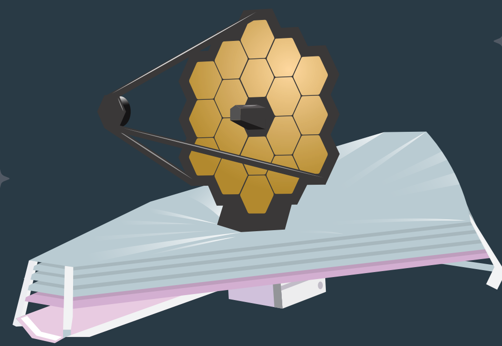
DESTINATION SPACE!



The James Webb Space Telescope

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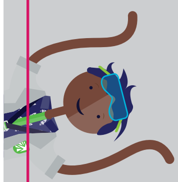
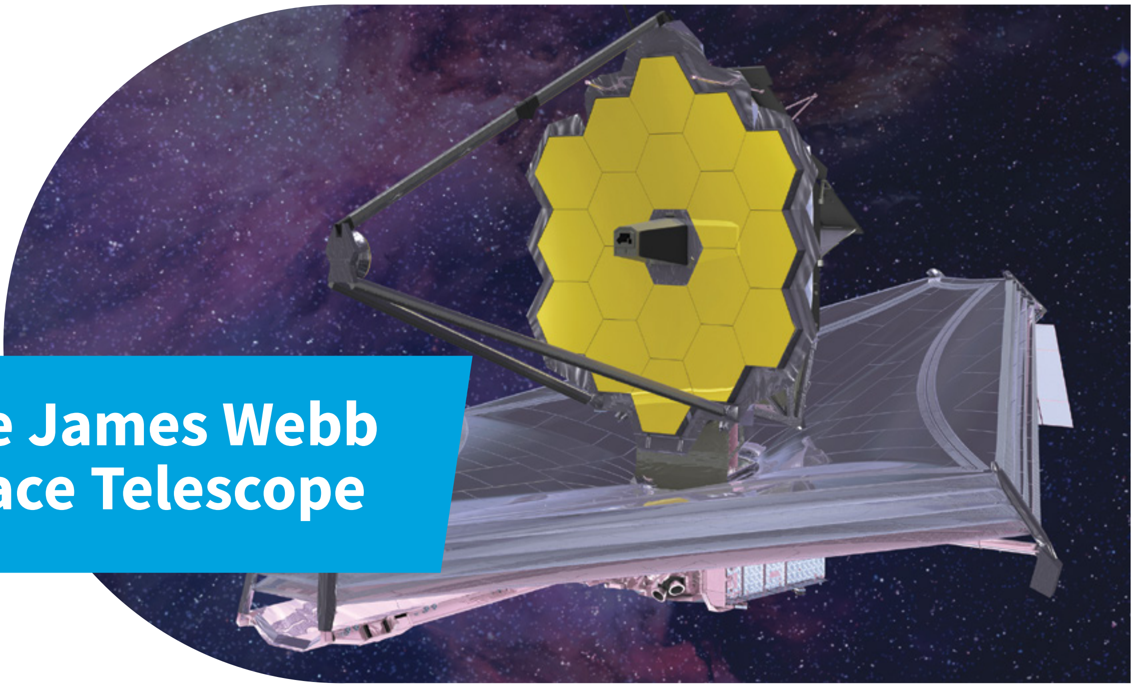


The James Webb Space Telescope



The James Webb Space Telescope is the biggest and the most ambitious space observatory ever to be launched. It has been built to look at the Universe in new ways to help answer some of the biggest questions in astronomy, such as 'how did the first stars and galaxies form?', 'how are planets actually made?' and 'are there Earth-like planets out there?'

What is the James Webb Space Telescope?

The James Webb Space Telescope is a very large, space-based telescope that sees in infrared.

The Webb Telescope's primary mirror spans over 6.5m, twice the diameter of the Hubble mirror and six times its area. This means it has 400 times greater sensitivity than current infrared space telescopes.

Looking in infrared means that Webb can see deep into dust clouds where stars and planets form, and observe the light from the most distant stars and galaxies.

The Webb Telescope is currently scheduled for launch in spring 2021 on an Ariane 5 rocket. Launched by the European Space Agency (ESA) from their site in French Guiana, it will then travel to its new home, 1.5 million kilometres from Earth to Lagrange point 2 (see page 57 for more info on this).

A great source of UK pride is that Webb's coolest (and coldest) science instrument had significant UK contributions. MIRI, the Mid-Infrared Instrument, looks at longer wavelengths than any other Webb detector. This ability is particularly exciting as it will allow us to see the most distant stars and galaxies.

Why is the Webb Telescope in space?

Space telescopes are able to get a better view than ground-based ones, as they don't need to peer through the dusty, water-laden and turbulent atmosphere. This is particularly true of infrared telescopes because water vapour absorbs infrared, making the sky mostly opaque to these wavelengths.

But there is another big reason: Earth is warm and warm things give out infrared light. For Webb's sensitive detectors, Earth is blindingly bright with an infrared glow that would warm the telescope, overwhelming faint signals from the distant Universe. Webb must be far enough away that its sunshield can hide not only the Sun but also the Earth and Moon.

Image: Artist's impression of the Webb Telescope. Credit: NASA, Northrop Grumman

An international team effort

The Webb Telescope will be the premier observatory of the next decade, built and used by scientists across the globe. It is a huge and complex project that has required significant technological innovation.

The initial proposal to build Webb was put forward over 20 years ago. Since then, its development and construction has been an immense, international collaboration. It is jointly funded by NASA, ESA and the Canadian Space Agency. The cost of the telescope over the lifetime of the mission is estimated at over $USD 10 billion, the vast majority of which has paid the salaries of the thousands of scientists and engineers from around the world who have collaborated to make this project possible.

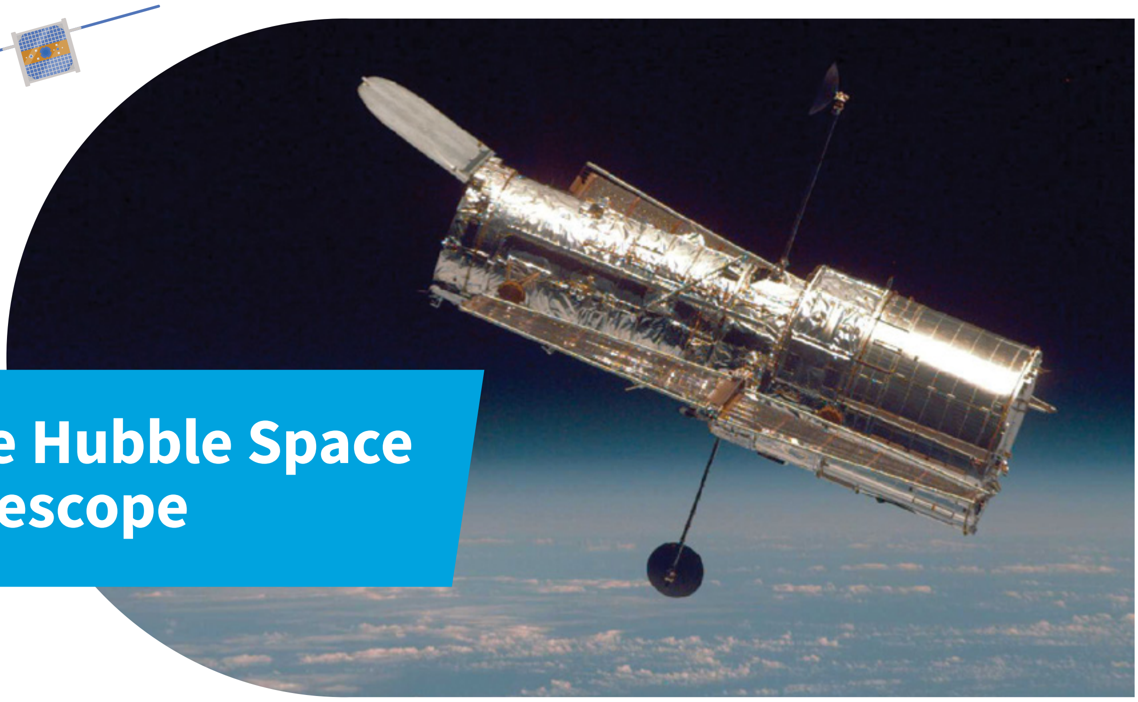
Webb is designed as a general purpose observatory, meaning that in principle anyone can use it: time is awarded on the basis of peer review. So although we know what it is designed to do, it will be up to the worldwide scientific community to decide how it is actually used. The Webb Telescope truly is an immense international team effort, driven by an ambition to discover more and unlock the biggest mysteries of the Universe.

Who was James Webb?

James Edwin Webb (1906–1992) was the administrator of the National Aeronautics and Space Administration (NASA) between 1961 and 1968. Webb wasn't a scientist or engineer; he was a trained businessman and attorney who had served under President Harry Truman.

Webb was originally reluctant to take up President John F. Kennedy's offer of the job of NASA administrator, assuming that it might be better handled by someone with a science or technology background. However, he led the development of NASA's Apollo missions and during his tenure was responsible for more than 75 launches. Thanks to his efforts, humankind got their first crewed missions to the Moon.

Middle image: The Antennae galaxies, A merging pair of galaxies, Credit: NASA, ESA and the Hubble Heritage Team (STSci/AURA)-ESA/Hubble Collaboration). Bottom image: James Edwin Webb



The Hubble Space Telescope

The Hubble Space Telescope is a large telescope orbiting the Earth. It is about the length of a bus and weighs as much as two adult elephants. Powered by the Sun, Hubble looks in the visible, ultraviolet and some near-infrared parts of the spectrum. Since its launch in 1990, Hubble has made more than 1.3 million observations.

Hubble's greatest hits

The Hubble Space Telescope orbits Earth just 545km above the ground. Here, above the light-polluted and distorting atmosphere, it enjoys a beautifully clear view of the Universe. This has allowed Hubble to capture some of the most iconic astronomical images of all time, including the 'Hubble Ultra Deep Field', which captured the most distant galaxies seen to date.

Top image: The Hubble Space Telscope begins its separation from Space Shuttle Discovery. Credit: NASA
Bottom left: The Hubble Ultra Deep Field. Credit: NASA and ESA

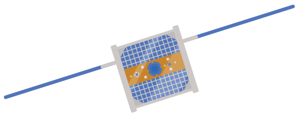
Hubble has played a central role in some of the most profound space science discoveries, from the birth and death of stars to volcanic eruptions on the moons of Jupiter. It has helped us estimate the age and size of the Universe, detected black holes and mysterious gamma-ray bursts, and played a key role in the discovery of dark energy.

Beyond Hubble

The Hubble Space Telescope is unique in that it could be visited while in space. Five space-shuttle missions have carried astronauts to repair or upgrade the telescope. Hubble is still going strong, easily outliving its proposed 15-year lifetime; however, there are no plans for future service missions and its orbit is slowly decaying.

The James Webb Telescope is considered Hubble's successor, but it has very different abilities. Hubble sees the Universe mostly in visible and ultraviolet light (0.1 - 0.8 microns, with some capability up to 2.5 microns), while Webb is optimised for operation at near-infrared to mid-infrared wavelengths (0.6-28 microns).

When Hubble dies, we will no longer have ultraviolet telescope capability. So, beyond Hubble and beyond Webb, could a new, ultraviolet space telescope be the next big mission?



Focusing on discovery

Looking back in time

The James Webb Space Telescope will collect data to investigate four key science themes: 'First light and reionization', 'Galaxy building', 'The birth of stars and planets' and 'The origins of life'

First light

Detection of first light refers to light from the first stars in the first galaxies, the farthest and oldest lights in the Universe.

Immediately after the Big Bang, 13.7 billion years ago, the Universe was a hot, dense, opaque soup of highly charged particles and radiation.

As the Universe expanded, it cooled, and particles combined to form atoms (mostly hydrogen and helium). At this point, the Universe became transparent, light was decoupled from matter, and 380,000 years after the Big Bang, intense light was emitted all over the Universe (we are now able to observe this light at microwaves, known as the cosmic microwave background).

There weren't any stars yet, so it was very dark. Later, the atoms' gravity pulled them together into the compressed balls of gas that became the first stars. These early stars ended the dark ages. But very little is known about them, they may have been ordinary or massive, perhaps up to 1,000 times the mass of our Sun and millions of times brighter. Whether they formed as single stars on in groups, or how the developed into galaxies is yet to be understood.

Massive stars explode as supernovae at the end of their short lives, with the cores of the very biggest stars collapsing to form black holes. Supernovae are very bright, and black holes can cause infalling matter to emit bright X-rays (micro-quasars).

The Universe is largely empty, and so ancient light from these bright events will still be travelling through space.

The continued expansion of the Universe means that the space between objects stretches, causing objects (galaxies) to move away from each other. The light's wavelengths travelling through the Universe from these ancient events will have been stretched out (redshifted) and would now be found in the infrared and should be observable by the Webb Telescope.

Detecting the light from this cosmic dawn, such as the death throes of these first generation stars, would be a fantastic discovery. The Webb Telescope can view objects that are older, further away, as well as viewing objects within our own galaxy in unprecedented resolution.

Galaxy building

Galaxies are vast assemblies of stars, accompanied by interstellar gas, dust and invisible dark matter. Galaxies are held together by their own gravity. Using telescopes like the Hubble Space Telescope and large ground-based telescopes, astronomers have detected hundreds of millions of galaxies. If you hold up a grain of sand, we believe the patch of sky it covers contains 10,000 galaxies! Webb is going to extend the knowledge we have from Hubble and ground based telescopes, as we close in on being able to view the first galaxies that ever formed.

Image: Artist's impression of the first stars in the Universe. Credit: NASA/JPL-Caltech/R. Hurt (SSC)

We know that galaxy structure and distribution changes through time. Scientists use observations, theory and computer simulations to investigate how this might happen. Current theories of how the first galaxies formed suggest that star clusters merged to form galaxies, which then came together to form clusters of galaxies. However, this is not certain and, despite all the work done to date, we still do not know exactly how galaxies form, what controls their shape, what triggers star formation and active galactic nuclei or how chemical elements are redistributed across a galaxy.

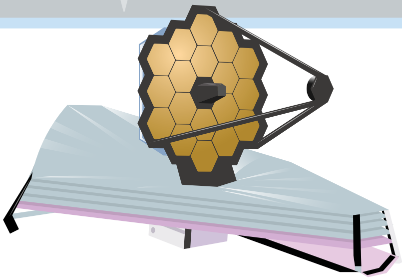
Many questions are still to be answered. The Webb Telescope will observe very distant galaxies, Specifically, MIRI (an instrument that views in the mid-infrared) is uniquely sensitive to both star formation and active galactic nuclei (AGN) activity in galaxies.

Webb will be capturing the light that left these galaxies many billions of years ago when the Universe was young, and the first galaxies were still forming. These early galaxy surveys will help scientists understand these longer-term changes that have occurred in our and other galaxies.

The birth of stars and their planets

It is less than a hundred years since our discovery that stars are powered by nuclear fusion, and that new stars are continually being born in our galaxy. We now know that stars form from dark, dusty clouds of gas. But how does this actually happen?

The Webb Telescope will observe newly born stars, still shrouded in their protoplanetary discs. These dense discs of gas and dust hide the details of planet formation from telescopes like Hubble but are transparent to infrared, allowing Webb to peek inside for our first ever high-resolution view of this process.



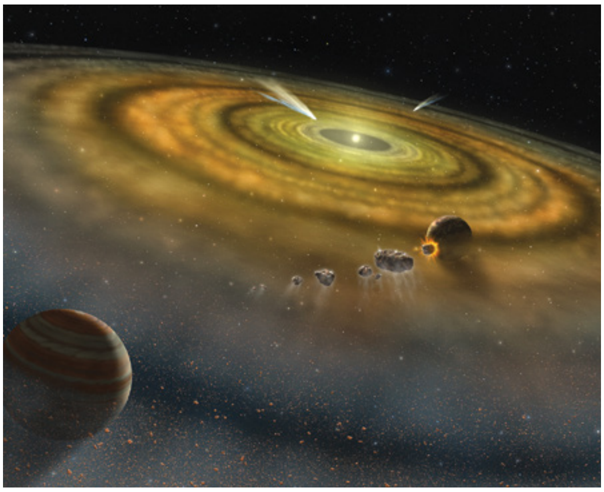


Image: Artist's impression of solar system formation. Credit: NASA

Using spectroscopy and other techniques, Webb will also be able to analyse the makeup of the dust and gas that is building protostars. Scientists will be looking for clues as to why stars most often form in groups, how turbulence within protoplanetary discs affects planet formation, and why so many stars have giant planets orbiting so close to them.

Webb may help us answer the mystery of why the structure of our own solar system currently appears to be unusual in the galaxy.

The origins of life

In order to understand life on Earth, we can study not only the initial formation of planets but also how they evolve through time, such as how organic molecules develop that are so important for life here on Earth.

Webb will be used to probe into the heart of solar systems and explore physical and chemical properties of exoplanets at various stages of their development. Most incredibly, it will be able to analyse exoplanet atmospheres using spectroscopy. This gives the potential to spot the chemical signatures of ozone, methane, carbon dioxide and water and to track seasonal changes or even clouds. Although we must be cautious about saying a planet around a distant star supports life, perhaps we might discover a planet with a similar atmosphere to Earth.

Watch this space

There are many questions about the Universe that we cannot yet answer with existing telescopes. Webb will provide us with a whole new view of the Universe. The four primary science goals are cutting edge areas of interest in modern astronomy. But the real excitement will come from the many discoveries that we have not planned for and cannot predict. Who knows what we might discover?

What does Webb look like?

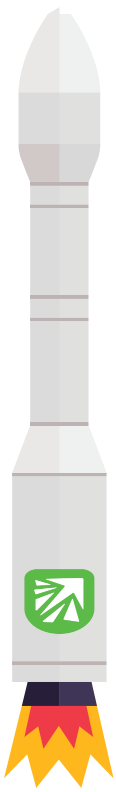
The delicate sunshield of the James Webb Space Telescope is the size of a tennis court, and its golden dish is three times higher than an average room. Three eight-metre struts reach out toward the main dish, holding the secondary mirror.
This massive telescope needs to fit inside the top of a rocket for launch.
Elegant and intricate mechanisms have been devised to fold the telescope for launch, and to unfurl it when in space.

Origami skills

The Webb Telescope is currently scheduled to launch in spring 2021 onboard an Ariane 5 rocket.

The telescope is around 8m x 14m x 21m. But the space in the nose cone of the rocket is only 4.6m diameter x 16.2m. To fit inside, Webb needs to be carefully folded. Once safely in space and on its way to its observing location, the Webb Telescope will slowly unfurl.

Watch great videos of the full unfolding process on the James Webb Space Telescope YouTube channel at **youtube.com/user/NASAWebbTelescope**



Anatomy of a space telescope

The Webb Telescope has four main sections:

1. The optical telescope element (the light-catcher)
2. The sunshield (to keep it cool)
3. The spacecraft bus (the support systems)
4. The integrated science instrument module (the detectors)

The optical telescope element

The huge primary mirror comprises 18 hexagonal segments, each 1.32m across. These assemble to create a 6.5m dish with a gap in the middle, totalling 25m² in surface area.

Below their shiny surfaces, the mirror segments are made of beryllium, a rare metal with excellent temperature stability. Each segment can be independently adjusted as required.

The light-collecting surfaces are covered in gold, which is highly reflective to infra-red. However, gold is not thermally stable and so this layer is extremely thin, only about 1,000 atoms thick.

For more information about the optical telescope element and for a mirror-assembly activity, see elsewhere in this section.

Image: Full-scale model of James Webb Space Telescope at South by Southwest in Texas, with people in the foreground for an idea of scale.
Credit: NASA/Chris Gunn

The sunshield

The Webb Telescope detects infrared. Warmer things emit more infrared so the telescope side of the spacecraft must be kept extremely cold to ensure it is not blinded by its own warm glow. The sunshield does most of this work. Webb will be located far from Earth, so that its sunshield is able to block out warming radiation not only from the Sun, but also the Earth and Moon.

The sunshield is made of a very thin material called Kapton and has five separate layers, minimising heat conduction from front to back. The sunward side will be about 110°C while the telescope side is kept at a cool -223°C.

The enormous challenge of building this complex structure has led to mission delays. With no option for post-launch adjustments, it is vital that the unfurling works perfectly first time. There will be several test deployments before launch to refine this mechanism, although we can't fully replicate the zero gravity deployment conditions on Earth which it will be subjected to in space.

See the 'Thermal Properties of Materials' (expansion to the Infrared activities) to explore how the sunshield works.

The spacecraft bus

This part of the telescope provides vital support functions such as propulsion, power (from solar panels), data management, communication and thermal control.

The integrated science instrument module

The Webb Telescope's integrated science instrument module contains four main science instruments:

a Near-Infrared/Visible Camera (NIRCam)

b Near-Infrared Spectrograph (NIRSpec)

c Mid-Infrared Instrument (MIRI)

d Fine Guidance Sensor/Near-Infrared Imager and Slitless Spectrograph (FGS/NIRISS)

Incoming light can be split between the different instruments as required. Between them, they are sensitive to a broad spectrum of infrared light, allowing for varied types of analysis.

Using the 3D printed model

Use the model of the James Webb Space Telescope to discuss its various parts using the descriptions on these pages. Don't forget to talk a bit more about the mirror, the heatshield and the science instruments.

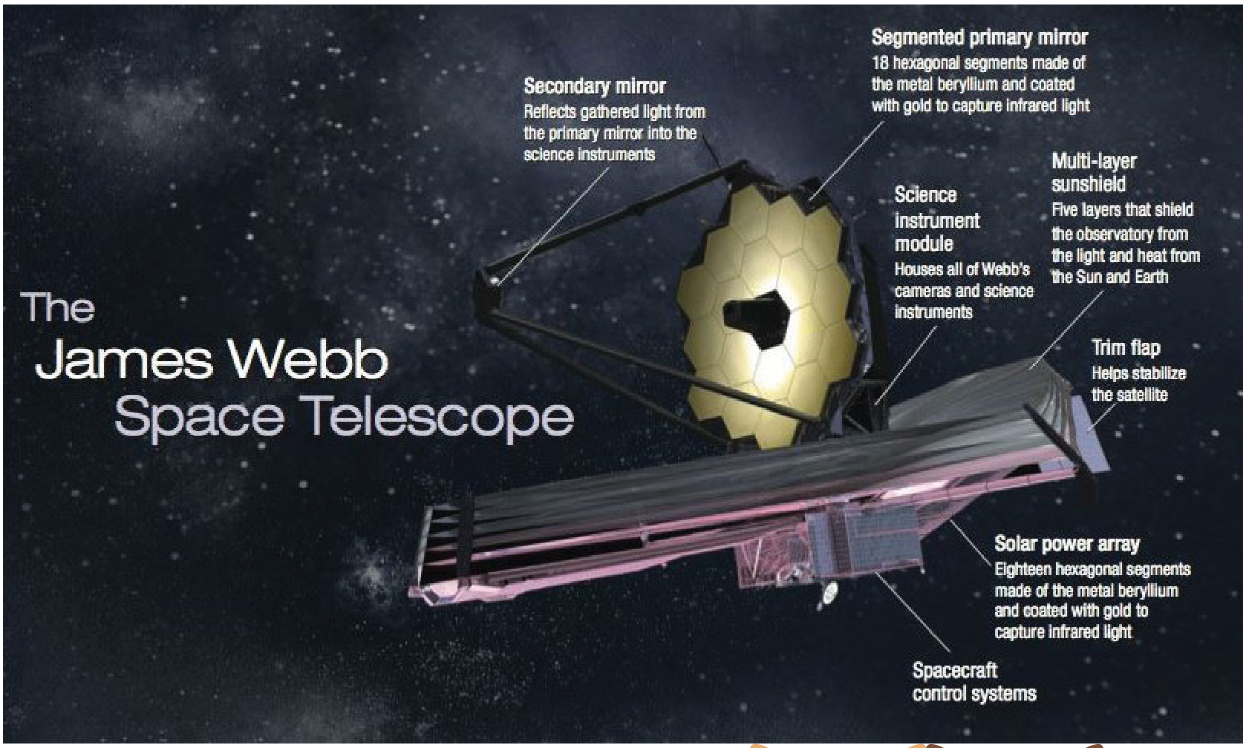
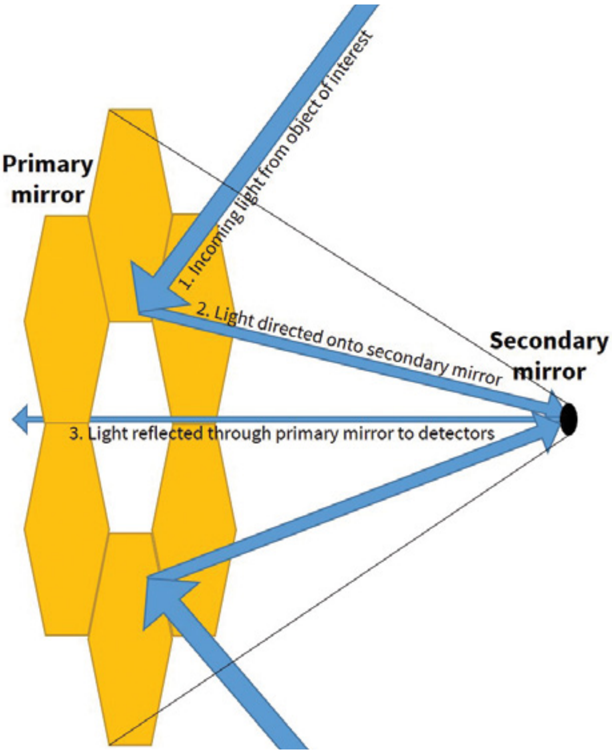


Image: Annotated image of James Webb Space Telescope. Credit: NASA

Building the mirror

The James Webb Space Telescope's primary mirror is surely its most iconic feature. At 6.5m and 705kg, it is significantly larger than that of any previous space telescope. It is so large that it has to be folded to fit inside the rocket.
Its golden surface is the collecting surface for incoming infrared light, making the mirror's 25m² area comparable to that of the pupil of an eye.



Mirror function

The primary mirror's job is to reflect incoming light from the object of interest, directing the light onto a smaller, secondary mirror held out in front by struts. From here, the light is reflected back and through the centre of the primary mirror, into the detectors.

The golden surface is excellent at reflecting infra-red, but it is only about 1000 atoms thick. The segments are mostly constructed from beryllium, a strong but lightweight and very thermally-stable metal.

The NIRCam instrument monitors the incoming light and adjusts the 18 mirror segments, as required to optimise focus and performance. Each 1.32 metre segment can be independently aligned to an accuracy of 1/10,000th of the thickness of a human hair.

Its huge mirror and sensitive detectors mean that Webb could repeat the (infrared) Spitzer Space Telescope's 550 hour observations in just 30 minutes.

Cool light needs big mirrors

A telescope's resolution is closely related to how many times you can fit the light's wavelength across its primary collecting surface. Infrared has a longer wavelength than normal light, and so makes lower-resolution images for a given mirror size.

Image: Engineers and technicians undertaking first optical measurement of Webb's primary mirror. Credit: NASA/Goddard/Chris Gunn

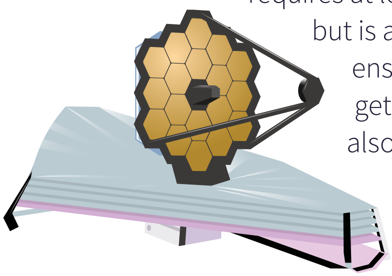
This is why Hubble's near-infra-red images are quite fuzzy compared to its stunningly sharp visible-light images. Webb will be able to achieve an infrared resolution similar to that which Hubble achieves for visible light, which is enough to see a penny from a distance of 40km.

How to run the activity

The provided mirror segments can be assembled to create a scale model where the total size is equal to just one segment of the real Webb mirror.

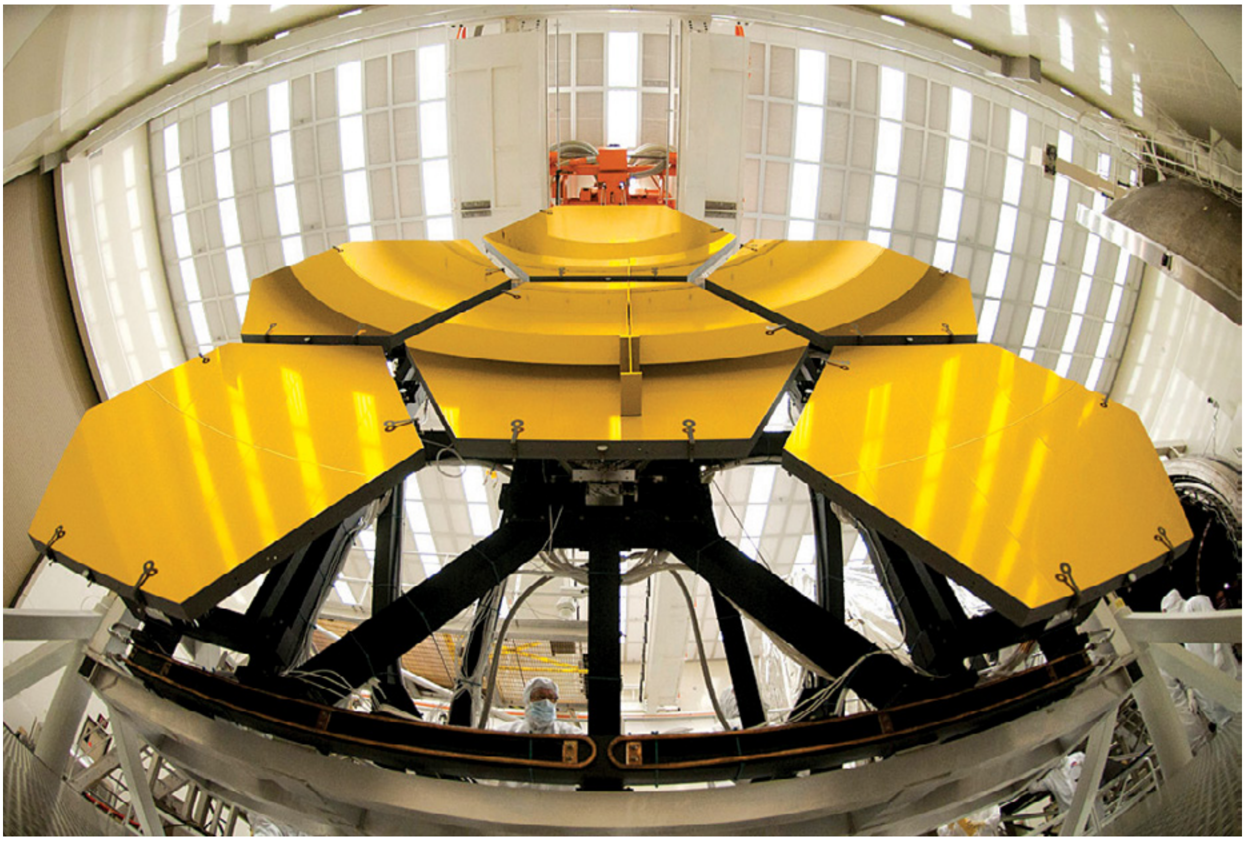
The segments can be assembled on the floor or a large table. You may choose to have a picture of Webb for them to use as a reference, or not. With a reference picture, a group of KS2 can complete the jigsaw very quickly.

Alternatively, have people hold them up, this requires at least nine people but is a great way to ensure everyone gets involved. It also slows down the activity and encourages discussion.



Once the mirror is assembled, get participants thinking about the design:

- Why is there a hole in the middle? Discuss the path the light takes.
- This is the size of one segment of the real mirror. Calculate/imagine how much space the real mirror would take up in this room.
- Compare to the size of the pupil mask to see how much the light is focused during its journey to the detectors.



Top right: Children assembling the James Webb mirror model. Credit: Guildford Astronomical Society
Bottom image: James Webb Space Telescope Mirrors undergoing cryogenic testing. Credit: Ball Aerospace

What can the Webb Telescope see?

Science instruments on-board

Scientists across the world were asked to propose ideas for science instruments to be included on the telescope. The four main instruments were chosen to have contrasting capabilities. Together, they allow us to investigate a wide variety of objects to different purposes, offering sensitivity across a broad spectrum of infrared light, for both direct imaging and spectral analysis.

The Near-Infrared/Visible Camera (NIRCam)

NIRCam takes pictures using near-infrared light (0.6-5 microns). There are several infrared activities later in this section as well as a nebula board demonstration to link to NIRCam and the other Webb Telescope science instruments.

NIRCam will image objects ranging from galaxies to proto-planetary discs. Coronagraphs (small discs) allow it to block out a star's light to image much fainter nearby objects such as orbiting planets. It can also carry out some spectroscopy.

Additionally, it will be used to analyse light reflecting from Webb's primary mirror, providing information to help fine tune the position and angle of each segment.

NIRCam was built by the University of Arizona and Lockheed Martin.

Image: M51, the Whirlpool Galaxy captured by Hubble. How much further will Webb see? Credit: NASA/ESA. Bottom image: Eagle nebula comparison, visible (left) and near infrared (right). Credit: NASA

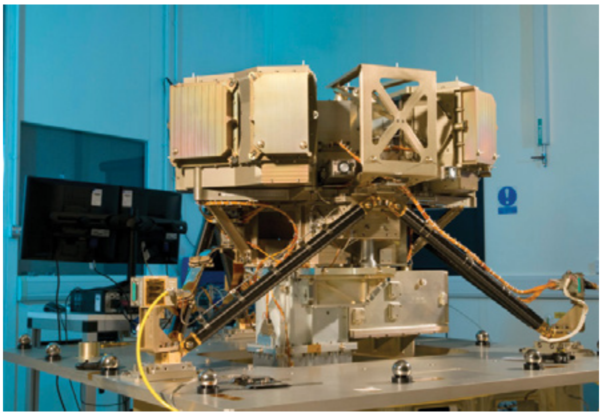
The Near-Infrared Spectrograph (NIRSpec)

NIRSpect analyses near-infrared spectra (0.6-5 microns).

By looking in detail at how an object's light intensity varies across its wavelengths, it is possible to get information about an object's temperature, mass, and even to identify particular atoms and molecules in the object. NIRspec is able to analyse over 100 objects at one time.

NIRspec will be able to investigate the chemical composition of exoplanet atmospheres as well as the chemical makeup and evolution of distant galaxies.

NIRSpec was funded by ESA and built in Germany by Astrium with contributions by NASA and some UK involvement.



The Mid-Infrared Instrument (MIRI)

MIRI takes pictures and analyses spectra in the mid-infrared range (5-28 microns).

MIRI can see longer wavelengths than any of the other detectors. This means it can see more distant objects than the other instruments, and also spot cooler objects, including comets and newly forming stars. MIRI's camera is so incredibly sensitive that it could detect the heat from a candle on one of Jupiter's moons.

MIRI will also be able to image the cool dust clouds warmed by starlight, giving us fresh information about the structure of planet-forming regions.

Because it detects 'cooler' light than the other instruments, MIRI itself must be kept extra-cold. A 'space fridge' will be used to cool MIRI to a frigid -266°C (the other instruments being at a relatively balmy -223°C).

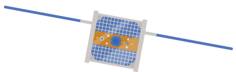
MIRI was developed in a collaborative effort between scientists and engineers from ten European countries, led by the UK and the Jet Propulsion Laboratory (JPL), with the support of ESA and NASA. The UK team is made up of a partnership between the Science and Technology Facilities Council in the form of STFC RAL Space and UK Astronomy Technology Centre (ATC), University of Leicester, and Airbus Defence and Space. The project received funding from the UK Space Agency and ESA. The European Principal Investigator (PI) is Professor Gillian Wright who is Director of STFC's UK ATC in Edinburgh.

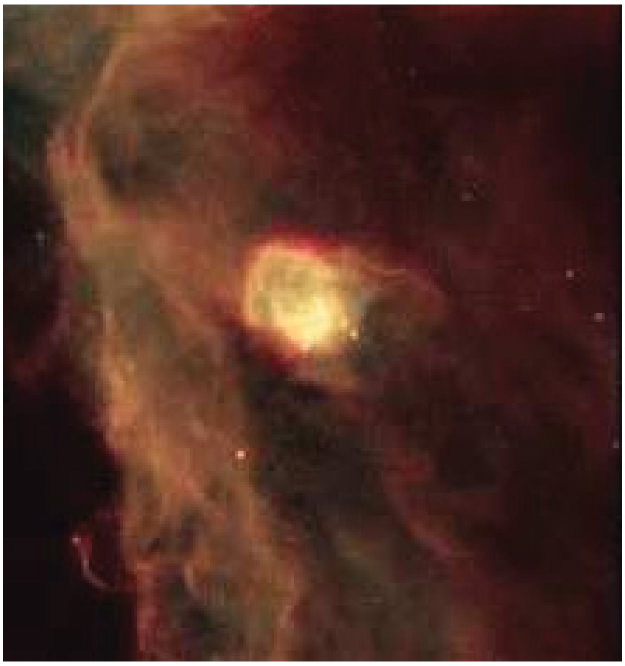
The Fine Guidance Sensor/Near InfraRed Imager and Slitless Spectrograph (FGS/NIRISS).

FGS helps guide the telescope to point precisely. NIRISS analyses near-infrared spectra at infrared (0.8-5 microns).

NIRISS compliments the other detectors and will be used for 'First light' detection and to discover and investigate exoplanets, including using its capability to analyse their spectra as they pass in front of their stars.

FGS/NIRISS was constructed by the Canadian Space Agency.





Top Image: The Mid-Infrared Instrument (MIRI) in Oxfordshire. Credit: RAL
Bottom image: Horsehead nebula comparison visible (left) and mid infrared (right). Credit: NASA

Infrared (IR) camera

Exploring our invisible universe

Infrared radiation is another type of light that we interpret as heat. In order to see through clouds of dust and gas in space (using near-infrared) and observe the fine structures of these clouds (in longer wavelengths) we are sending a tennis court-sized telescope into space.

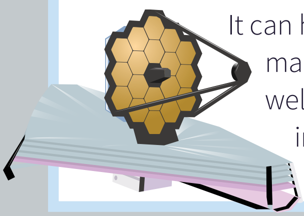
How it works

Electromagnetic radiation is emitted across a spectrum of wavelengths. Wavelengths that are a little too long for us to detect with our eyes are in the infrared (IR) part of the spectrum.

One way that IR radiation is produced, is through molecular vibrations in materials. Although we cannot see it, we detect it through our skin in the form of heat.

The James Webb Space Telescope is optimised for operation at near-infrared to mid-infrared wavelengths, giving scientists the ability to image the most distant galaxies and objects all the way down to newly formed planets obscured by dust and gas.

The IR camera used in these demonstrations contains electronic sensors that detect infrared radiation and convert it to a visible image. It can help to explain the observations made with the Webb Telescope as well as looking at thermal transfer in spacecraft.



How to run the demonstrations

'Seeing through' dust clouds

Vast regions of star birth and death are hidden by nebulae (clouds of dust and gas). Webb will detect IR radiation travelling through these nebulae making it possible to 'see' these hidden stars.

You can demonstrate that some materials are transparent to infrared radiation, even when they are opaque in visible light. Ask a volunteer to put their hand in a black bag. You will be able to view their hand using the IR camera.

Sunshield: demonstrating thermal reflection

Webb will study IR radiation from space. However, the Sun gives off a huge amount of IR radiation which would heat the telescope meaning any cosmic signal would be drowned out as the telescope detects itself. Webb has a huge shield to deflect the Sun's radiation so that the sensitive IR detectors stay cool enough to operate. The heat shield will also separate the detectors from the heat generated by the spacecraft itself.

This can be demonstrated using a mylar emergency blanket. Get a volunteer to hold the blanket in front of them and their thermal signature behind it will disappear due to reflection. If you have a whiteboard or window available, point the IR camera at it to observe your infrared reflection.

Keeping cool

Protecting the Webb Telescope from the Sun's heat

The James Webb Space Telescope is huge, mainly due to the huge Sunshield needed to keep the sensitive infrared instruments cool. This activity uses an infrared lamp to simulate the Sun, allowing visitors to consider what materials are best for such protection.

Keeping the Webb detectors cool

Observing distant infrared objects with a warm detector is like trying to see a candle flame a mile away while standing next to a stage light. To detect weak infrared signatures, we need a very cool detector. In fact, most of the detectors on the Webb Telescope need to be cooled to just 40K (-233°C).

The huge Sunshield has five layers of thin, reflective material. The first layer reflects most incoming infrared away, conducting and re-radiating only a small fraction through to the next layer, which reflects most of this infrared and so on. This is a very simple, but effective solution.

How to run the demonstration

You will need:

- Infrared lamp and hand-held infrared thermometer
- Squares of card backed with space blanket, bin bag and coloured paper
- Stopwatch

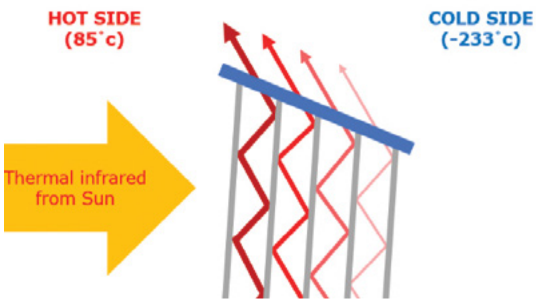
The infrared lamp represents the Sun, emitting infrared radiation. To find out which material is best for keeping the telescope cool, we must measure the temperature on the 'dark' side of the card.

Place a square 40cm away from the lamp. Get a member of the audience to point the thermometer at the 'dark side' of the card, standing off at an angle, so as not to look directly at the lamp.

Turn on the lamp for 20 seconds. Turn it off and note the temperature. Repeat with the other pieces of card and compare the results, which material kept the dark side coolest?

What does this show?

The space blanket shows the lowest temperature (it's the best material), reflecting most infrared away and allowing only a small amount to be conducted through the card and radiated to the thermometer. The black bag absorbs a lot of the infrared, becoming hot and re-radiating this heat. The coloured paper will perform somewhere in between.



Bottom image: Thermal effects of layers, Credit: National Space Academy

Seeing through a nebula

Seeing more stars with infrared

The nebula board is fitted with visible and infrared LEDs. When you view it with an infrared camera, a host of stars will emerge.

Looking for hidden stars

The Webb Telescope will look at really distant stars and the planetary systems around them.

One of the ways which NIRCam and MIRI will allow astronomers to observe planets orbiting stars, is by using something called a corongraph. This coronograph will block out the light of brighter objects, allowing much fainter ones to be seen, like shielding your eyes from the Sun to enjoy the view in front of you.

How the nebula board works

The board depicts the Carina nebula. A combination of visible (representing the stars you can see in visible light) and infrared (representing the stars that emerge only in infrared) LEDs are located at points corresponding to the locations of the most luminous stars.

As with the bin bag demo (see infrared camera demo), the longer wavelengths of near-infrared are able to pass through the clouds of dust and gas in the nebula to an observer. This is a good way of demonstrating how the James Webb Space Telescope uses infrared to see even more of the Universe.

How to run this activity

You will need:

- Nebula board
- Infrared Camera
- Bin bag (optional)

Explain that this nebula is a region of dust and gas in space where stars are forming. Since there is so much dust and gas, visible light cannot penetrate through to the observer.

Turn on the nebula board and point out the stars that you are able to see in visible light.

The infrared camera detects infrared light instead of visible light, converting infrared signals into a visible image. View the board with the infrared camera and ask the audience how many additional stars they can now see. The image above shows a comparison between the nebula in the visible and near-infrared spectra.

Health and safety

The diodes will become very hot if left on for too long. Make sure you switch the board off as soon as the demo is complete.

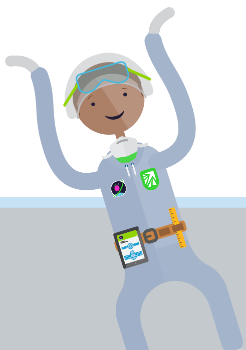


Image: Carina nebula comparison visible (left) and mid infrared (right). Credit: NASA

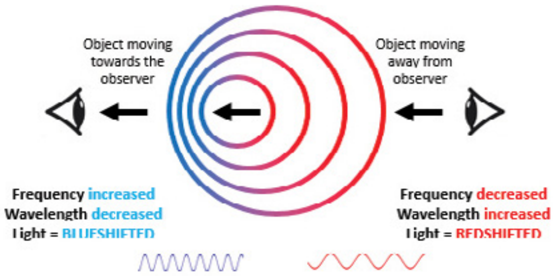
Redshift

Modelling the motion of objects through space with sound and stretch

Spectrum Lab is a free software program allowing users to visualise the frequency of a tone and observe the change in tone of an object moving away.

The Doppler effect

As an ambulance drives past, you can hear the pitch of its siren increase (while it comes towards you) and then decrease (as it moves away). This shift in tone is known as the Doppler effect. The same process occurs in light as in sound.



Shifting sounds demo

Note: a more in-depth guide to installing, setting up and using Spectrum Lab is available as a digital copy.

You will need:

- Computer with Spectrum Lab and microphone
- Phone or tablet with a tone generator app

Open Spectrum Lab. When first opened, you will see a rolling 'waterfall', showing you the frequencies of sounds that are present in the room. Select a tone of frequency 5,000 Hz on the tone generator app, you will see a strong peak on the frequency analyser, represented as a very bright line on the 'waterfall'.

Ask for a volunteer and get them to stand next to the computer. Hand them the tone generator and while the tone is being emitted, ask them to move swiftly away from the computer, holding the tone generator. As they move, the peak will be 'shifted' to a lower frequency on the 'waterfall'.

Discuss the results and talk about the Doppler effect.

Visually explaining redshift

Just as with sound, the frequency of light observed from an object will increase if an object is moving towards you and decrease if an object is moving away from you. The relationship between the frequency and wavelength of light is given by the wave equation:

$$\textit{wave speed} = \textit{frequency} \times \textit{wavelength}$$

Since the speed of light is constant, that means that frequency and wavelength are inversely proportional. That is, if the frequency of the light from a distant object is lower than at rest, the observed wavelength is longer than at rest.

This can be effectively visualised using a pilates exercise band with a wave drawn on it.

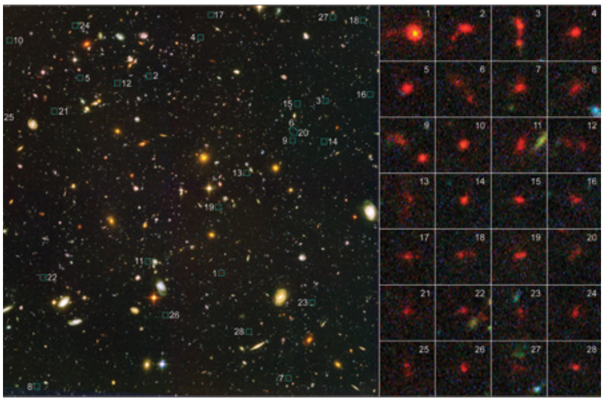
Hand one end of the band to a member of the audience and hold the other yourself – make sure you mention to hold on tight.

The audience member is representing a distant galaxy, emitting light in all directions. Get them to slowly move away from you and observe what happens to the wavelength of the wave (the distance between adjacent peaks). The wavelength increases, so its frequency would be decreasing, just as with the sound demo.

Since the wavelength of light is increasing, the visible light will appear redder, and that is why we call this effect 'redshift'. For very distant objects, this redshift is not caused by the fact that the galaxies are moving away from us, but rather that space itself is expanding, much like the stretching of the pilates band. We call this observed effect cosmological redshift.

Light, messenger of the Universe

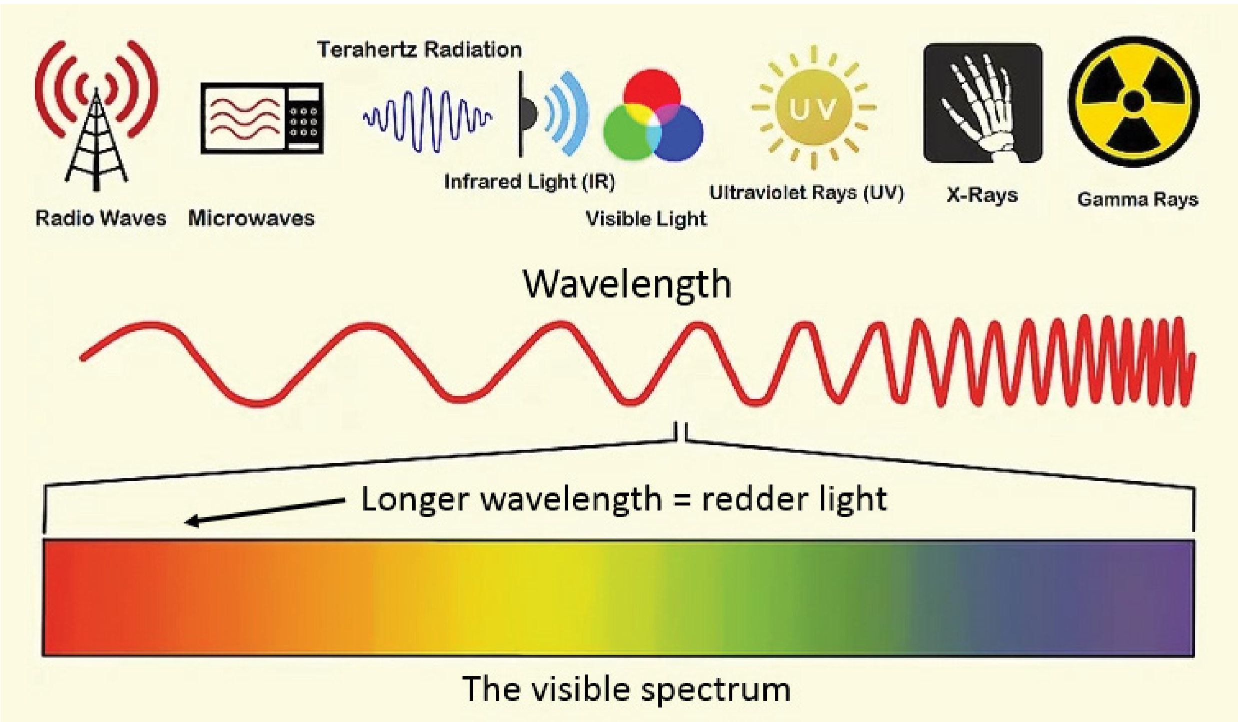
Astronomer Edwin Hubble discovered that the further away an object like a galaxy is, the faster it moves away from us, and the redder the light we observe. We know that this expansion of the Universe is, in fact, increasing. This understanding is one of the major pieces of evidence in support of the Big Bang model of our Universe.



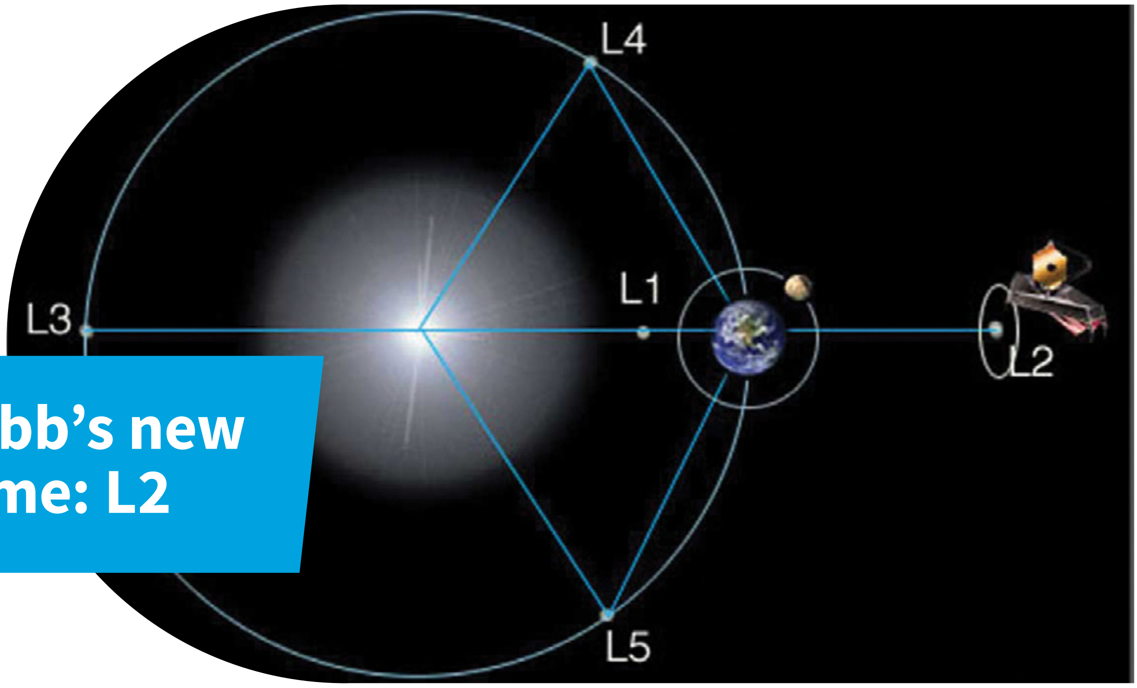
Almost all galaxies we observe show redshift. However, the Andromeda galaxy, the nearest major galaxy to our own Milky Way, is actually blue-shifted and moving towards us.

Light holds the key to understanding our Universe. All we know about objects beyond the limits of human or robotic exploration has come from the analysis of the light from those objects.

Looking in the infrared, Webb will unlock mysteries we are yet to have seen. Through cameras and spectrometers, we will be able to look at the glow from newly forming stars, analyse atmospheric compositions and temperatures of planets within our own solar system and those of exoplanets circling distant stars, and view the faint whispers of light from the most distant galaxies in the Universe.



Top image: Distant galaxies redhift, Credit: NASA
Bottom image: The electromagnetic spectrum, Credit: Wikipedia



Webb's new home: L2

The James Webb Space Telescope will be launched in an Ariane 5 rocket, blasting off from the European Spaceport in French Guiana (South America).
Webb will then embark on a four-week journey to its new home, 1.5 million kilometres from Earth, in a gravitationally advantageous place in space called L2.

Why go so far?

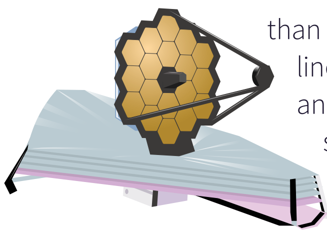
The Hubble space telescope observes from low Earth orbit, but for Webb, with its sensitive infrared detectors, the infrared glow of Earth would be blindingly bright.

Webb has to go far from Earth to avoid its light pollution and to keep itself cold. From its position in L2, its sunshield will be able to block out warming radiation from the Sun, Earth and Moon all at once.

Why is L2 so special?

L2 is an example of a Lagrange point: an area of space where the gravitational forces from two or more objects cancel each other out or combine together to allow for unusual orbits. At L2, the gravitational forces of the Sun, Earth and Moon are balanced.

Normally, the further an object is from the Sun, the more time it will take to make an orbit. L2 is 1.5 million kilometres further out from the Sun



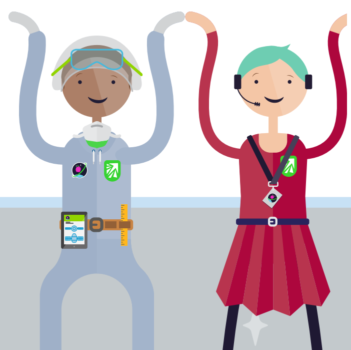
than Earth. However, L2 is lined up with the Earth and Sun at a particularly significant distance. The extra tug it gets from Earth's gravity (towards the Sun) adds together with the Sun's own pull. With the benefit of this extra gravity boost, objects at L2 orbit the Sun in perfect step with the Earth. This means Webb can always keep the Earth, Moon and Sun behind its sunshield, and maintain communications with Earth.

What are Lagrange points?

For the Sun and Earth, these are the points where an object will maintain the same relative position to Earth's throughout their orbits:

L1 is positioned between the Earth and Sun. Earth's gravity tugs the object slightly away from the Sun, so that it orbits more slowly than would normally be expected. ESA and NASA's Solar and Heliospheric Observatory (SOHO) is at L1, providing early warnings of solar storms that might damage satellites in Earth orbit.

Image: diagram showing Lagrange points around Earth. Credit: NASA



L2 is Webb's home, further out from the Sun than Earth, where objects orbit more quickly than would normally be expected.

L3 is the opposite side of the Sun from Earth. It is a little further out from Earth's orbit due to the extra tug from Earth's gravity.

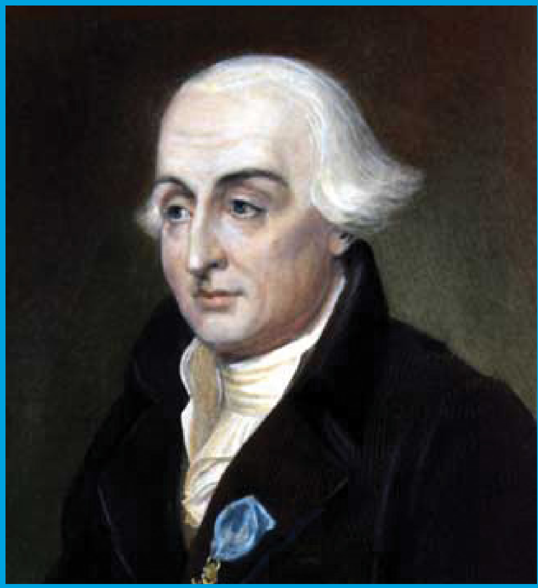
L4 and L5 are either side of Earth in its orbit. These are gravitationally stable places in space around which objects can orbit. This means that natural objects can collect in these locations. Jupiter's L4 and L5 points are orbited by thousands of known asteroids.

Webb at L2

As it orbits the Sun, the Webb Telescope will also circle around L2, which will allow it to use very little fuel and require few manouvres to hold its position. This 'halo' orbit around L2 is huge - wider even than that of the Moon around Earth. Webb will never enter the Earth's shadow, giving it a stable operating environment.

Webb will not be alone at L2 - the Herschel (infrared), Plank (microwave) and Gaia (optical and near-infra-red) telescopes are already orbiting in this location.

Who was Lagrange?

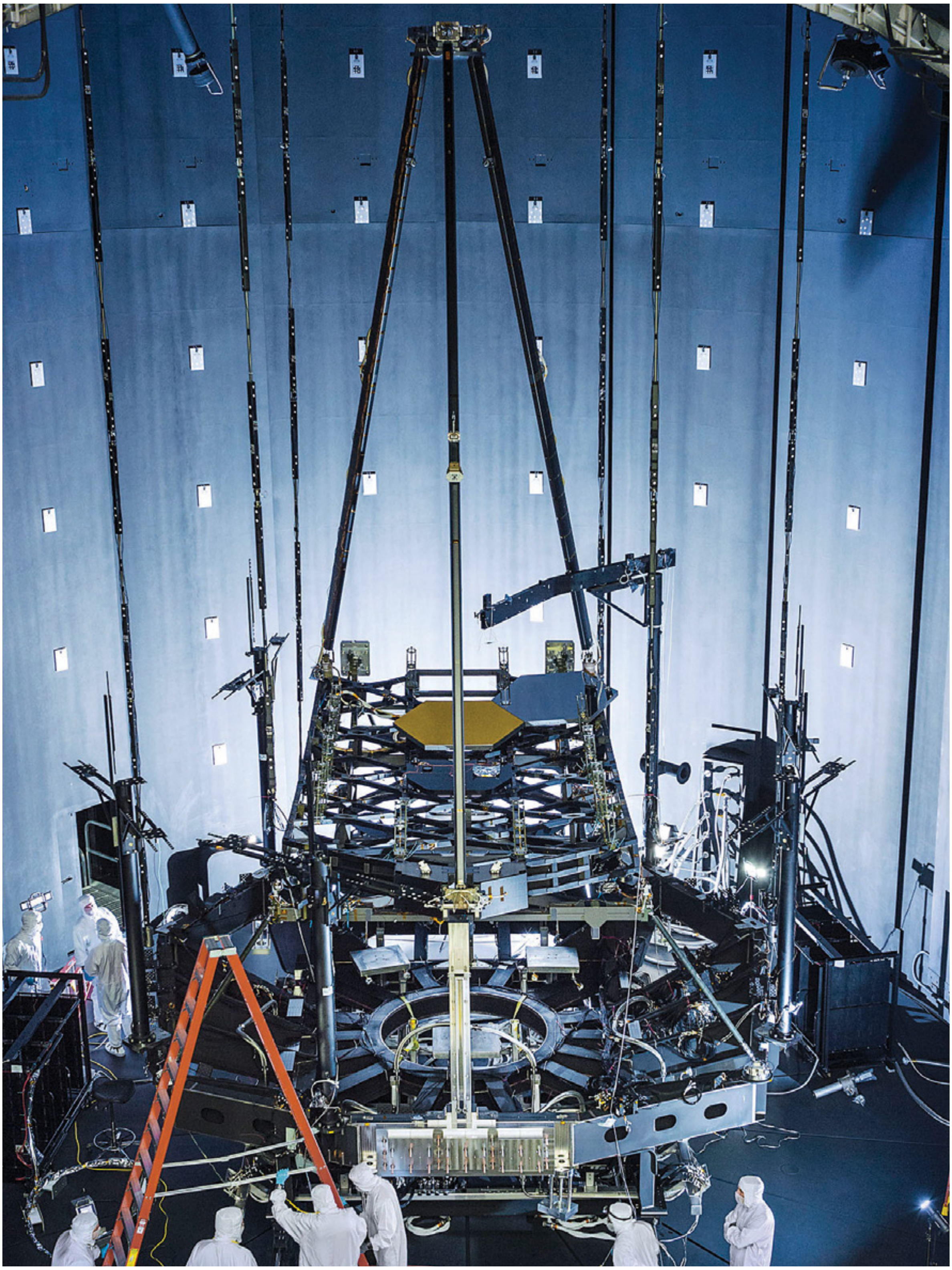


Lagrangian points are named after Joseph-Louis Lagrange, the 18th century Italian astronomer and mathematician who first described them.

Lagrange was born in Turin in 1736. He moved to Paris in 1787, where he remained until his death in 1813. He discovered that any two massive objects in orbit would have five nearby points in space where their forces on a small object would be balanced such that all three objects maintained the same relative positions throughout their orbits.

Image: Portrait of Joseph-Louis Lagrange. Credit: Wikisource

UK involvement in the James Webb Space Telescope



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ASDC would like to thank STFC for their help and support in creating this section on the James Webb Space Telescope.

Image: James Webb Space Telescope in NASA's giant thermal vacuum chamber, Credit: NASA/Chris Gunn