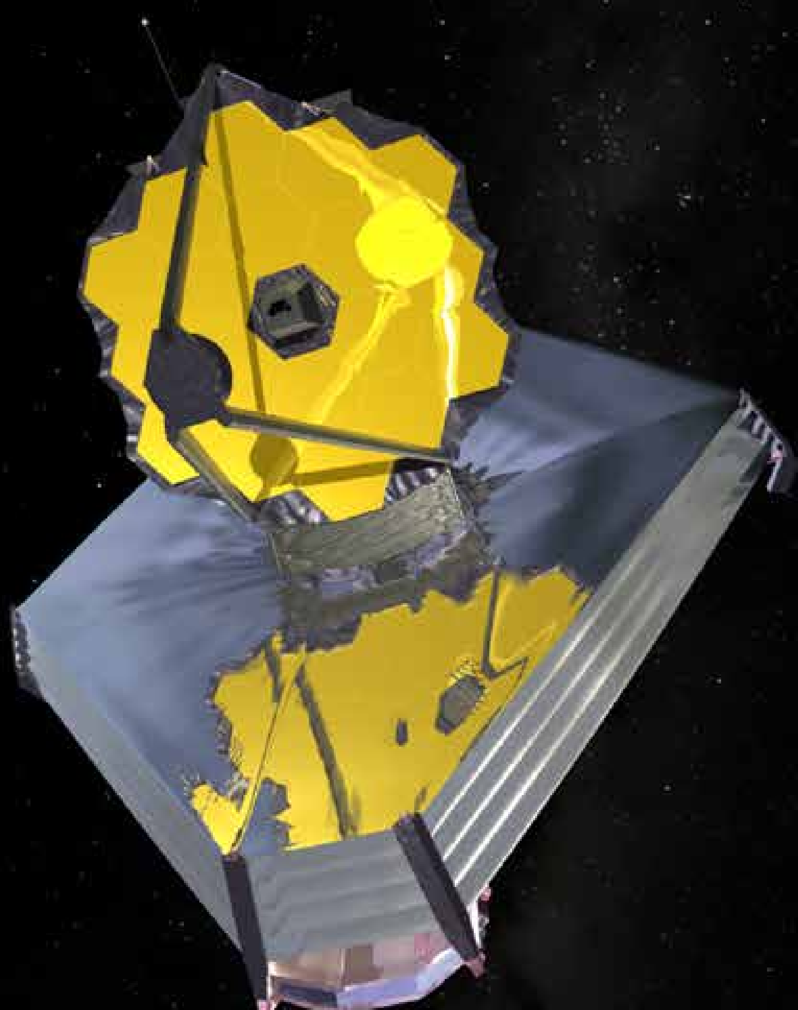
INFRARED ASTRONOMY

EDUCATOR GUIDE



INSIDE NASA

FROM DREAM TO DISCOVERY

Museum of Science

Connections to Education Standards

INSIDE NASA
FROM DREAM TO DISCOVERY

Next Generation Science Standards:

PERFORMANCE EXPECTATIONS	
4-PS3-2	Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electrical currents.
MS-PS3-3	Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.
MS-PS4-2	Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
HS-ESS1-2	Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.
HS-ETS1-3	Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Massachusetts Science and Technology/Engineering Standards (2013 Draft)

STANDARDS	
3-5-ETS1-5 (MA)	Evaluate relevant design features that must be considered in building a model or prototype of a solution to a given design problem.
3-5-ETS2-2 (MA)	Describe that technological products or devices are made up of parts. Use sketches or drawings to show how each part of a product or device relates to other parts in the product or device.
MS-ETS2-2 (MA)	Given a design task, select appropriate materials based on specific properties needed in the construction of a solution.
MS-PS3-3	Apply scientific principles of energy and heat transfer to design, construct, and test a device to minimize or maximize thermal energy transfer.
MS-PS3-6 (MA)	Explain how thermal energy is transferred out of hotter regions or objects and into colder ones by convection, conduction, and radiation.
HS-ESS1-2	Describe the astronomical evidence for the Big Bang theory, including the red shift of light from the motion of distant galaxies as an indication that the universe is currently expanding, the cosmic microwave background as the remnant radiation from the Big Bang, and the observed composition of ordinary matter of the universe, primarily found in stars and interstellar gases, which matches that predicted by the Big Bang theory (3/4 hydrogen and 1/4 helium).

Connections to Education Standards *(continued)*

Massachusetts Science and Technology/Engineering Curriculum Framework (2001)

GRADE LEVEL	SUBJECT	LEARNING STANDARD
3 – 5	**Physical Sciences (Chemistry and Physics)**	12: Recognize that light travels in a straight line until it strikes an object or travels from one medium to another, and that light can be reflected, refracted, and absorbed.
3 – 5	**Technology/ Engineering**	1.1: Identify materials used to accomplish a design task based on a specific property, i.e., weight, strength, hardness, and flexibility.
6 – 8	**Physical Sciences (Chemistry and Physics)**	14: Recognize that heat is a form of energy and that temperature change results from adding or taking away heat from a system.
6 – 8	**Technology/ Engineering**	1.1: Given a design task, identify appropriate materials (e.g., wood, paper, plastic, aggregates, ceramics, metals, solvents, adhesives) based on specific properties and characteristics (e.g., weight, strength, hardness, and flexibility).
9 or 10	**Physics**	6.1: Describe the electromagnetic spectrum in terms of wavelength and energy, and be able to identify specific regions such as visible light.
9 or 10	**Technology/ Engineering**	2.4: Identify and explain the engineering properties of materials used in structures, e.g., elasticity, plasticity, thermal conductivity, density.
9 or 10	**Technology/ Engineering**	4.2: Give examples of how conduction, convection, and radiation are used in the selection of materials, e.g., home and vehicle thermostat designs, circuit breakers.

TEACHER TIP

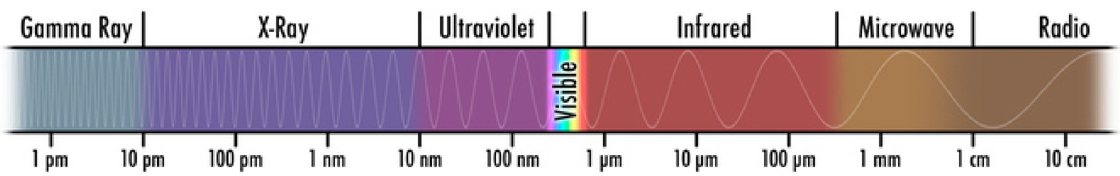
DOWNLOAD FIELD TRIP GUIDES!

Use these handy activity sheets for chaperones and students to make the most of their day at the Museum. Download them before your visit: mos.org/educators.

Bolded words are defined further in the glossary (page 10).

Introduction

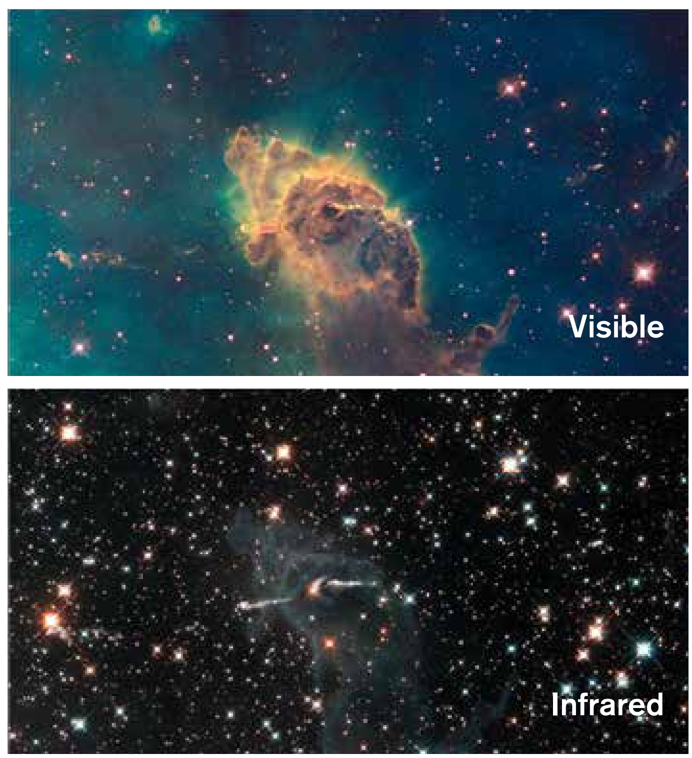
No single telescope is capable of seeing everything in the universe. It is important to remember that the light collected by these telescopes breaks down into the many wavelengths of the **electromagnetic spectrum**, and that different wavelengths are better for seeing different things.



Electromagnetic spectrum, from highest energy (gamma rays) to lowest energy (radio waves). *Image: Cool Cosmos/IPAC.*

For example, the **Hubble Space Telescope (Hubble)**, which has sent back some of the clearest and most exciting images of the universe, is designed to look primarily in *visual* wavelengths of light. Generally, Hubble excels at observing phenomena like stars, galaxies, and nebulae.

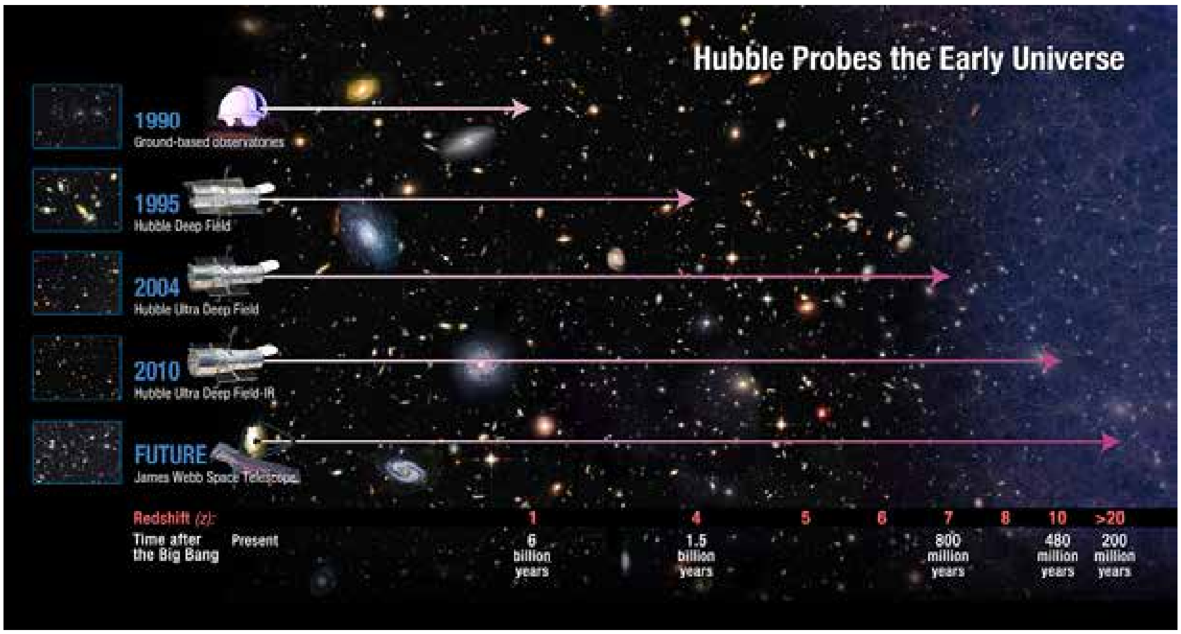
The upcoming **James Webb Space Telescope (Webb)**, on the other hand, is designed to observe primarily in the *infrared*. Infrared light is invisible to the human eye, and is commonly perceived as heat. Essentially, Webb can see warm objects like young stars and planets because in infrared, they outshine the colder dust clouds that may surround them. These same clouds would be opaque to Hubble.



Examples of the difference between visible and infrared observations. This is an image of the same section of a dust pillar in the Carina Nebula. The dust is brightly illuminated in the visible image, while the infrared image makes it possible to see through the dust to the young stars within. *Image: Hubble/NASA.*

At the same time, observing in the infrared also allows Webb to "see" farther into the universe, which correlates to looking back in time at the earliest galaxies.

Because the universe is expanding, effectively moving away from us in all directions, the visible light from more distant galaxies becomes stretched out to longer wavelengths, such as the infrared. We call this phenomenon **redshift**. For objects at greater distances from us, this redshift is more pronounced.



Relative viewing distances for recent telescopes. The farther into the universe (and back in time) you look, the more shifted the light becomes, making Webb the ideal candidate for observing the early universe.

Image: NASA.

Parts of the universe have expanded so far from us that the light from those galaxies has redshifted beyond Hubble's range of vision. This highlights the benefit of infrared telescopes like Webb, which are capable of seeing the wavelengths into which this distant light has shifted.

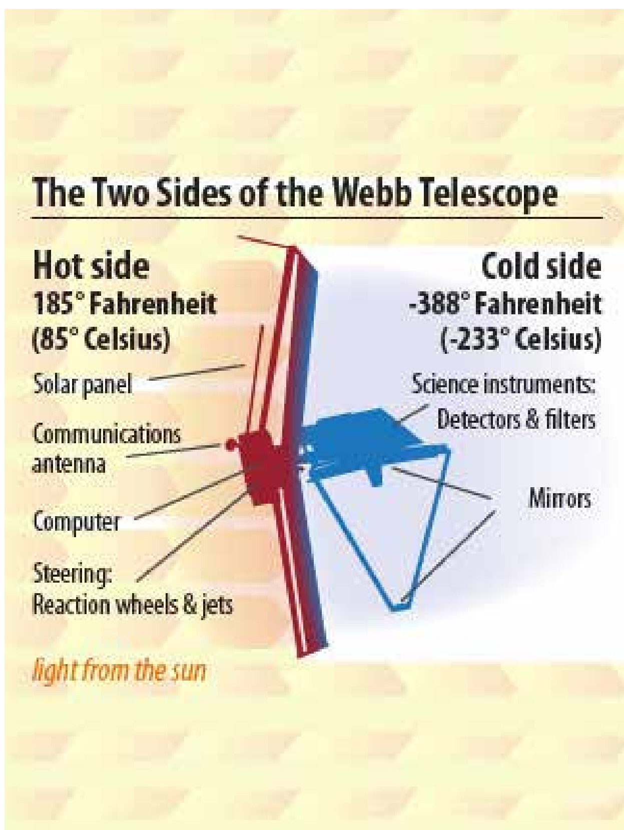
WHO IS JAMES WEBB?

James Webb, the namesake of the James Webb Space Telescope, was the NASA administrator from 1961 – 1968. Though he retired before the historic Moon landing in 1969, he was in charge of NASA during the time leading up to and preparing for the Apollo missions.

How Do You Keep A Telescope Cold?

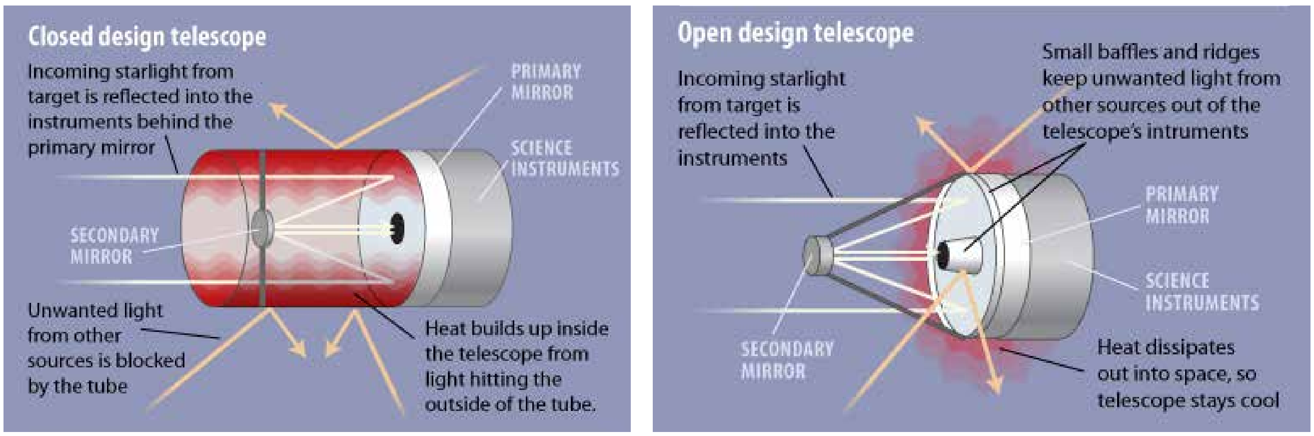
In space, electromagnetic radiation is everywhere, coming from a multitude of sources. For example, the infrared radiation (heat) coming from Earth would overwhelm Webb's sensors if the telescope were in Earth orbit. Additionally, any heat from the telescope's own computers would register as infrared radiation that could affect the observations. As a result, incredibly intricate engineering had to go into Webb's design and orbit to keep it as cold as possible.

For the physical design of Webb, engineers came up with some ingenious solutions to get rid of excess heat. First, Webb has a huge **sunshield**. Each of the sunshield's five layers is made of materials designed to be either heat-resistant or reflective, bouncing as much sunlight and stray heat back into space as possible. To maximize its efficiency, the sunshield will always be oriented perpendicular to the Sun's light, essentially forming a wall between the Sun and Webb's most sensitive instruments and mirrors.



Locations of the Webb instruments and hardware, divided onto different sides of the sunshield to deal with solar radiation.
Image: NASA/STSci.

Second, Webb has no "tube." A typical telescope tube helps block out unwanted light, but unfortunately traps heat inside it as well. Webb's **open design** will allow it to effectively radiate unwanted heat back into space, and blocks unwanted light using special ridges.



Differences between a closed and open design telescope. Webb takes advantage of open design to help dissipate heat more effectively. *Image: NASA/STSci.*

The materials chosen for Webb's mirror segments were also important engineering decisions. While most people may be familiar with telescope mirrors made of glass, Webb's mirrors were instead made of an element called beryllium. Beryllium was chosen because it is strong, light, and – most importantly – holds its shape reliably over a wide range of temperatures, which was important because Webb will be kept so cold.

A very thin coating of gold was added on top of the beryllium segments because gold is a better reflector of infrared light. Depending on the desired wavelengths, telescope mirrors are coated in a variety of materials, such as aluminum, silver, or gold.

Webb's planned position in space has also been carefully engineered. To escape radiant heat from Earth and the Moon, Webb will be located on the far side of the Earth, away from the Sun, and well beyond the orbit of the Moon. In the Sun-Earth system (or any two-body system), there are five special points where you can put a small mass, like a spacecraft, and have it stay in that position with respect to the Sun and Earth. These are **Lagrange points**, and are called "L1, L2, L3, L4, and L5." The Lagrange point of interest in Webb's case is L2, which is ideal for the telescope because it can still easily communicate with Earth and have a relatively unobstructed view of space.

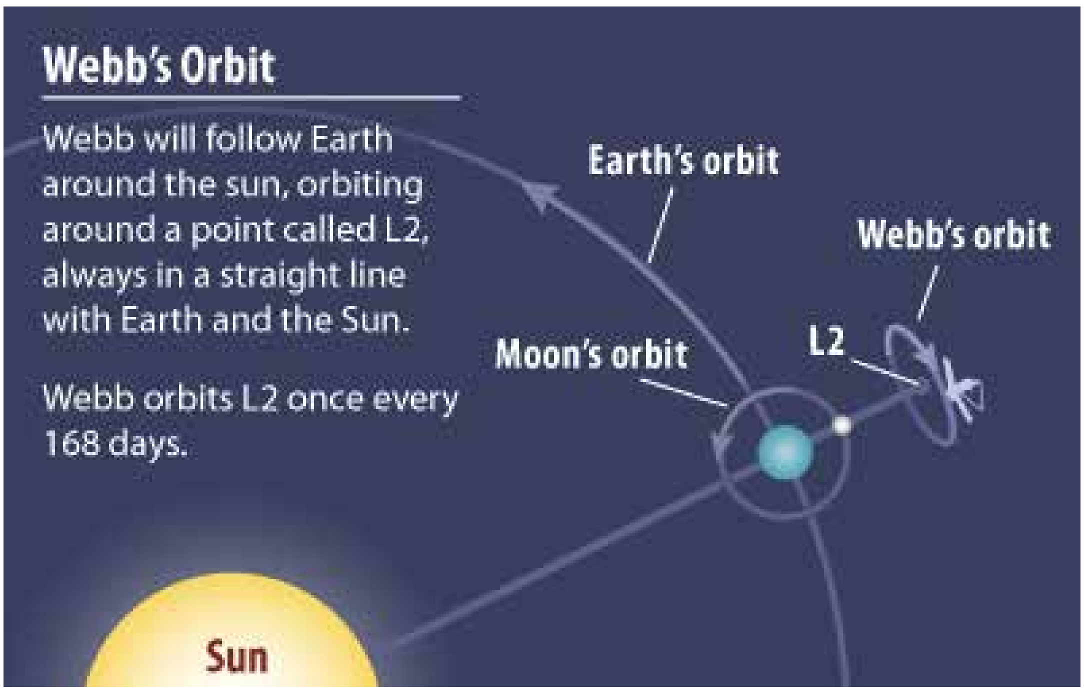


Diagram of Webb's location in space at L2. Note that at L2, Webb is still actually orbiting a point in space.

Image: NASA/STSci.

Conclusion

The engineering behind Webb's design and mission planning will allow the telescope to make some of the best observations of the universe to date. Keeping the spacecraft as cold as possible means that Webb can search the infrared for mysteries shrouded in interstellar clouds and for galaxies far back in the infancy of the universe.

Online Learning Tools

These websites are intended to provide access to further information about the electromagnetic spectrum and infrared light.

Cool Cosmos

coolcosmos.ipac.caltech.edu
Offers lessons and activities involving infrared light.

NASA Wavelength

nasawavelength.org
NASA Resources for Earth and Space Science Education.

The James Webb Space Telescope – Technology at the Extremes

webbtelescope.org/webb_telescope/technology_at_the_extremes/keep_it_cold.phpv
An in-depth discussion of the engineering challenge behind keeping Webb cold.

What Are Lagrange Points?

esa.int/Our_Activities/Operations/What_are_Lagrange_points
A more detailed explanation, with illustrations, of Lagrange points in space.

What Is Infrared?

coolcosmos.ipac.caltech.edu/page/what_is_infrared
More details regarding infrared light and its uses in astronomy.

What Is a Redshift?

spitzer.caltech.edu/video-audio/125-ask2006-001-What-Is-a-Redshift-
Video explaining the concept of redshift in the context of Doppler shift and sound.

Glossary of Terms

Electromagnetic spectrum The range of all types of electromagnetic radiation. Astronomers use different wavelengths within the spectrum to observe different phenomena in the universe.

Hubble Space Telescope A telescope carried into Earth orbit by Space Shuttle *Discovery* in 1990. It is designed specifically to see in the near-ultraviolet, visual, and near-infrared parts of the electromagnetic spectrum.

James Webb Space Telescope A telescope scheduled to be launched into space during or after 2018. Webb is designed to look primarily in the infrared part of the electromagnetic spectrum.

Lagrange point One of a set of five gravitationally stable points defined by a smaller mass (like a planet) orbiting a larger mass (like a star). A much smaller mass (like a spacecraft) can orbit in tandem with two larger objects (like the Earth and the Sun).

Open design telescope A telescope design that does not involve using a traditional tube for collecting and focusing light. Webb uses an open design to avoid trapping unwanted heat inside a tube.

Redshift A phenomenon where the light/electromagnetic radiation from an object is stretched or increased in wavelength, shifting it to the "redder" part of the electromagnetic spectrum due to the motion of the object away from the detector.

Sunshield In the case of Webb, the sunshield is made of five layers of highly reflective and heat-resistant materials to block as much heat as possible from reaching the light-collecting instruments.

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