James Webb Space Telescope | Handbook

UK esero

Contents

Note: numbers in square brackets, e.g. [1] refer to entries in the glossary.

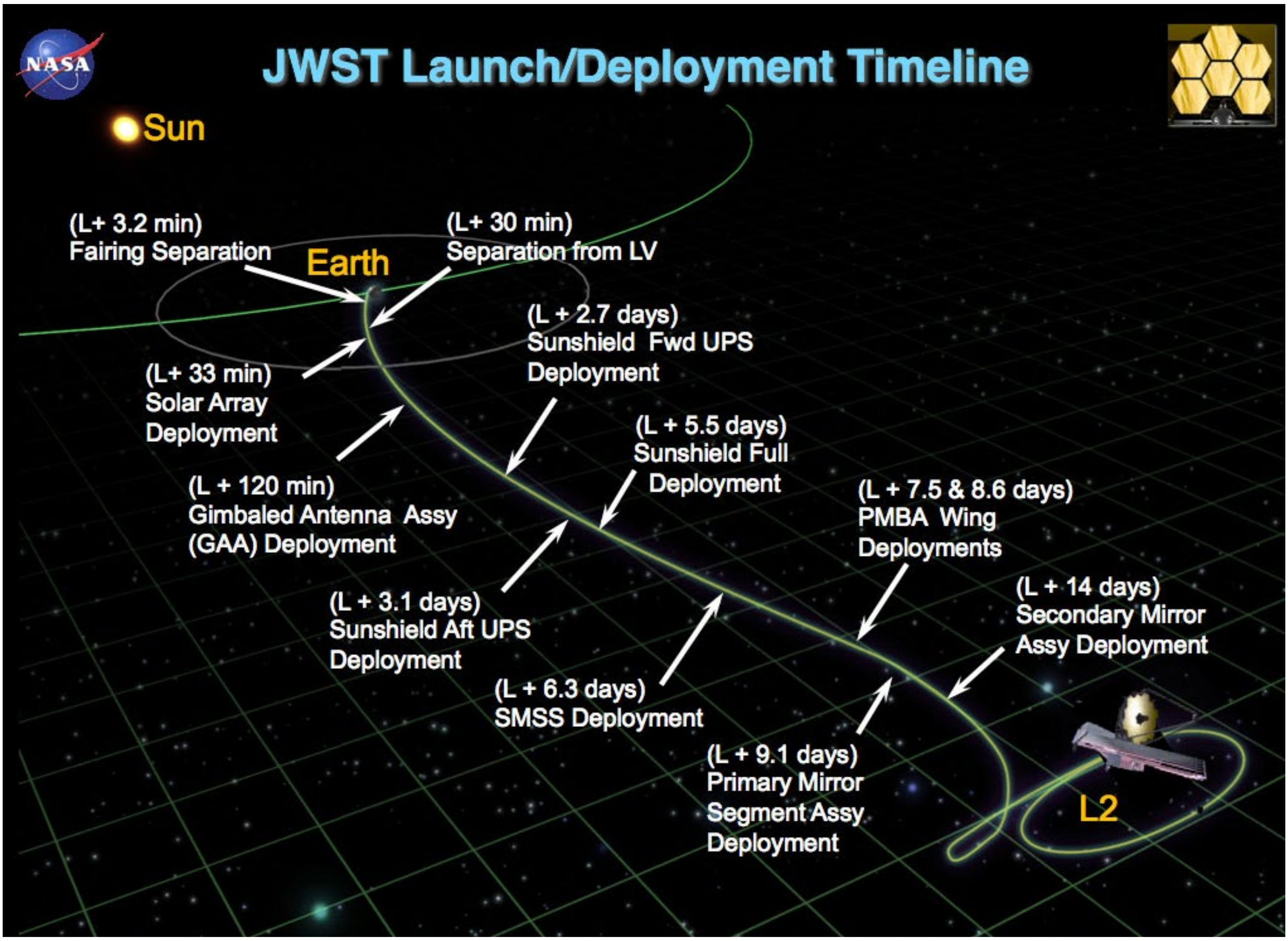
1. Introduction

This guide contains information about the James Webb Space Telescope. Webb is a collaboration between ESA, NASA, and the Canadian Space Agency. It is named after the NASA administrator James E. Webb who oversaw the first human spaceflight programmes of Mercury and Gemini and the establishment of the Apollo missions.

Webb is the largest space telescope ever built and it will see objects up to 100 times fainter than those the Hubble Space Telescope can see. Hubble observes mainly visible light but Webb will use infrared light.

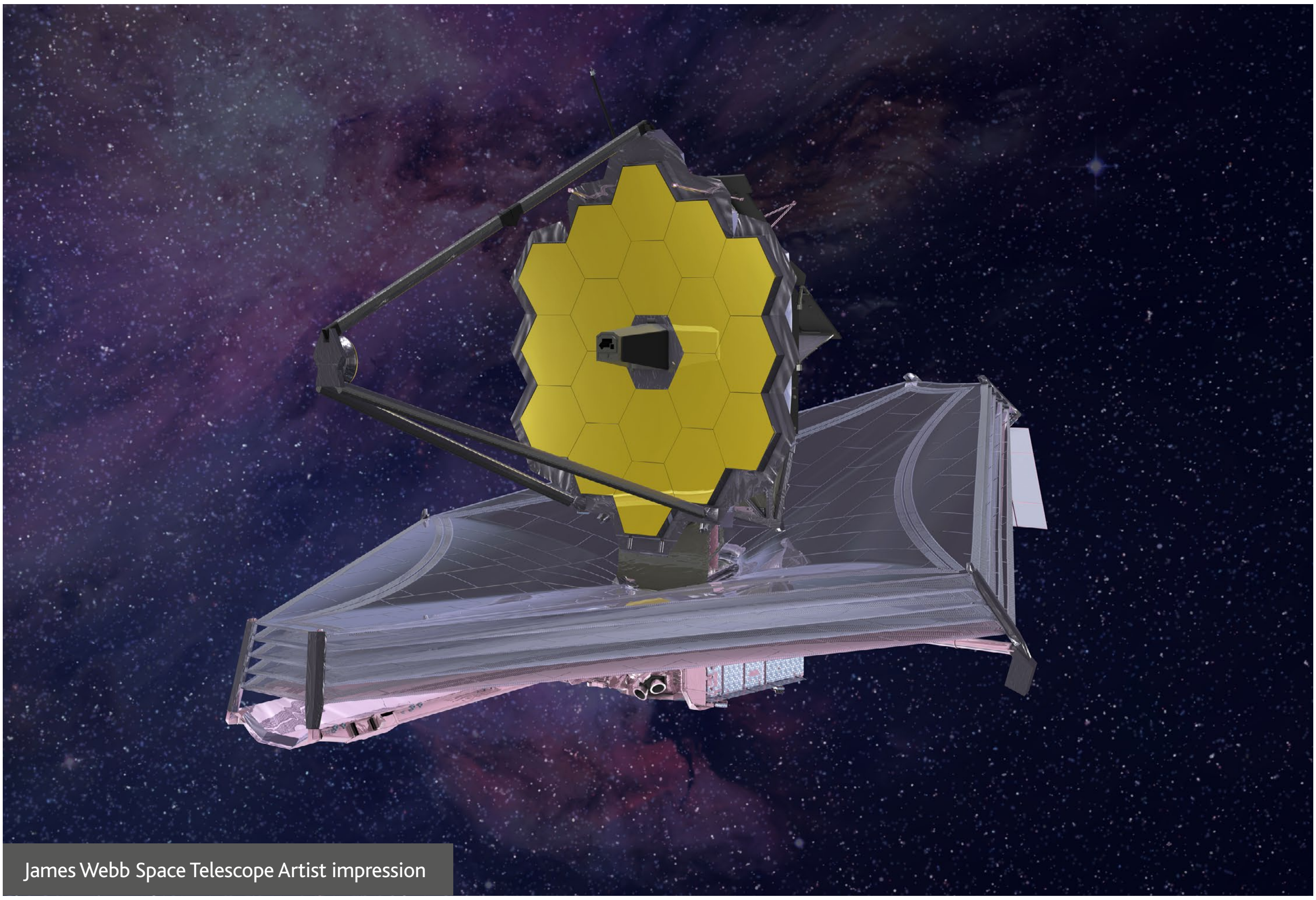
Infrared light allows scientists to see further back in time to when the earliest stars and galaxies formed and into areas where visible light cannot get through, such as clouds of gas where stars and planets form. Scientists will use these observations to understand as much as possible about how the Universe evolved into what is seen today.

Thousands of engineers and scientists from across the world have worked together for over twenty years to design and develop the technologies required for such a large and complex telescope.



2. Design

There were teams responsible for different aspects of the spacecraft. They developed new ideas and tested them before the final versions of the telescope, sunshield and instruments were brought together for launch.



James Webb Space Telescope Artist impression

2.1 Development timeline

- From the mid-1990s various telescope designs and concepts were being worked on.
- In 2002 NASA awarded the first contract for Webb, asking for a 6.1m primary mirror [6] and a 2010 launch.
- Costs rose and Webb was reviewed in 2005. Changes were recommended and launch was delayed for nearly two years to 2012.
- By 2007 the key technologies (mirror and sunshield) had been successfully tested.
- In 2010 the Mission Critical Design Review was passed. This meant that based on the mirror, sunshield and instrument designs, Webb could meet the science and engineering requirements.
- Launch has moved back for a variety of reasons. Some delays have been caused by the complexity of the telescope. A large amount of testing has been required and detailed work is needed to bring all of the telescope elements together.
- Launch is now planned for Spring 2019.

2. Design

2.2 Testing

Each element described in this section has been through tests which simulated - as close as possible - the conditions experienced on launch (vibration, G-force and noise tests) and in space (vacuum, radiation, high-velocity impacts and low temperature tests). These were carried out at specialist NASA sites.

Tests on the Mid-Infrared Instrument (MIRI) took place at RAL Space, Oxfordshire, before being shipped to the US.

2.3 Sunshield

To observe infrared light, Webb operates at around -220 degrees Celsius (50 Kelvin). To achieve this Webb will have a sunshield to block sources of heat, including the Sun, Earth and Moon.

Webb will sit at the L2 Lagrange point (located five million kilometres from Earth) [4] where the Sun and the Earth's gravitational pulls are balanced. To keep it out of the shadow of the Earth and Moon it will move in an orbit around L2.

- The sunshield is made of a flexible material called Kapton and is coated with aluminium and silicone. Aluminium increases the amount of heat being reflected whereas silicone increases the strength.
- There are five layers, each separated by 3 cm:

Layer	Thickness	Aluminium (Al) layer	Silicone doped Al
1	0.05mm	100nm (both sides)	50nm (one side)
2	0.025mm	100nm (both sides)	50nm (one side)
3	0.025mm	100nm (both sides)	-
4	0.025mm	100nm (both sides)	-
5	0.025mm	100nm (both sides)	-

2. Design

James Webb Space Telescope's sunshield

- Each layer is the size of a tennis court and is the shape of a kite. The layers will be folded twelve times in order to fit inside the Ariane 5 launch vehicle.
- Assembled by hand, the material has a grid pattern designed to stop the spread of a hole or tear.
- Layer one will receive 300 kilowatts of heat from the Sun but by layer five this will reduce to 23 milliwatts. There is a 300 degree drop between layers one and five. If the sunshield was sunscreen, it would have an SPF of 1.2 million.
- Ninety per cent of the heat is blocked by layer one. Layers two to five reflect more and more heat, which is vented to the sides of the telescope.

2. Design

2.4 Mirror

Telescopes use their primary mirror [6] to collect light from their targets. The larger the mirror, the more light it can collect. Webb's mirror is three times the diameter of Hubble's.

The James Webb Space Telescope Folds Its Wings

- Webb's mirror is made up of eighteen hexagonal tiles. Hexagons are used instead of circles to ensure there are no gaps.
- Each mirror is 1.32m from flat to flat, has a mass of twenty kilograms and has six motors that can adjust the shape of it in very small steps.
- The eighteen segments work together as one mirror with a total collecting area of around 25m2.
- The mirrors are made of beryllium with a layer of gold on the surface to reflect as much infrared light as possible.

The final tiles manufactured for the mirror were only ten per cent of the mass of the initial mirror design. Engineers found ways to remove mass from the tiles without affecting how they reflected light.

2. Design

2.5 Instruments

There are four science instruments on board. Each was developed by a different collaboration between space agencies, universities and specialist organisations. Electricity is provided by solar panels on the Sun-side of the spacecraft.

Once the light has been collected by the primary mirror it moves through the telescope via two more mirrors before being delivered to the instruments and then the results are sent back to Earth for analysis.

Instrument	Wavelength	Type	Operating temperature	Field of view [3]
Near infrared camera (NIRCam)	0.6 – 5 microns [5]	Camera	-235 °C or 37 K	2.2 x 2.2 arcmin
Near infrared spectrograph (NIRSpec)	0.6 – 5 microns	Spectrograph [8]	-235 °C or 37 K	3 x 3 arcmin
Mid Infrared Instrument (MIRI)	4.6 – 28.6 microns	Camera and spectrograph	-266 °C or 7K	3.5 x 3.5 arcmin
Fine guidance sensor/Near infrared image and slit-less spectrograph (FGS/NIRISS)	0.8 – 5 microns	Guidance sensor and spectrograph	-235 °C or 37 K	2.2 x 2.2 arcmin

The UK contribution to Webb has been funded by the UK Space Agency. In addition to the organisations mentioned below, there are scientists and groups all around the UK who will be involved in analysing results from Webb and commercial companies and university spin-offs have made contributions to the design and construction.

NIRCam:

- Coronagraphs will be available to block out the light of a star. Webb will use this to directly image exoplanets [2].
- Filter wheels can be used to select specific wavelengths of incoming light. By using multiple filters it will be possible to make an estimate of redshift [7].

NIRSpec:

- Simultaneously measures the spectrum of up to one hundred different objects, such as stars and galaxies.
- It has different operational modes. For example, one allows for the study of the spectrum of large objects such as galaxies. This means that its speed, direction and other properties can be easily identified.
- From the UK Airbus, Mullard Space Science Laboratory (MSSL), Surrey Satellite Technology Limited (SSTL), University of Durham, University of Oxford, UCL made contributions to this instrument.

2. Design

MIRI:

- Observes longer wavelengths than other instruments so needs to be cooled even further.
- The cryocooler (which can be thought of as a sophisticated refrigerator) developed for MIRI is pioneering technology. It has limited moving parts and is designed so that it won't run out of coolant.
- The UK Astronomy Technology Centre led the MIRI European consortium. Additional UK contributions came from Airbus, Cranfield University, Rutherford Appleton Laboratory, University of Leicester, and the University of Reading.

Installation of MIRI

FGS/NIRISS:

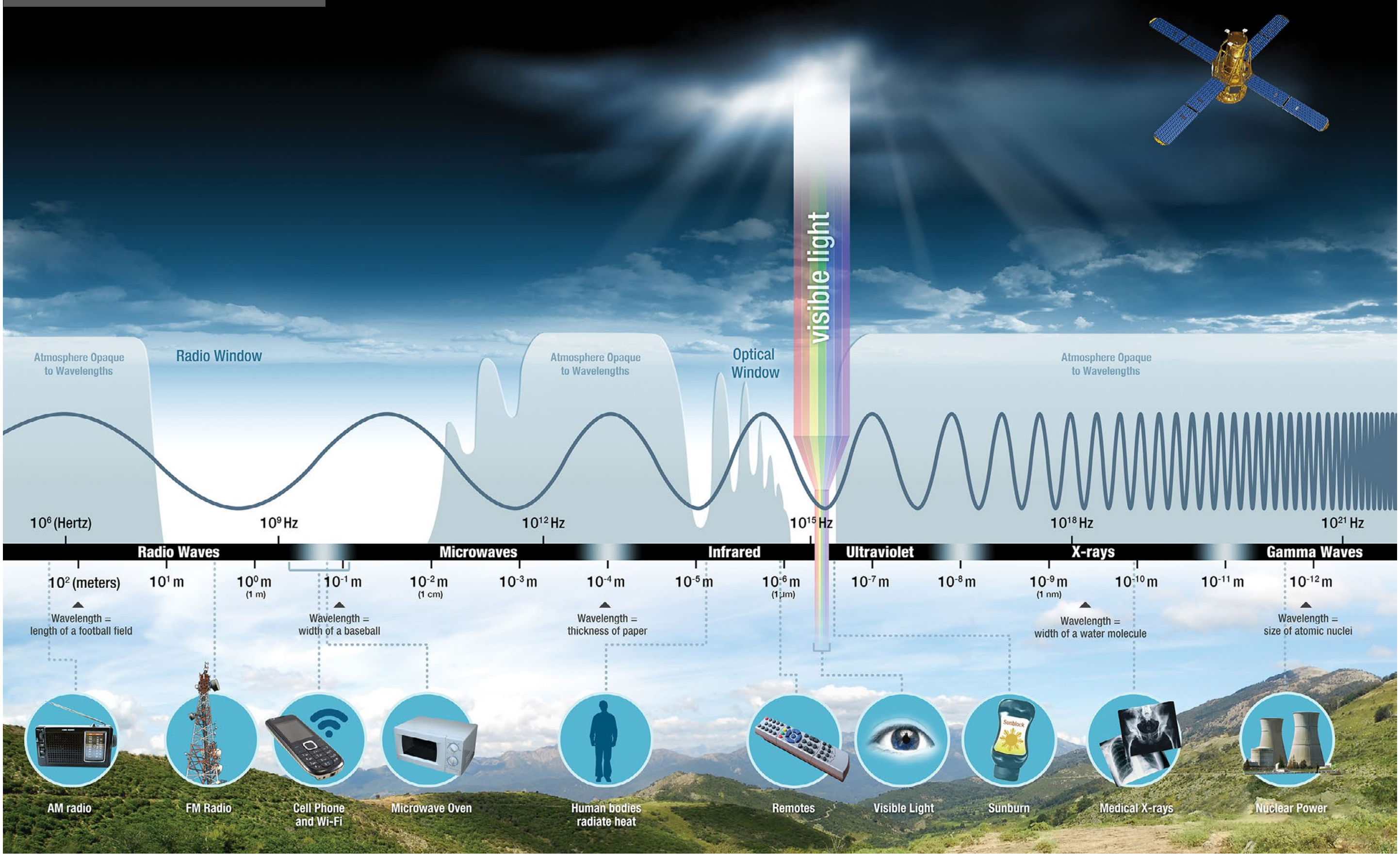
- The fine guidance sensor keeps the telescope on target. This feeds information into the attitude control system.
- The spectrograph [8] is designed to allow observation of exoplanets [2] at specific ranges of light and around certain types of stars.

3. Mission

3.1 Infrared light

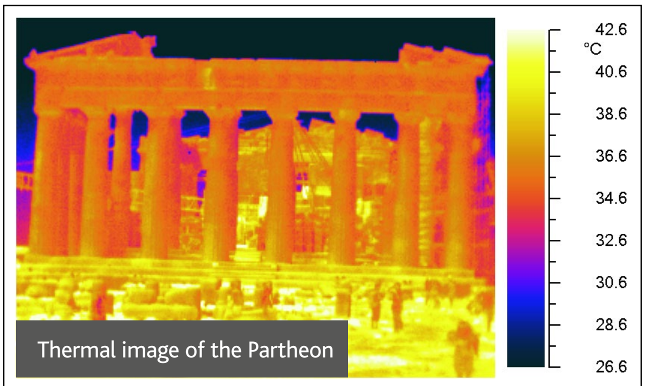
Light comes in many different forms and is not limited to what is seen by the human eye:

The electromagnetic spectrum



Unlike Hubble which sees mainly visible light, Webb will detect infrared light.

Thermal emission from everyday objects peaks in the infrared part of the spectrum. Our skin can detect this emission as heat, and we can visualise it using thermal cameras. With the sunshield in place, Webb's instruments are so sensitive that they can detect the heat signature of a bumble bee at the distance of the Moon.



Thermal image of the Partheon

3. Mission

There are many advantages to observing celestial objects in the infrared. Using Webb, astronomers will be able to detect very distant stars and galaxies whose light has been stretched to infrared wavelengths as it travels to us through our expanding Universe. They will also be able to observe within very dusty environments where stars and planets form, like this one


The Eagle nebula - visible


The Eagle nebula - invisible

Webb was designed to tackle some of the most exciting open questions in astronomy, all of which require high-resolution observations at infrared wavelengths. Four primary science goals are defined:

3.2 First light

- Webb has been designed to detect the first stars and the galaxies to form after the Big Bang and to investigate how these first bright objects illuminated a dark Universe.
- These objects emitted visible and ultraviolet light, but this light has been stretched as it travelled to us across an expanding Universe. We therefore observe it redshifted [7] into the infrared part of the spectrum.
- The first stars formed were very large (thirty to three hundred times the size of our Sun) and short-lived (a few hundred million years, compared to the Sun's lifetime of ten billion years).
- Understanding this period of time is important for several reasons. It is thought that these early stars influenced the structure of the Universe seen today.
- Black holes could have formed as these early massive stars died. These were potentially the seeds of the now super-massive black holes observed at the centre of almost every massive galaxy.

3. Mission

3.3 Formation and evolution of galaxies

- Webb will be the first telescope able to observe how galaxies form and evolve over the full history of the Universe. By detecting faint, infrared light they will be able to see galaxies as they appeared just a few hundred million years after the Big Bang.
- Looking at galaxies at different distances allows us to compare their shapes, their orientation relative to other galaxies, and the populations of stars within them. All of these things help us to understand more about how galaxies and the stars within them change over cosmic time.
- Spiral galaxies, such as the Milky Way, did not start off with that shape. The earliest galaxies currently observed are small and have plentiful knots of dust and gas (star forming regions). Most galaxies will have undergone at least one collision with another galaxy at some point and this will have influenced their shape.
- By taking observations of large numbers of galaxies, it will be possible to track the appearance of heavier elements. These tend to be formed in the high temperature and pressure explosions of a supernova when a star dies.
- Some scientists are interested in looking for a hint of the presence of dark matter [1]. So far evidence for dark matter has been found clumped around galaxies.

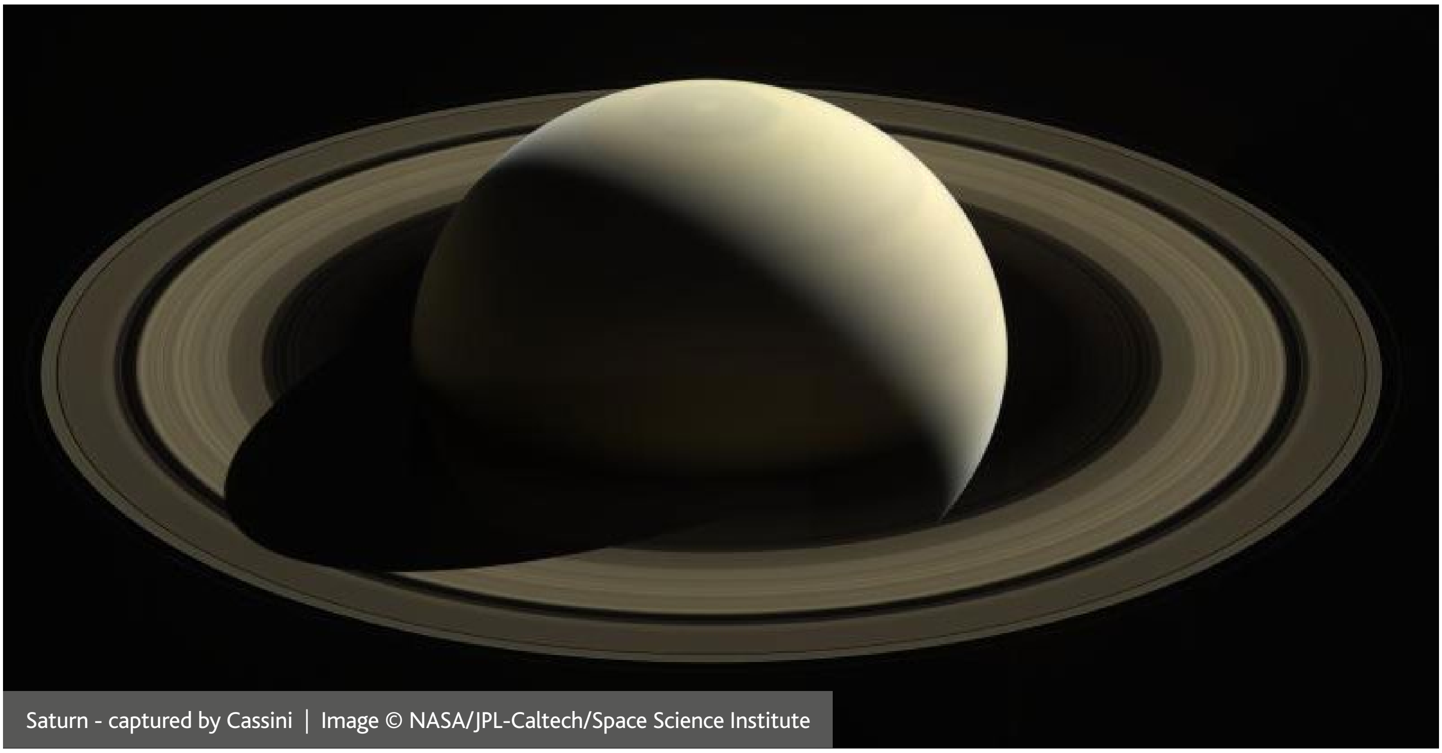
A rose made of galaxies | Image © ESA / NASA

3.4 Formation of stars and planetary systems

- Stars and their planetary systems form when sections of nebulous clouds of dust and gas collapse under their own gravity. The dense cocoons in which the stars and planets form are extremely dusty environments through which visible light cannot penetrate.
- Whereas visible light is absorbed by or bounces off dust, infrared light at the wavelengths Webb will observe will pass through it. Observing in infrared light will give us a chance to view inside star forming regions and also to take a closer look at forming exoplanets [2] than has been possible previously.
- It will be possible to see stars in the process of forming.
- Webb will be searching for young stars with dust rings or signs of planetary formation in its early stages. There are various theories about how planets form, but a large-scale series of observations is needed in order to improve understanding.

3.5 Planetary systems and the origins of life

- Webb is designed to look at the atmospheres of exoplanets and to search for evidence of water and other building blocks of life.
- Spectroscopy [9] will be used to identify the chemicals and elements in the atmospheres of exoplanets. One goal is to explore the similarities and differences between exoplanetary atmospheres and those found in our own Solar System.
- Direct images of some exoplanets will also be possible through the use of coronagraphs to block out the light from the host star.
- Webb will be also be used to examine objects in our own Solar System, from planets to asteroids and other objects.



Saturn - captured by Cassini | Image © NASA/JPL-Caltech/Space Science Institute

4. Taking Webb into schools

The language used throughout this booklet is suitable for use with secondary pupils. Some sections are more appropriate for primary pupils. Guidance is offered below:

	Content suitable for...	
Section of guide:	primary?	secondary?
Sunshield	✓	✓
Mirror	✓	✓
Instruments	✗	✓
Infrared light	✓	✓
First light	✓	✓
Formation and evolution of galaxies	✗	✓
Formation of stars and planetary systems	✗	✓
Planetary systems and the origins of life	✓	✓

When working with pupils it is helpful to find out how much they know about the topic you will be discussing at the start of your session. For example, you can ask questions of the group to find out if they have worked on a space topic recently and if so, what have they learned? Encourage pupils to discuss their ideas and ask them further questions. Alternatively, you can ask for this kind of information from your school contact.

Aspects that link to Webb which will prove more challenging to discuss with younger pupils include infrared light, redshift [7] and spectroscopy [9]. The underlying concepts tend not to be introduced until secondary.

In general, try to use non-technical language and simpler words in descriptions. For example, "Webb will help us understand more about the formation and evolution of the Universe" could be expressed as "Webb will help us understand more about how the first stars and galaxies were made and how the galaxies we see today got their shapes".

5. Glossary

The language used throughout this booklet is suitable for use with secondary pupils. Some sections are more appropriate for primary pupils. Guidance is offered below:

[1] Dark matter	No direct observations of this material have been made. It was discovered due to its interaction via gravity with objects that are visible (e.g. galaxies). There is five times more dark matter than ordinary matter (e.g. atoms).
[2] Extra-solar planet or Exoplanet	Planet which is found to be orbiting a star other than our Sun.
[3] Field of view	This is the area of the sky that can be captured by the telescope. The unit of measurement – arcmin – can be used to describe small areas on the sky and relates to an angular measurement. 1 arcmin = 1/60 of 1 degree.
[4] L2 Lagrange point	Position where the pull of gravity from two larger objects cancels out. This allows an object such as a spacecraft to stay in the same position relative to the two larger objects.
[5] Microns or micrometres	1 micron or micrometre = 1×10^{-6} metres.
[6] Primary mirror	Largest mirror on the telescope that gathers light for observation by the telescope's instruments.
[7] Redshift	The Doppler effect describes how waves change frequency if the source moves. If the source moves towards you it increases frequency, if it moves away it decreases in frequency. Galaxies are moving away from each other as the Universe expands. Light observed from other galaxies is shifted towards the red end of the spectrum. This is called Cosmological Redshift.
[8] Spectrograph	An instrument that splits incoming light into its different wavelengths to allow further study. The recorded measurement is called a spectrum.
[9] Spectroscopy	Gives detailed information about the intensity of light at different wavelengths. Light can be absorbed by different atoms and molecules, each with their own signature so they can be identified. This allows scientists to identify the elements and molecules in a nebula or atmosphere of an exoplanet.

6. Useful links

ESA: http://sci.esa.int/jwst/

NASA: https://www.jwst.nasa.gov/
https://jwst.stsci.edu/

UK-related: http://jwst.org.uk
https://www.stfc.ac.uk/research/astronomy-and-space-science/astronomy-space-science-programme/james-webb-space-telescope/

Education-related: https://www.stem.org.uk/esero

UK esero