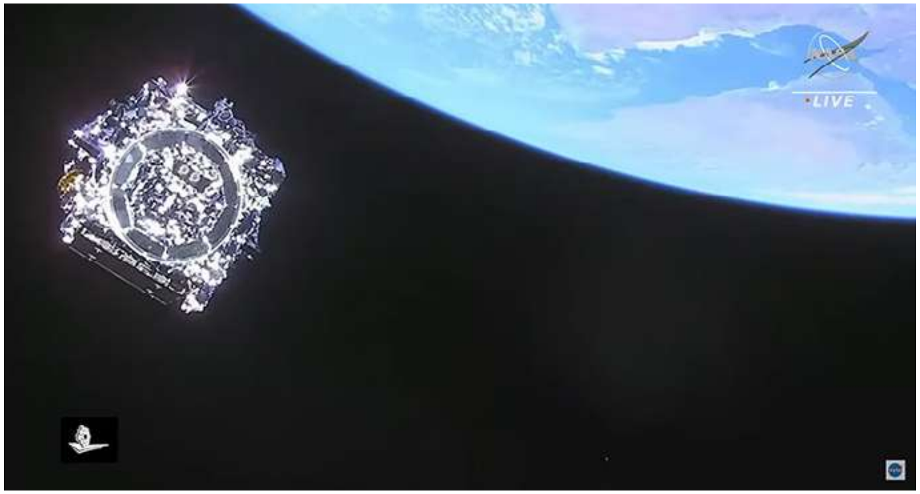
A space fleet for science

The Webb telescope was originally planned to have a 5-year mission duration, but good breaks during the launch to L2 could extend that out significantly. "The precision with which Ariane [5 rocket] put Webb on orbit was absolutely phenomenal," says Espinoza. Some program managers at a post-launch NASA town hall meeting were hinting at a mission length of over 20 years. "It was a great New Year's present for us to hear that," adds Espinoza. "The attendees were all jumping up and down." A firm estimate, of course, will have to wait until all commissioning steps are complete, but engineers are optimistic.

The data gleaned with Webb will be stored at the Mikulski Archive for Space Telescopes (MAST), available online to astronomers and the public. The archive, maintained at STScI, already hosts data from more than a dozen missions like Hubble, Kepler, and the Transiting ExoPlanet Survey Satellite (TESS). And if Hubble continues to operate, the combined missions of Webb and Hubble could overlap with the planned 2027 launch of the Nancy Grace Roman Space Telescope, designed to generate the first wide-field, high-resolution maps of the universe from space.



Scientists and engineers are aligning the 18 segments that make up the James Webb Space Telescope's primary mirror. This image shows the same star in each of the segments; next up is to make smaller corrections to the alignment. *[NASA/STScI/J. DePasquale]*



The successful launch on Christmas day was a gift to astronomers across the globe. *[NASA/ESA]*

"That would be a great suite of observatories," notes Strolger. "Those instruments would enable discoveries through a panchromatic set of windows."

And that would give astronomers a lot to do. "We need to make sure that we have everybody available to get into all that data," he adds. "We have a lot of exciting projects on the horizon that require tremendous technical skill, and we're going to need a tremendous workforce to see that through."

The first results from Webb could be just months away, and they'll establish a foundation for new ways of understanding the universe that future astronomers will build upon. "Science isn't a sprint," says López-Morales, "it's a marathon.

"I tell my youngest grad students that I'm jealous of them."★

STEVE MURRAY is a freelance science writer & NASA Solar System Ambassador. A former research engineer, he follows developments in astronomy, space science, & aviation. His Winter 2021 *Mercury* story, about human spaceflight, won a local journalism award.