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News & Highlights

# Webb Space Telescope Hits Its Stride, Dazzling Astronomers

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The James Webb Space Telescope (JWST), which cleared a slew of complex technical hurdles and became operational over 2021, has awed and surprised astronomers (Figs. 1 and 2). "We are able to see things we had not imagined we would see," said Christopher Willmer, associate research professor at the University of Arizona Steward Observatory in Tucson, AZ, USA, who has worked on the project since 2007.

In just its first few months of observations, the telescope revealed an unexpectedly large number of early galaxies, a discovery that may challenge current understanding about their formation [1,2]. It detected the first signs of chemical reactions driven by starlight in the atmosphere of a planet outside the solar system [3]. And it homed in on what may be some of the earliest stars in the universe [4].

Although the Hubble Space Telescope (HST), launched in 1990, provided a much more detailed view of the universe than previous instruments, JWST "is a step beyond Hubble or anything else," said Garth Illingworth, professor of astronomy and astrophysics at the University of California in Santa Cruz, CA, USA (Fig. 3). Illingworth was part of the team that initially proposed a space-based infrared telescope in the late 1980s, an idea that evolved into JWST [5,6].

The 25 December 2021 launch of the Ariane rocket carrying JWST came as a huge relief for astronomers [6]. The 10 billion USD infrared telescope was finally on its way into space after more than 30 years of planning, design, construction, and delays [6,7]. Still, scientists agonized through "50 days of terror" before knowing whether the telescope worked, said Michael Meyer, professor of astronomy at the University of Michigan in Ann Arbor, MI, USA, who helped design two of JWST's instruments. During that period, JWST had to complete a complex choreography that included steering to its orbital location $1.5 \times 10^7$ km from Earth, unfolding and locking into position the 18 segments of its 6.5 m diameter main mirror, and unfurling its sunshield, a flimsy-looking stack of reflective sheets pulled into position by 8 motors, 90 cables, and some 400 pulleys [8–10]. Any of 344 potential single-point failures could have crippled the telescope during deployment [11].

A triumph of engineering, the now fully operational space telescope probes the universe with four instruments [12]. The near-infrared camera (NIRCam) captures wavelengths between 0.6 and 5.0 μm. The mid-infrared instrument (MIRI) is sensitive to the portion of the spectrum between 5 and 28 μm. The near-infrared spectrograph (NIRSpec) dissects light between 0.6 to 5.0 μm. The fourth instrument, near-infrared imager and slitless spectrograph (NIRISS), takes images from 0.6 to 5.0 μm and spectra from 0.6 to about 2.0 μm. The telescope's fine guiding sensor keeps it in position while it collects data. HST could detect a sliver of the infrared spectrum [13], but with JWST "we are seeing much farther into the infrared," said Willmer.

That capability allows researchers to delve deeper into the early universe. "We are looking back through 97% of time," said Illingworth. For instance, scientists think that galaxies appeared within a few hundred million years of the Big Bang, but they know little about these objects [14,15]. The early galaxies are very far away,

**Fig. 1.** The ring-shaped Cartwheel Galaxy is about 500 million light years from Earth. JWST's mid-infrared instrument (MIRI) delineates the spokes of the galaxy, which are rich in hydrocarbons and silicate dust. Credit: National Aeronautics and Space Administration (NASA); Space Telescope Science Institute (STSI) (public domain).

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**Fig. 2.** The Tarantula Nebula, about 161 000 light years from Earth, is a stellar nursery. A clump of young stars glows brightly near the center of this image taken by JWST's near-infrared camera (NIRCam) instrument. Credit: NASA; STSI (public domain).

**Fig. 3.** Left: In 2014, HST captured this astonishing image of the Pillars of Creation, towers of gas and dust about 6500 light years from Earth. Right: Because JWST's NIRCam instrument can penetrate this dust, it reveals more newly formed stars. Credit: NASA; STSI (public domain).

and because the universe is expanding, they are speeding away so fast that their light is shifted into the infrared. "By about 500 million years after the Big Bang, galaxies are so red they are almost invisible to Hubble," said Steve Finkelstein, professor of astronomy at the University of Texas in Austin, TX, USA.

But these galaxies are visible to JWST, and their prevalence suggests they are more common in the early universe than researchers expected. By analyzing some of the first JWST data, Finkelstein and his colleagues on the *Cosmic Evolution Early Release Science Survey* identified what may be one of the most distant galaxies ever observed, a bluish blob that the researchers informally named Maisie's galaxy after Finkelstein's 9-year-old daughter [16]. The team tentatively dated Maisie's galaxy to around 373 million years after the Big Bang [17].

Scientists poring over JWST data have identified other galaxies from about the same time as well. A research group that included Illingworth reported a galaxy that may date to about 350 million years after the Big Bang [18,19]. Two galaxies that Willmer and colleagues described appear to have formed around 330 million years after the Big Bang [20,21]. And researchers say that JWST will likely uncover even earlier galaxies. But the telescope has already provided an important lesson about this period in the history of the cosmos, said Finkelstein. "Galaxies started forming very, very early in the universe, earlier even than theoretical models predicted," he said. Astronomers now need to explain this discrepancy—one possibility is that early stars were brighter than their successors [1].

JWST is also allowing scientists to take a closer look at planets outside our solar system, known as exoplanets, and analyze their atmospheres for molecules that might indicate the presence of life. A standard technique for determining the chemical make-up of an exoplanet's atmosphere involves analyzing the light passing through the atmosphere as the planet crosses in front of its star [22]. JWST's infrared instruments can discern more detail in spectra taken of the atmosphere, thus providing more information about its composition [23].

The telescope will scrutinize around 70 exoplanets in its first year of operation, but it has already made noteworthy finds [24]. One of its early targets, a planet known as wide angle search for planets (WASP)-39b that is about 700 light years away from Earth, turned out to have $CO_2$, marking the first time that researchers have detected this gas in any planetary atmosphere outside the solar system [25]. "We had suspected it was there," but the evidence from older instruments, including HST, was equivocal, said Meyer. "The Webb data are robust, and they give us confidence that the identification is solid," he said. Further observations of WASP-39b, which is roughly the same mass as Saturn, revealed the first signs of chemical reactions powered by starlight in an exoplanet's atmosphere [8,24]. Such chemical reactions also occur in Earth's atmosphere and generated the ozone layer [24].

Another area where JWST may provide illumination, so to speak, is in the detection of dark matter, the invisible mass that makes up as much as 90% of the universe [26]. Dark matter may coalesce into clumps called halos that alter galaxy formation and star movement, but such structures are hard to pinpoint. Anna Nierenberg, assistant professor of physics at the University of California in Merced, CA, USA, and colleagues are using JWST to search for dark matter halos. To detect these hidden structures, the researchers look for their effects on light emanating from distant objects called quasars [27]. If this light passes close to a halo, Nierenberg said, the halo's gravity will bend the light, an effect known as gravitational lensing that can produce multiple images of the quasar.

The researchers wanted to look for light emanating from a small portion of a quasar, but before JWST they did not have a telescope with enough spatial resolution to detect the multiple images, since the light is shifted far to the red, said Nierenberg. Now that she and her colleagues have observing time on JWST, however, they have already uncovered preliminary evidence of gravitational lensing by halos, and they hope to release results of a more thorough analysis in 2023, she said. If the researchers find that halos are widespread, that result would support one of the leading explanations for dark matter composition, the cold dark matter hypothesis [28].

Some of JWST's spectacular early results, however, should be viewed with caution, researchers say, because the telescope was still undergoing calibration [29]. For instance, Kristen McQuinn, assistant professor of physics and astronomy at Rutgers University in Piscataway, NJ, USA, and her team trained JWST's NIRCam on a clump of stars known as a globular cluster that is often used as a standard for comparison among instruments. Their work, published in September 2022, revealed that NIRCam's measurements were off by as much as 23% [30]. These deviations are typical for new astronomical instruments and do not indicate anything wrong, said McQuinn. "It is not supposed to be well-calibrated right out of the box," she said. The JWST team has since issued new calibrations that have improved the telescope's performance [31]. However, some groups studying the early universe, including Illingworth's, had to revise their calculations of galaxy ages to reflect the new calibrations, and additional refinements could be forthcoming as JWST undergoes further adjustments over the next several years [31].

JWST has settled into more routine operation but still faces some threats. For example, tiny objects known as micrometeoroids could damage its main mirror. Fourteen of these objects struck the mirror in the telescope's first 11 months in space, about as many as scientists expected, but one caused more damage to a mirror segment than anticipated [32,33]. Still, astronomers expect that these large, damaging hits will be rare, and they hope the telescope will provide much more than a decade of further observations. JWST has used less of its fuel than anticipated and should be able to remain in orbital position for up to 20 years, twice as long as expected [34]. Though "things will go wrong, space hardware can last a long time," said Illingworth, noting that HST is still functioning more than 14 years after astronauts last serviced it.

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