ARCHIVAL

# James Webb Space Telescope (JWST)

**Article by:**

**Seery, Bernard D.** Goddard Space Flight Center, National Aeronautics and Space Administration, Greenbelt, Maryland.

**Last reviewed:** 2004

**DOI:** https://doi.org/10.1036/1097-8542.YB040500 (https://doi.org/10.1036/1097-8542.YB040500)

*Content* Hide

  - Observing early stars and galaxies
  - Additional scientific goals
  - Reduction of size and cost
  - Orbital considerations
  - Cryogenic cooling
  - Cold mirrors and motors
  - Integrated science instrument module
  - Detectors
  - Microshutters
- Additional Reading

The National Aeronautics and Space Administration (NASA) plans to launch the James Webb Space Telescope, which in many ways is the scientific and technological successor of the Hubble Space Telescope, in 2011. In 2002, the company now known as Northrop Grumman Space Technology (which was then TRW Space and Electronics) and its partners, Ball Aerospace and Eastman Kodak, were awarded the prime contract to build the observatory, formerly known as the Next Generation Space Telescope.

## *Observing early stars and galaxies*

Equipped with a large, 6.6-m-class (260-in.) deployable mirror (**Fig. 1**) and a suite of revolutionary, infrared-sensing cameras and spectrometers, JWST will make it possible to see even farther into space than is currently possible with Hubble (**Fig. 2**) and will help to analyze faint sources of light that Hubble cannot even detect. Light from these nascent stars and galaxies, emitted early in the history of the universe, has traveled so far by the time it reaches us that it has stretched into the infrared wavelength band and is invisible to the human eye.

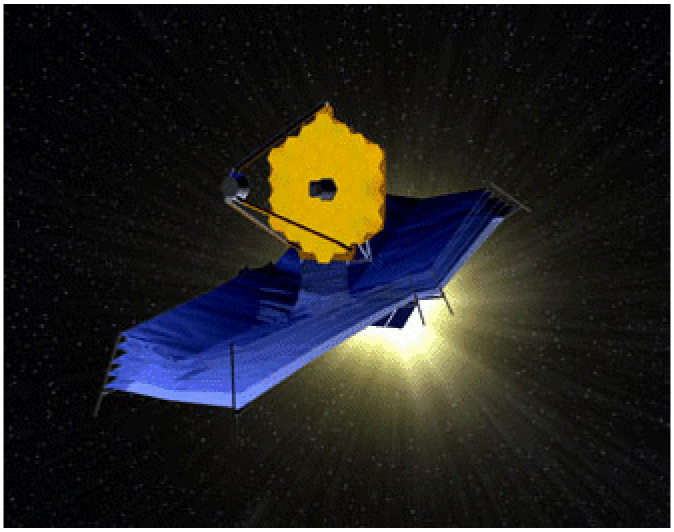

**Fig. 1 Conception of the James Webb Space Telescope (JWST), with a 6.6-m-class (260-in.) mirror and large sunshield. (*NASA Goddard Space Flight Center*)**

**Full-size image**

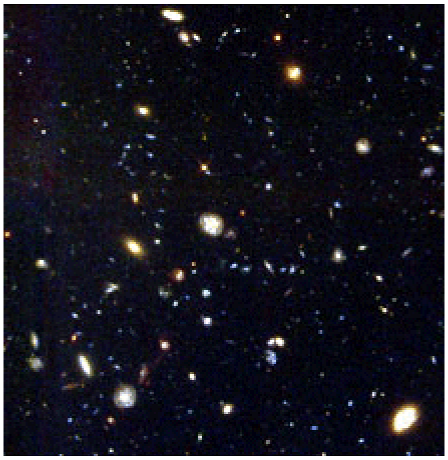

**Fig. 2 Image taken by the Hubble Space Telescope in 1998 of a small area of the southern sky with galaxies whose light was emitted 12 billion years ago, early in the history of the universe, and has thus traveled 12 billion light-years to reach us. The James Webb Space Telescope will be able to observe even farther into space, to a time when stars and galaxies were beginning to take form. (*Space Telescope Science Institute; NASA*)**

**Full-size image**

Consequently, no one up to now had the tools to observe this cosmic “dark zone,” but this “first light machine” will finally reveal what the universe looked like when it was a fraction of its current age and size, and the first stars and galaxies were beginning to take form. In addition, JWST will demonstrate new technologies needed for future missions. For this reason, the National Academy of Science has ranked JWST as one of NASA's top science goals.

## *Additional scientific goals*

In addition to observing these young galaxies, JWST will tackle four other major objectives over its 5–10-year lifetime.

JWST will help determine the geometry of the universe, its age, and its ultimate fate. In 2000, two teams of astronomers found evidence that the expansion of the universe is accelerating rather than slowing down. Their observations seemed to confirm the existence of a new form of energy that causes the expansion of the universe to accelerate. JWST is capable of studying this phenomenon.

Although mission planners designed the spacecraft primarily to observe the farthest reaches of the universe, it also can look closer to home. With JWST, scientists can study the history of the Milky Way and its nearby neighbors by studying the old stars and star remnants that formed over the galaxy's lifetime.

Astronomers also will use JWST to study star birth and formation. Its infrared sensors can pierce the dust and gas that surround stellar nurseries and reveal the processes that dictate the mass and composition of stars, as well as the production of heavy elements.

Finally, NASA designed JWST to study the origin and evolution of planetary systems like our own. JWST may be able to directly detect large, Jupiter-sized planets around nearby stars. Although smaller planets cannot be imaged directly, JWST's high resolution will make it possible to see how they behave as a planetary system, especially when they are in the process of formation, which will provide a larger picture of their evolution.

## *Reduction of size and cost*

A thousand times more sensitive in the infrared than Hubble, JWST will accomplish far more than what current ground- and space-based observatories can do. Yet, JWST will achieve this at a fraction of Hubble's size and overall cost. JWST will weigh about 5000 kg (11,000 lb), compared with Hubble's 11,000 kg (24,000 lb), and a medium-sized rocket, such as the Atlas 5, will likely launch the spacecraft. The European Space Agency has agreed to provide an Ariane 5 launcher. *See also:* **Satellite launch vehicles (/content/satellite-launch-vehicles/YB040600)**

NASA could not have considered a mission of this magnitude just a few years ago. Since NASA began studying the mission in 1995, the agency has made significant progress in advancing technologies and management approaches that would allow it to pack a lot of scientific capability into a relatively small package.

## *Orbital considerations*

JWST's orbit (**Fig. 3**)—at the second Lagrangian point (L2) of the Sun-Earth system, located 1.5 million kilometers (940,000 mi) from the Earth in the anti-Sun direction—allows NASA to perform this mission. (The point L2 is one of the five Lagrangian points in the orbital plane of the Earth and Sun at which a third object of negligible mass can remain in equilibrium.) The L2 orbit offers a thermally stable environment. At the L2 point, JWST will be in orbit around the Sun rather than the Earth, as with the Hubble Space Telescope. This arrangement will allow JWST to reside in the shadow of a lightweight sunshield, the size of a tennis court, which will deploy in orbit (**Fig. 1**). In this shadow, JWST can passively cool to about 35 K (about −400°F). Although passive cooling is an old concept, NASA has never flown a mission before that uses this method to reach these extreme temperatures.

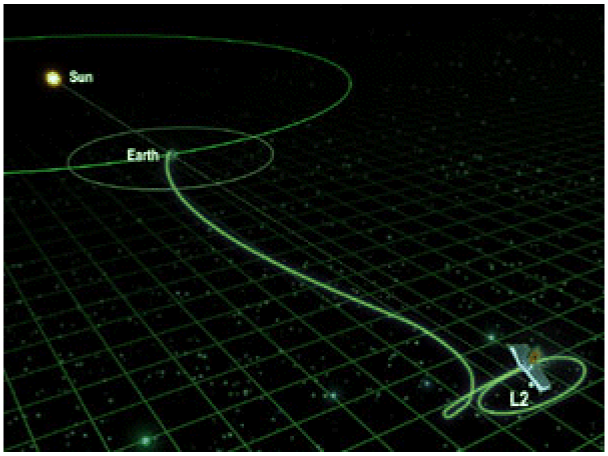

**Fig. 3 Trajectory of JWST from Earth to the neighborhood of the second Lagrangian point (L2) of the Sun-Earth system, and its orbit near L2. (*NASA Goddard Space Flight Center*)**

**Full-size image**

## *Cryogenic cooling*

To observe the farthest reaches of the universe, temperature is an essential consideration. Observations in the near- and mid-infrared wavelength bands (0.6–0.9 to 28 μm) cannot be conducted at temperatures above 35 K. Anything warmer would create too much of its own infrared "noise" or heat, and interfere with JWST's attempt to detect extremely faint infrared photons. NASA could maintain these cryogenic temperatures at a different orbital location closer to Earth, but the spacecraft would then have to carry heavy cooling systems, preventing it from being launched on an expendable vehicle and allowing less mass to be allocated to the telescope and instruments.

## *Cold mirrors and motors*

Even more technologically demanding than the deployable sunshield is JWST's segmented, 6.6-m-class lightweight, deployable mirror (**Fig. 1**), which will do what no other mirror has done—it will use a combination of small, ultraprecise actuators and sophisticated computer algorithms to align and properly figure the mirror. Moreover, JWST's primary mirror will have six times the collecting area of Hubble's, yet more than a factor of 100 lower areal density (mass per square meter). In contrast, Hubble's 2.4-m (94-in.) primary mirror weighs 180 $kg/m^2$ (37 $lb/ft^2$) and is a single piece of polished glass. Although the segmented approach using lightweight materials accomplishes these objectives and allows the telescope to fit inside a commercial rocket fairing, it complicates the task of making sure the mirror holds its proper shape.

Once in orbit, JWST will take several images of stars. With those images, ground controllers will use computer algorithms to determine the level of distortion in the mirror segments caused by the supercold temperatures of space, misalignment, and fabrication errors. They can correct distortions by activating computer-controlled mechanical actuators that move and change the radius of curvature of the mirror segments until they are perfectly aligned and shaped. Their goal will be to reduce the size of these distortions to no more than 0.5 μm, 200 times smaller than the width of a human hair. These actuators must work in extremely cold temperatures. This on-orbit wavefront sensing and control will undoubtedly find applications in other space missions.

To foster the development of these technologies, three companies were awarded contracts to build three 1.6-m (63-in.) versions of the mirror and to test them in vacuum chambers. With four actuators, a semirigid design made of beryllium required the least amount of on-orbit correction. [A beryllium mirror that flies on the Space Infrared Telescope Facility (SIRTF) had provided experience with this technology.] A more complex design, with 37 actuators, featured fused silica that measured just a few millimeters thick. The third model, made of glass, had 16 actuators.

## *Integrated science instrument module*

The telescope will carry three instruments. The Near-Infrared Camera (NIRCam) will be JWST's primary imager in the wavelength range of 0.6–5 μm. Required by many of the core science goals, the instrument is particularly well suited for detecting the first light-emitting objects that formed after the big bang. It also will come equipped with a coronagraph, which will be used to obtain images of debris disks, Kuiper Belts, and massive giant planets around nearby stars. The camera's tunable filter, provided by the Canadian Space Agency, can be adjusted to any narrow color range, making it possible to isolate objects with special color features, particularly in the very distant universe.

A multiobject Near-Infrared Spectrometer (NIRSpec), provided by the European Space Agency (ESA), will serve as the principal spectrograph in the 0.6–5-μm wavelength range. Spectroscopy is the study of light after it has been separated into its component colors. This diagnostic tool reveals the composition, temperature, and other physical characteristics of celestial objects. It will obtain simultaneous spectra of more than 100 objects in a 9-square-arc-minute field of view. By obtaining data on many objects in one observation, astronomers can better characterize the early universe and increase their chances of finding rare and unique objects through a factor of 1000 increase in observing efficiency.

The Mid-Infrared Instrument, provided by a NASA/ESA Consortium, will provide imaging and spectroscopy at wavelengths of 5–28 μm. This capability opens a new window of discovery. This instrument will study the creation of the first heavy elements and the formation and evolution of galaxies and very old stellar populations. It is uniquely capable of studying the very early stages of star and planet formation in regions where all visible light is blocked by dust and most of the emission is radiated at mid-infrared wavelengths.

All three instruments will be packed into a special module that will form the heart of JWST. This Integrated Science Instrument Module (ISIM) will provide the structure, thermal environment, control electronics, and data handling for the science instruments and the fine-guidance sensor.

However, it must do this by maintaining two very different temperature regimes. The optics and instruments must operate at 35 K, while the electronic computer systems prefer much warmer temperatures of about 250 K (−10°F). A dewar filled with solid hydrogen or a mechanical cryo-cooler will provide additional cooling for the mid-infrared detectors, which work best at about 7 K (−447°F).

Two groundbreaking technologies, large-format detectors for all three instruments and a programmable spectrometer aperture mask (microshutters) for the Near-Infrared Spectrometer, are vital for carrying out the telescope's rigorous scientific program.

## *Detectors*

The detector is the heart of any astronomical instrument. It records the position, the intensity and, by means of filters and spectrographs, the wavelength of incoming radiation. Because JWST's prime targets are intrinsically faint, with as few as a single photon arriving every second, its detectors must be more sensitive than any detector ever flown. Furthermore, because the detectable first star-forming regions in the universe are very rare, JWST must be able to image large areas of the sky and JWST's detector assemblies must be large mosaic arrangements of 4-million-pixel arrays for a total of 64 million pixels. This detector complement is nearly 500 times larger than that employed by SIRTF.

Indium antimonide (InSb) and mercury-cadmium-telluride (HgCdTe) make the best near-infrared detectors. Both types of material have been used to develop 2000 × 2000 (2k × 2k) detector arrays, which contain 4 million pixels and are about 10 times larger than a standard-sized television screen. Researchers have yet to develop anything approaching the size needed by JWST because the underlying electronics make larger devices difficult to build. However, JWST's technology-development program aims to accomplish this goal by placing close-to-perfect 2000 × 2000-pixel chips into a mosaic assembly. Prototype arrays using both HgCdTe and InSb have been developed. For the mid-infrared instrument, a detector made of arsenic-doped silicon (Si:As) will be used because it works well in this wavelength band.

## *Microshutters*

Multiobject spectroscopy using JWST's Near-Infrared Spectrometer represents another major advance in space-based astronomy. To characterize the nature of the early universe, JWST will have to take spectral data of many different targets simultaneously. On the ground, this is relatively easy. From camera images, astronomers simply choose the objects they wish to target in their spectral studies and they create an aperture plate that allows light only from those targets to enter the spectrometer. The technique is like punching holes in a piece of cardboard.

Aperture plates for space-based observatories cannot be created on the ground. However, micro-electro-mechanical systems (MEMS) technology offers a revolutionary solution. A MEMS device will be installed in the Near-Infrared Spectrometer. Featuring 2 to 4 million microscopic shutters (**Fig. 4**) aligned on a silicon grid—each no larger than a dust mite—the large-format device will perform like the aperture plate used on ground-based spectrometers.

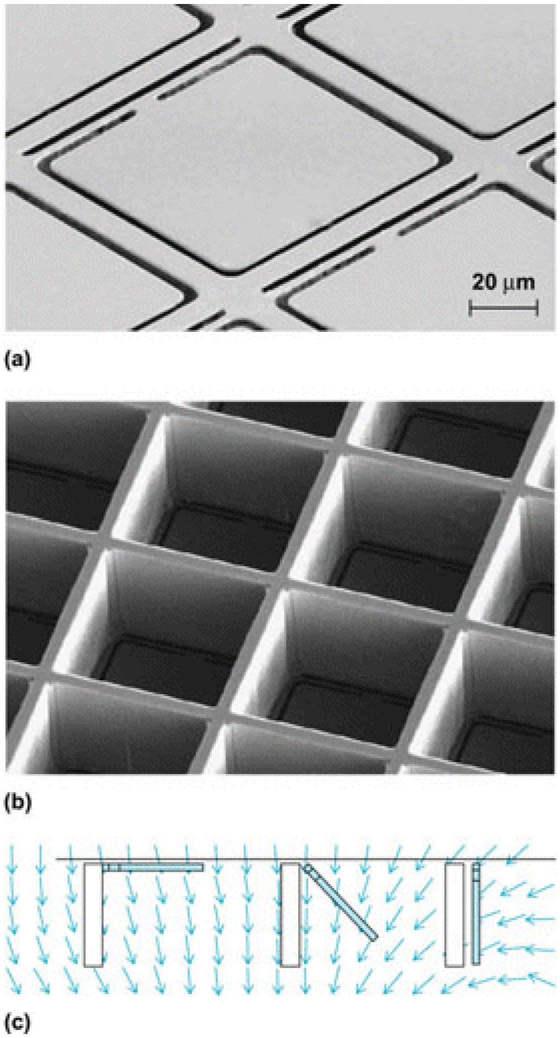

**Fig. 4 Microshutters, measuring 100 × 100 µm, seen (*a*) from above and (*b*) from below. (*c*) Magnetic actuation to open or close microshutters. Arrows indicate magnetic field. (*NASA Goddard Space Flight Center*)**

**Full-size image ❯**

Instead of punching holes, however, ground controllers will send commands directing specific shutters in the array to open or close, forming “slits,” depending on which objects have been identified for study. The shutters will open or close through magnetic actuation (**Fig. 4c**). The technology will allow astronomers to simultaneously gather spectral data on at least 100 objects per observation.

*See also:* **Adaptive optics (/content/adaptive-optics/010000)**; **Observatory, astronomical (/content/observatory-astronomical/057500)**; **Astronomical spectroscopy (/content/astronomical-spectroscopy/057700)**; **Cosmology (/content/cosmology/164200)**; **Galaxy, external (/content/galaxy-external/277700)**; **Infrared astronomy**

**(/content/infrared-astronomy/344200)**; **Micro-electro-mechanical systems (MEMS) (/content/micro-electro-mechanical-systems-mems/757726)**; **Planet (/content/planet/521900)**; **Redshift (/content/redshift/576450)**; **Hubble Space Telescope (/content/hubble-space-telescope/757724)**; **Telescope (/content/telescope/681600)**

**Bernard D. Seery**

## Additional Reading

A. Dressler et al., *HST and Beyond, Explorations and the Search for Astronomical Origins: A Vision for Ultraviolet-Optical-Infrared Space Astronomy*, AURA, 1996

H. S. Stockman, *Next Generation Space Telescope: Visiting a Time When Galaxies Were Young*, AURA, 1997

NASA: Explore: James Webb Space Telescope (http://jwst.gsfc.nasa.gov)

// For Enabling the HTML-CSS for overline