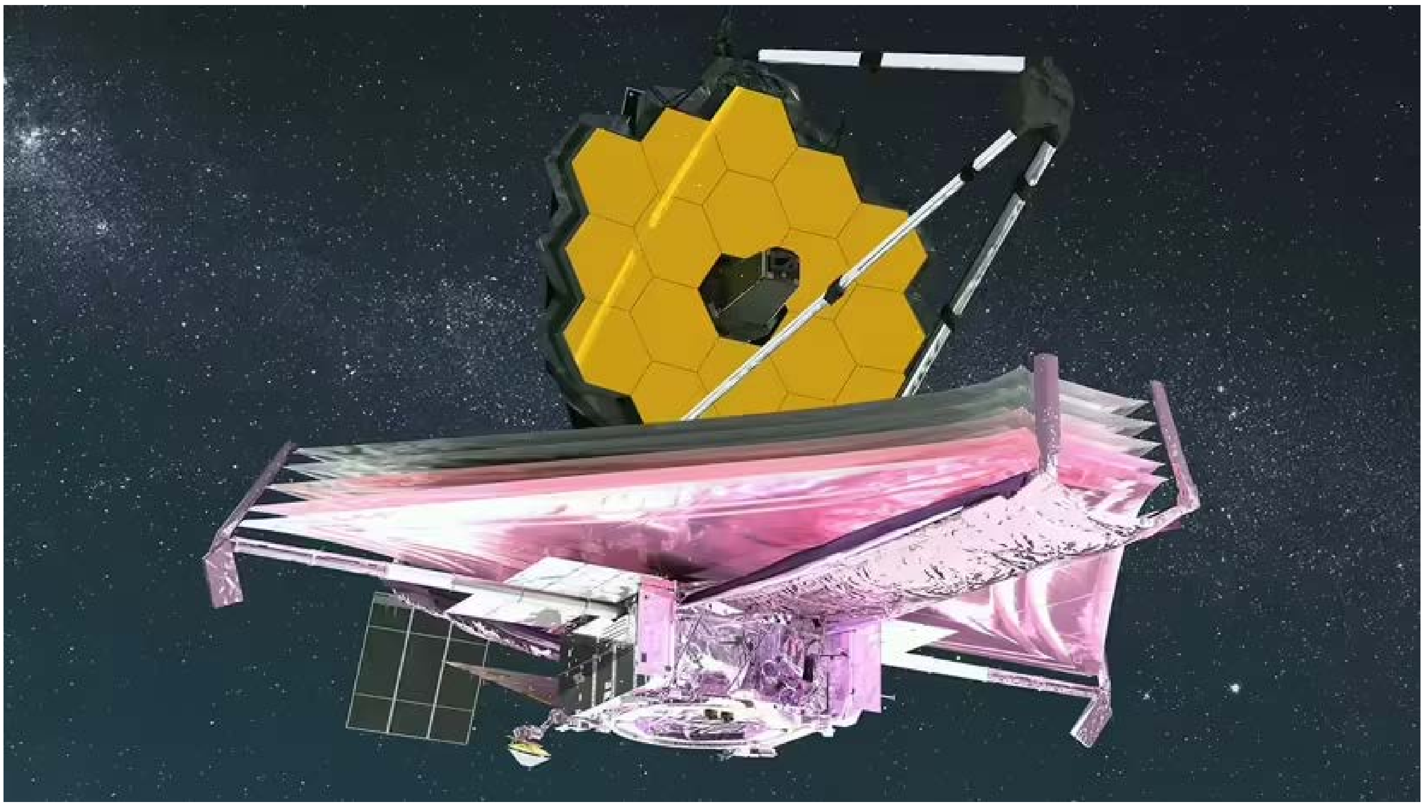
How the James Webb Space Telescope Works

By: Nicholas Gerbis & Sarah Gleim | Updated: Sep 23, 2021



This artist conception shows what the James Webb Space Telescope will look like when it's launched in space. NASA GSFC/CIL/ADRIANA MANRIQUE GUTIERREZ

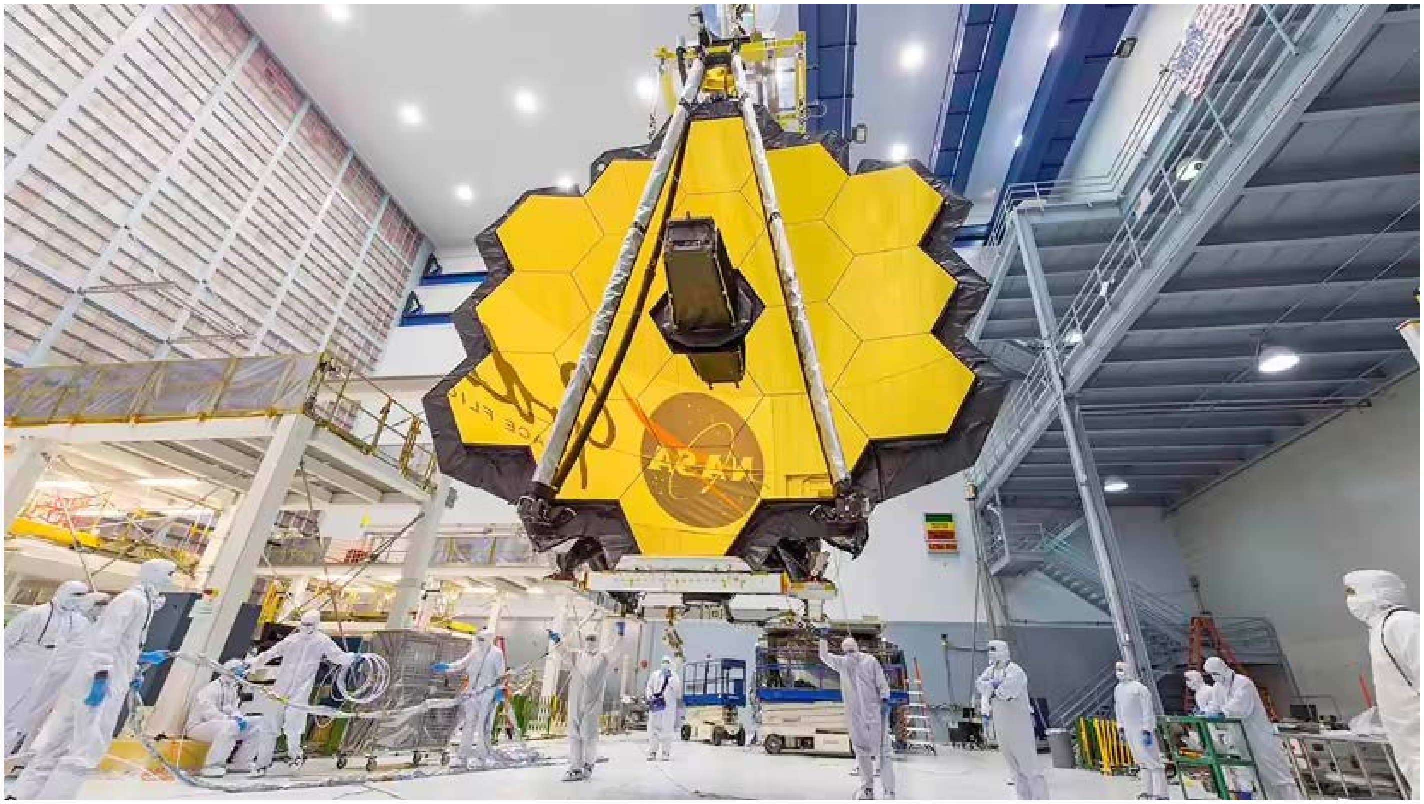
Our knowledge of the universe is bound by the scope of our senses, but our minds know no such limits. When a campfire's glow blinds us to the source of a twig-snap in the wooded darkness, we imagine all sorts of dire prospects. But step out a few paces, set the fire to our backs, and we see more deeply and clearly. Imagination meets information, and we suddenly know what we are dealing with.

But it takes more than a good set of eyes and some distance from city lights to comprehend the cosmos; it requires instruments capable of expanding our senses beyond our evolutionary limits, our atmosphere or even our planetary orbit. Astronomy and cosmology are both compelled and limited by the quality of these instruments.

Around 400 years ago, the telescope revealed unsuspected moons, planets and sunspots, sparking a succession of new cosmic theories and better tools to test them, revealing billowing nebulae and congregating stars along the way.

In the mid-20th century, radio telescopes showed that galaxies — far from static blobs — were in fact active and bursting with energy. Before the Kepler Space Telescope, we thought exoplanets were rare in the universe; now we suspect they might outnumber stars. More than three decades of the Earth-orbiting Hubble Space Telescope helped pierce the veil of time, photograph stellar nurseries and prove that galaxies collide. Now, the James Webb Space Telescope stands poised to place its back to the sunlight, step away from Earth and make the keen, delicate observations possible only in the cold, dark spaces beyond the moon.

Slated for a Dec. 22, 2021, launch date from Europe's Spaceport in Kourou, French Guiana, Webb was built by an international collaboration between NASA, the European Space Agency (ESA) and the Canadian Space Agency (CSA), and is charged with answering some *very* ambitious questions. It also will take astronomers closer than ever to the beginning of time, granting glimpses of sights long hypothesized but never before seen, from the birth of galaxies to light from the very first stars.



The James Webb telescope's 18-segmented mirror is specially designed to capture infrared light from the first galaxies that formed in the early universe, and will help the telescope peer inside dust clouds where stars and planetary systems are still forming.
NASA

The Mission: Standing on the Shoulders of Giants

This image shows the difference between Hubble's visible and infrared views of the Monkey Head Nebula. The James Webb Telescope will focus on infrared imaging. THE HUBBLE HERITAGE TEAM (STSCI/AURA), AND J. HESTER

Webb's mission builds upon and expands the work of NASA's Great Observatories, four remarkable space telescopes whose instruments cover the waterfront of electromagnetic spectra. The four overlapping missions have enabled scientists to observe the same astronomical objects in the visible, gamma ray, X-ray and infrared spectra.

The school-bus-sized Hubble, which sees primarily in the visible spectrum with some ultraviolet and near-infrared coverage, kicked off the program in 1990 and, with further servicing, will complement and work with Webb. Appropriately named for Edwin Hubble, the astronomer who discovered many of the events that it was built to investigate, the telescope has since become one of the most productive instruments in scientific history, bringing phenomena like star birth and death, galactic evolution and black holes from theory to observed fact.

Joining the Hubble in the big four are the Compton Gamma Ray Observatory (CGRO), Chandra X-ray Observatory and Spitzer Space Telescope.

- The CGRO, launched in 1991 and now decommissioned, detected high-energy, violent spectacles in the 30 kiloelectron volts (keV) to 30 gigaelectron volts (GeV) spectrum, including the energy-spewing nuclei of active galaxies.
- Chandra, deployed in 1999 and still orbiting at about an altitude of 86,500 miles (139,000 kilometers) in space, monitors black holes, quasars and high-temperature gases in the X-ray spectrum, and provides vital data about the universe's birth, growth and ultimate fate.
- Spitzer, which was launched in 2003 and occupied an Earth-trailing orbit, viewing the sky in thermal infrared (3-180 microns), a bandwidth useful for observing star births, galactic centers and cool, dim stars, and for detecting molecules in space. Spitzer was originally built to last for a minimum of about two-and-a-half years, but Spitzer continued to operate until Jan. 30, 2020.

What makes Webb different is it has the capability to gaze deeply into the near- and mid-infrared, and it will have four science instruments to capture images and spectra of astronomical objects. Why does that matter? Stars and planets that are just forming are hidden behind dust that soaks up visible light. However, infrared light emitted can pierce this dusty blanket, revealing what's behind. Scientists hope that will allow them to observe the very first stars in the universe; the formation and collision of infant galaxies; and the birth of stars and protoplanetary systems, possibly even those containing the chemical constituents of life.

These first stars could hold the key to understanding the structure of the universe. Theoretically, where and how they formed relates to early patterns of dark matter — unseen, mysterious matter detectable by the gravity it exerts — and their life cycles and deaths caused feedbacks that affected the formation of the first galaxies [source: Bromm et al.]. And as supermassive, short-lived stars, estimated at around 30-300 times the mass (and millions of times the brightness) of our sun, these firstborn stars might well have exploded as supernovae then collapsed to form black holes, later swelling and merging into the huge black holes that occupy the centers of most massive galaxies.

Witnessing any of this is a feat beyond any instrument or telescope built so far.

First Light

The term first light refers to the first stars ever to form in the universe, which ignited 400 million years after the big bang and are made up entirely of primordial gas. These ancient suns are not the oldest radiation sources, however. That honor belongs to the cosmic background radiation, the microwave radiation released by the formation of the first atoms around 400,000 years after the big bang and observed by NASA's Wilkinson Microwave Anisotropy Probe (WMAP) and Cosmic Background Explorer (COBE) missions. Webb, however, won't get to see this early radiation.

Take a Tour of the James Webb Space Telescope

Technicians successfully performed a critical test on Webb's five-layer sunshield by fully deploying each of its uniquely sized layers to the same position that they will have while orbiting the sun a million miles away from Earth. NASA/CHRIS GUNN

Webb looks a bit like a diamond-shaped raft sporting a thick, curved mast and sail — if the sail was built by giant, beryllium-chewing honeybees. The "raft" (or sunshield) is made of membrane layers — all as thin as a human hair — of Kapton, a high-performance plastic coated with a reflective metal. Together they protect the main reflector and instruments.

Webb's "keel" is what you'd think of as its unitized pallet structure. That's where the massive sunshield folds up for liftoff. In the center lies the spacecraft bus, which packs all of the support functions that keep Webb running, including electrical power, attitude control, communications, command and data handling, and thermal control. A high-gain antenna adorns the Webb's exterior, as do a set of star trackers that work with the fine guidance sensor to keep everything pointed in the right direction. Finally, at one end of the sunshield, and perpendicular to it, is a momentum trim tab that offsets the pressure that photons exert on the ship, much like a trim flap does on a sailing ship.

Above the sunshield is the "sail," or Webb's giant mirrors. Webb has a primary mirror that is 21.4 feet (6.5 meters) across that measures the light from distant galaxies. (In comparison, the Hubble Space Telescope's mirror is 7.8 feet [2.4 meters]). It's made of 18 hexagonal beryllium sections that unfold after launch, then coordinate to act like one whopping primary mirror. This mirror has a much lighter design and allows the entire structure to fold like a drop-leaf table. The hexagonal shape of the mirrors allows the structure to be roughly circular, without gaps. If the mirror segments were instead circles, there would be gaps between them.

Let's take a closer look at the instruments that will make all of those studies possible.

The James Webb Telescope mirrors are covered in a microscopically thin layer of gold, which optimizes them for reflecting infrared light, the primary wavelength of light it will observe.
NASA

The Instruments: Sight Beyond Sight

Webb's Near Infrared Camera features a 16-megapixel mosaic of light sensors. The mosaic comprises four separate chips mounted together with a black mask covering the gaps between the chips. KENNETH W. DON

Although it sees somewhat into the visual range (red and gold light), Webb is fundamentally a large infrared telescope.

- Its primary imager, the Near Infrared Camera (NIRCam), senses in the 0.6-5.0 micron range (near-infrared). That means it can detect infrared light from the earliest stars and galaxies being born; take a census of nearby galaxies; and spot objects swinging through the Kuiper Belt, the expanse of icy objects orbiting beyond Neptune. It will also aid with correcting Webb's telescopic vision as needed.
- NIRCam comes equipped with a coronagraph, which will enable the camera to observe the wispy halos surrounding bright stars by blocking their blinding light — an essential tool for spotting exoplanets.
- The Near Infrared Spectrograph (NIRSpec) operates in the same wavelength range as NIRCam. Like other spectrographs, it analyzes the physical characteristics of objects such as stars by splitting their light into a spectrum, the pattern of which

varies according to the target's temperature, mass and chemical makeup. NIRSpec will study thousands of ancient galaxies with radiation so faint that Webb's giant mirror will be required to point at them for hundreds of hours to collect enough light to form a spectrum. To aid in this task, the spectrograph has a grid of 62,000 individual shutters, each capable of opening and closing to block out the light of brighter stars. Thanks to this microshutter array, NIRSpec will become the first space-based spectrograph designed to observe 100 different objects at once.

- The Fine Guidance Sensor/Near Infrared Imager and Slitless Spectrograph (FGS-NIRISS) is actually two sensors packaged together that will help examine first light detection, exoplanet detection and characterization, and exoplanet transit spectroscopy. FGS will also help point the telescope in different directions.
- The final Webb instrument extends its range beyond near-infrared and into the mid-infrared, handy for picking planets, comets, asteroids, starlight-heated dust and protoplanetary disks. Both a camera and a spectrograph, this Mid-Infrared Instrument (MIRI) covers the widest wavelength range, from 5-28 microns. Its wide-field broadband camera will snap more of the kinds of images that made Hubble famous.

But infrared observation is essential to understanding the universe. Dust and gas can block the visible light of stars in stellar nurseries, but infrared passes through. Moreover, as the universe expands and galaxies move apart, their light "stretches out" and becomes redshifted, sliding toward longer electromagnetic (EM) wavelengths such as infrared. The farther away the galaxy, the faster it recedes and the more redshifted its light, hence, the value of a telescope like Webb.

Infrared spectra also can provide a wealth of information on exoplanet atmospheres — and whether they contain molecular ingredients associated with life. On Earth, we call water vapor, methane and carbon dioxide "greenhouse gases" because they absorb thermal infrared (aka heat). Because this tendency holds true everywhere, scientists can use Webb to detect such substances in the atmospheres of distant worlds by looking for telltale absorption patterns in their spectroscopic readings.

The Hidden Universe

Astronomers nickname the infrared range of the electromagnetic (EM) spectrum the "hidden universe." Although any object with heat radiates infrared light, Earth's atmosphere blocks most of it, rendering it invisible to ground-based astronomy.

Questions Webb Could Answer

Webb is tasked with answering a lot of life's greatest mysteries, like how did life develop on Earth; how do galaxies, like this one known as Messier 81, form; and was there ever life on Mars? NASA/JPL-CALTECH/ESA/HARVARD-SMITHSONIAN CFA

The James Webb Space Telescope is the largest, most powerful space telescope ever built. It will be the most complex telescope launched into space. The data it provides during its mission, which is expected to last anywhere between five and 10 years, could change our understanding of the universe.

Why? Because its goal is to examine all of the phases of our cosmic history, including the big bang. But there are four distinct objectives for the Webb Telescope during its mission, and they're grouped into four themes:

1. The End of the Dark Ages: First Light and Reionization: Webb will use infrared capabilities to "see" back to about 100 million to 250 million years after the big bang when the first stars and galaxies were forming. We have heat signature proof of the big bang from the microwave COBE and WMAP satellites from about 380,000 years after it occurred. But we still don't know what the universe's first light looked like and when these first stars formed. Some of the questions Webb might answer include what are the first galaxies; when and how did reionization occur; and what sources caused reionization?
2. Assembly of Galaxies: Webb's extraordinary infrared capabilities will allow us to see the faintest, earliest galaxies as well as massive spirals. Those abilities will help answer questions about galaxies like how they evolve and develop over billions of years; what is the relationship between black holes and the galaxies that host them; and how are chemical elements distributed through galaxies?
3. The Birth of Stars and Protoplanetary Systems: Unlike Hubble, Webb will see through massive dust clouds where stars and planetary systems are being born. That's because Webb sees the heat — or infrared light — emitted by the stars inside the dust clouds. Hubble can't do that. Hopefully it will help answer questions like how do clouds of gas and dust collapse to form stars; why do most stars form in groups; and how do planetary systems form?
4. Planetary Systems and the Origins of Life: In addition to studying planets outside our solar system, Webb will allow scientists to learn more about our own home, including small bodies in our solar system: asteroids, comets and Kuiper Belt objects. Many questions could be answered, including how are the building blocks of planets assembled; how do planets reach their ultimate orbits; how did life develop on Earth; and was there ever life on Mars?

Originally Published: Oct 9, 2014

Lots More Information

Related Articles

- Who Was James Webb?

- How the Big Bang Theory Works
- Could Dark Matter Spawn 'Shadow Life'?
- How Hubble Space Telescope Works
- NASA's 10 Greatest Achievements

Sources

- Billings, Lee. "Space Science: The Telescope That Ate Astronomy." Nature. Vol. 467. Page 1028. Oct. 27, 2010. (Sept. 11, 2014) http://www.nature.com/news/2010/101027/full/4671028a.html
- Bromm, Volker, et al. "The Formation of the First Stars and Galaxies." Nature. Vol. 459. May 7, 2009. (Sept. 19, 2014) http://sdcc3.ucsd.edu/~ir118/SIO87W13/FirstStars.pdf
- NASA. "The James Webb Space Telescope." (Sept. 23, 2021) http://www.jwst.nasa.gov/
- NASA. "A Look at the Numbers as NASA's Hubble Space Telescope Enters its 25th Year." May 12, 2014. (Sept. 18, 2014) http://www.nasa.gov/content/goddard/a-look-at-the-numbers-as-nasas-hubble-space-telescope-enters-its-25th-year/#.VBr4UfldV8E
- Overbye, Dennis. "More Eyes on the Skies." The New York Times. July 21, 2014. (Sept. 11, 2104) http://www.nytimes.com/2014/07/22/science/space/more-eyes-on-the-skies.html?_r=0
- Space Telescope Science Institute (STSI). "James Webb Space Telescope FGS - Fine Guidance Sensor." (Sept. 11, 2014) http://www.stsci.edu/jwst/instruments/fgs/
- Space Telescope Science Institute (STSI). "James Webb Space Telescope Near-InfraRed Imager and Slitless Spectrograph." (Sept. 11, 2014) http://www.stsci.edu/jwst/instruments/niriss
- Stiavelli, M., et al. "A Strategy to Study First Light with JWST." Space Telescope Science Institute. (Sept. 11, 2014) http://www.stsci.edu/jwst/science/strategy-to-study-First-Light.pdf

Featured

Loading...