2022 BREAKTHROUGH OF THE YEAR

GOLDEN EYE

A new space telescope makes a spectacular debut after a troubled gestation

By **Daniel Clery**

On 11 July, in a live broadcast from the White House, U.S. President Joe Biden unveiled the first image from what he called a "miraculous" new space telescope. Along with millions of people around the world, he marveled at a crush of thousands of galaxies, some seen as they were 13 billion years ago. "It's hard to even fathom," Biden said.

Not many telescopes get introduced by the president, but JWST, the gold-plated wunderkind of astronomy built by NASA with the help of the European and Canadian space agencies, deserves that honor. It is the most complex science mission ever put into space and at $10 billion the most expensive. And it did not come easy. Its construction on Earth took 20 years and faced multiple setbacks. New perils came during the telescope's monthlong, 1.5-million-kilometer journey into space, as its giant sunshield unfurled and its golden mirror blossomed. Engineers ticked off a total of 344 critical steps—any one of which could have doomed the mission had they gone wrong.

The first data and images beamed back to Earth by JWST suggest it was all worthwhile. They are "beautiful" and "mind-blowing," according to astronomers who have spoken with *Science*. It was like putting on infrared glasses, one said, and seeing the universe anew.

Because of the controversy surrounding the telescope's name (see p. 1145), *Science* now refers to it as JWST.

But those images only hint at what is to come. With the largest mirror ever flown in space and a suite of instruments sensitive to infrared light, JWST will peer further into the past than any predecessor, including the much smaller Hubble Space Telescope. It can reveal exquisite detail in closer objects and parse the atmospheres of alien worlds. Although papers started to pop up on preprint servers such as arXiv within days of data being released, firm results are still scarce. But few doubt the telescope will revolutionize our picture of the cosmos, and so we name JWST *Science*'s 2022 Breakthrough of the Year.

Space telescopes see the universe undistorted by Earth's atmosphere, whose shifting air causes stars to scintillate, or twinkle, and whose gas molecules block many wavelengths entirely, including much of the in-

IMAGE: NASA; ESA; CSA; STSCI; JOSEPH DEPASQUALE, ALYSSA PAGAN, AND ANTON M. KOEKEMOER/STSCI

JWST captures the birth of a star, only visible in the infrared light the telescope is designed to capture. (The image has been recolored.)

frared. The Hubble telescope showed the immense power of a mirror in space. Its data have fueled more than 22,000 papers.

But even before Hubble got off the ground in 1990, astronomers began to plan its successor. Next time, they wanted a telescope with infrared eyes. The earliest stars and galaxies in the universe, hot and newly formed, shine brightest at ultraviolet and visible wavelengths. But in the billions of years it took that light to travel across space to reach Earth, the universe itself expanded, stretching the light to longer—infrared—wavelengths. As a result, infrared light provides the best view of those early times.

Astronomers also wanted to capture enough light from the far reaches of the universe to separate it out into a spectrum of its constituent colors, which reveal what an object is made of and how it's moving. The spectrum of starlight passing through the atmosphere of an exoplanet, for example, carries the fingerprints of gases in the planet's atmosphere and hints as to whether conditions are favorable to life.

To do all that, astronomers drew up plans for a telescope with a huge mirror—JWST's is 6.5 meters across, nearly three times the width of Hubble's. That was too big to fit inside a rocket, so it had to be able to fold up for launch. Another challenge was keeping the whole telescope cold, to prevent its own warm glow from spoiling the infrared observations. So engineers devised an unfolding multilayered sunshield to keep it at an icy –233°C and a mechanical cryocooler to chill one instrument to –266°C. They also chose to make the mirror from toxic beryllium, rather than the usual glass, because it is light and performs better in the extreme cold.

The expense and complexity of these innovations nearly doomed the mission. Delays and costs mounted, leading the U.S. Congress to threaten the project with cancellation in 2011. Astronomers lobbied hard for JWST's survival, however, and lawmakers relented, setting a firm deadline and cost ceiling. NASA kept to those limits, for a while.

All those travails were forgotten on 25 December 2021 when a European Ariane 5 rocket deposited JWST in space. The telescope opened its solar arrays, and set off for a gravitational balance point far from the noise and warmth of the Sun and Earth. Over the next several months, engineers and astronomers watched nervously as the tennis court–size sunshield unfurled, mirror sections swung into place, and starlight passed through its instruments for the first time.

JWST began to collect data for scientists on 21 June, and NASA released the first images and spectra on 12 July. Within days researchers began to find galaxies more distant than any previously documented. Hubble's deepest images took more than 100 hours of observing, and the most distant galaxy it found was shining when the universe was just 3% of its current age of 13.8 billion years. But in just a dozen hours, JWST revealed a galaxy that pushed the record back another 50 million years and another galaxy possibly 100 million years earlier still. These ages are rough estimates and are only now beginning to be confirmed, but they show JWST can peer deep into the universe's galactic nursery.

Already, that nursery is looking crowded. JWST's initial glimpses revealed many more galaxies than researchers expected, shining more brightly. Broader surveys are now underway to see whether the crowding is an anomaly—a localized cluster of galaxies—or an artifact due to a telescope calibration issue or more recent galaxies shrouded in dust that reddens them and makes them look older. But if JWST shows that this era, soon after the universe's birth, is as bustling and bright as it appears, theorists will have to rewrite their accounts of the universe's early history to explain how so many galaxies could form so fast.

In September, JWST gave another taste of things to come when it focused on a planet orbiting another star, a young giant seven times the mass of Jupiter called HIP 65426 b. Most exoplanets are lost in the overwhelming brightness of the parent star, and only about 20 have been caught on camera to date. But by using an optical mask to block out the star's glare, JWST imaged HIP 65426 b at four different wavelengths. Capturing the planet's own glow will provide important clues to how planetary systems form. With JWST's sharp vision, researchers are looking forward to imaging smaller exoplanets, down to the size of Saturn or even Neptune.

And last month, the telescope captured the spectrum of starlight that filtered through an exoplanet's atmosphere—an extremely challenging task for other telescopes. The spectrum showed that WASP-39 b, a Saturn-mass planet orbiting close to a star 700 light-years from Earth, is shrouded by gases including water vapor, sodium, potassium, and carbon monoxide, as well as patchy clouds.

Earlier observations had hinted at some of these gases, but JWST picked up two others never previously detected around an exoplanet: carbon dioxide and sulfur dioxide. The sulfur dioxide signature was so strong that astronomers concluded ultraviolet light from the star is driving the formation of the gas, in the same way the Sun creates ozone in our atmosphere. It's the first evidence of photochemistry around an exoplanet and hints that as JWST continues to probe exoplanet atmospheres, it will deliver new surprises about these alien worlds.

As data continue to pour in from JWST and thousands of astronomers around the world work to mold them into concrete results, the pace of discoveries will accelerate. And they should keep coming for a good while. JWST's journey used far less fuel than expected, so the telescope has enough to hold it steady at its celestial vantage point well into the 2040s. For those riding the first wave, it's a time of wonders. As one astronomer said: "Every day I open up arXiv and there are fireworks in there." ■

S **VIDEO AND PODCAST**
Interviews with JWST scientists and more: science.org/boty2022