James Webb Space Telescope – Demo show

What's it all about?

The Royal Astronomical Society's AstroBoost project was funded by a STFC Spark Award and supported by project partners Guildford Astronomical Society, Hampshire Astronomy Group, Newbury Astronomical Society and the STFC's UK James Webb Space Telescope campaign. The project was managed by Dr Jenny Shipway.

This document outlines a flexible 30 – 60min demo-led show aimed at ages 8-12yr. Led from the front by a presenter, with volunteer opportunities. Adaptable for other ages, including mixed-age groups.

Designed to be delivered in a classroom type situation to a group of about 30 people. Requires mains power. Some demos require space to move around, but could be cut if necessary.

Learning objectives:

1. Light comes in different colours/wavelengths, including ones invisible to our eyes
2. Infrared's properties make it useful for astronomy.
3. How the design of Webb relates to its use of infrared.
4. The UK is a major player in the international NASA-led Webb project.

This document:

The Powerpoint presentation, details of the demos, and risk assessment are provided in other documents.

SECTION 1: Overview (sections of the show)

1. Introduction
2. Telescopes catch light
3. Webb's (invisible!) light goes to detectors like MIRI
4. Colours past the end of the rainbow (Prism demos)
5. Ultraviolet light is real (UV demo) [this section can be cut to save time]
6. Infrared light is real (Camera 1 demos)
7. Colour mapping images does not add information
8. Infrared behaves differently to visible light (Camera 2 demos)
9. Why infrared astronomy
10. Why and how Webb is kept cold (Cold Webb demos)
11. Webb project progression

SECTION 2: Objectives for each section

You can add extra bits and pieces as you choose, but if you focus on these objectives then the show will flow nicely and hopefully not over-run.

1. Introduction
- Introduce self/talk
- Introduce *James Webb Space Telescope*
- An international collaboration with significant UK involvement

2. Telescopes catch light
- We see by light entering our eye.
- All telescopes collect light and direct it to a detector
- They are better than eyes because they collect more light – more light is GOOD

3. Webb's (invisible!) light goes to detectors like MIRI
- Gross structure of the telescope (mirror + sunshield)
- The primary mirror is a light collector, directing light.
- Webb mirror is HUGE
- The light goes into detectors, eg MIRI
- MIRI detects light that is invisible to our eyes
- MIRI was assembled in the UK by a UK-led team / Webb is international project
- Show engineers at work

4. Colours past the end of the rainbow (Prism demos)
- Sunlight / white light contains all the colours of the rainbow
- These colours can be separated to be seen as a *spectrum*, eg by a *prism*
- There are other 'colours' we can't see, off the end of the rainbow
- KS3 – different colours are due to different *wavelengths*
- KS3 – types of *electromagnetic radiation*

5. Ultraviolet light is real (UV demo) [this section can be cut to save time]
- *Ultraviolet* light is real
- If you could see UV, it would give you additional information about the world

6. Infrared light is real (Camera 1 demos)
- *Infrared* light can be seen by special cameras
- Everyday objects emit infrared, usually swamping reflected signals
- Infrared cameras can tell us about objects' properties from their IR signal
- Brighter bits on the camera image = more IR received from that direction

7. Colour mapping images does not add information
- Colours on infrared images do not add more information, they just make it easier to read
- Colour choice for colour-mapped images is arbitrary

8. Infrared behaves differently to visible light (Camera 2 demos)
- Words: *opaque*, *translucent*, *transparent*, *reflective*, *absorb*
- Materials that are opaque to visible light can be transparent / translucent to IR
- Some materials reflect IR
- The properties of infrared have been considered in the design of the telescope

9. **Why build an infrared telescope**
    - There are interesting space things that you can only see with infrared
    - Webb will be much better than previous infrared telescopes

10. **Why and how Webb is kept cold (Cold Webb demos)**
    - Infrared interference from Earth, Moon and Sun would warm the telescope
    - Warm telescope emits infrared radiation which is collected by the detector
    - Being at L2 means that Earth, Moon and Sun can all be blocked by sunshield
    - Spacecraft design is explicable

11. **Webb project progression**
    - Webb is a huge challenge! Success is not predetermined
    - International collaboration, lots of teams/people involved.
    - Nearly there?!
    - This is a real, ongoing project

SECTION 3: SCRIPT (see other docs for full demo notes)

Everyone will deliver this show differently and in their own style. You should certainly not try to learn any of this word for word! The main points that need to be made are shown bulleted under each slide title – these are the goals to aim for. The detail is given only as an example of how the show might go.

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1. Introduction (slide 1 – title)

- Introduce self/talk
- Introduce *James Webb Space Telescope*
- An international collaboration with significant UK involvement

Hello, my name is [Mildred] and this is a talk all about this beautiful, incredible machine: the James Webb Space Telescope. It is different from any telescope that we've ever built before and will make it possible for us to discover new things about our Universe.

No one country could carry out a project of this complexity alone – this telescope is a collaboration between the American space agency – NASA - the European Space Agency, and the Canadian Space Agency.

It uses technologies and understanding that build upon thousands of years of discoveries and research, and will push our knowledge further into the future.

The UK is part of the European Space Agency* and one of the most important detectors on this telescope has been assembled right here in the UK, led by the Scottish Professor Gillian Wright. This isn't a huge surprise though as the UK is a world leader in space technologies – did you know they build lots of satellites in Portsmouth? There are also satellite companies in Surrey and just north of London they're building parts of the next Mars rover. But anyway, back to Webb.

[* Brexit has no effect on this membership, although it does affect Euro funding of science projects.]

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2. Telescopes catch light (slides 2 – trad telescope; slide 3 – Webb light paths; slide 4 – mirror size)

Slide 2 – traditional/familiar telescope

- We see by light entering our eye.
- All telescopes collect light and direct it to a detector
- They are better than eyes because they collect more light – more light is GOOD

We see by light entering our eye. The black pupil of your eye is a hole, the light goes through, and the back of your eye detects the light.

The most important thing about telescopes is that they can catch more light than your eye – look how huge the end of the telescope is compared to her pupil. Inside the telescope there will be lenses to focus all that light into her eye.

This means that she can now see things that would be too dim for her eye alone – brilliant for astronomy.

It also means that she can zoom in on distant objects. The telescope is able to capture enough light from just one tiny part of the scene to make a good image to fill her whole eye. In fact, daytime telescopes – like this one – have to do this otherwise there would be so much light going into her eye that she would surely be blinded. This is why using astronomy telescopes in the daytime is so dangerous.

So if you want to quickly judge how good a telescope is, look at how WIDE the end is, not its length.

Slide 3 – Webb light paths (click to bring up light paths)

- Gross structure of the telescope (mirror + sunshield)
- The primary mirror is a light collector, directing light
- Do not mention its size, or that it detects infrared

Here is the Webb telescope. It just doesn't look anything like the traditional telescope we saw in the previous picture. There is no tube, and there's this big, gold satellite dish looking thing, on top of a sunshield. I'll talk about the sunshield later.

Although it looks different, it works just like all telescopes. It collects lots of light and sends it into a detector. The light here is collected using a series of mirrors, including this large gold mirror made of hexagons.

The gold mirror looks a bit like a satellite dish, and it works the same way.

< click – light ray appears, bouncing on primary mirror >

Light from a distant object comes through space, and hits the mirror. It reflects from the mirror at just the right angle to hit this little bit here. This is in fact another mirror …

< click – light ray continues into detector >
… which neatly reflects the light ray into that small hole, where the telescope's detector is.

A light ray coming from another direction …

< click – light ray comes from lower down the screen>

… hits a different part of the mirror and also is reflected into the detector. The mirror is shaped so that all the parallel light lights coming from this direction …

< click – another light ray >

… will get reflected perfectly into the telescope. Light rays from other objects in different parts of the sky will be reflected away so they don't mess up the image.

The gold mirror is like the end of the traditional telescope we saw a moment ago: the bigger it is, the more light is collected. And the little hole leading to the detector is like the pupil in the eye of the person using the telescope.

Slide 4 – mirror size

- Webb mirror is HUGE

The more light something detects, the more information it has, and the better it can see. The pupil of the human eye opens as far as 8 mm in the dark. The telescope we saw at the start was maybe about 20 cm wide. It could capture a LOT more light than an eye.

< click – Hubble 2.4 m >

The Hubble Space Telescope has a 2.4 m mirror. Have you heard of Hubble? It took pictures like …

< click – nebula image on >

… this. But anyway … [Note: don't talk about the nebula, it's just a pretty pic]

< click – nebula image off >

… what about Webb?

< click – Webb 6.5 m >

This is HUGE. Look at it!! Look how much bigger than Hubble! Although actually there's a reason it needs to be so big, which I'll come to later.

OPTIONAL DEMO – Build Webb's Mirror

[Note: forward to Slide 5 for this demo]

This mirror is the most iconic thing about the telescope's appearance – it really is beautiful. It is made of hexagonal pieces cleverly joined together. I have some gold hexagons here, who's up for helping me build a copy here?

The mirror we have built is the size of just one of the real Webb's hexagonal pieces.

Note: the mirror could be built on the floor, or by holding the mirrored pieces up. If the latter, one of the people can put their head in the hole so that their eye can represent the detector. Once the mirror is made, recap the light paths using it as a model. Can talk also about each hexagon constantly moving to tweak the image.

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3. Detectors: Webb's (invisible!) light goes to detectors like MIRI (slide 5 – Webb in space; slide 6 – MIRI)

Slide 5 – Webb alone in space

- The light goes into detectors, eg MIRI
- MIRI detects light that is invisible to our eyes

So what does Webb do with all this light.

One thing you may have noticed is that it is a SPACE telescope. And yes, it is in space!

< click – astronaut appears >

This means there is nobody there to look through it.

< click – cross through astronaut >

In fact, once it has left Earth, nobody will ever see it again.

But this is actually fine. Even a lot of Earth-based telescopes don't have people looking through them these days. Instead they have cameras and other automated detectors which collect the data. This works a lot better, even, as the information is easy to store and share, and can be studied by many people at the same time.

There are also a lot of *robotic* telescopes – you can sit at home and control a telescope in Hawaii through the internet! So controlling it remotely is fine too. Webb can communicate with Earth to receive commands and send data back, it has two antennae, including that small satellite dish that you can see sticking out under the sunshield.

But anyway it would be pointless to have an astronaut look through it even if we could get there. Because this telescope will be looking for things that are invisible to our eyes! Webb has a number of different, very special, detectors, but possibly the most awesome, and the one I want to talk about, was assembled right here in the UK …

Slide 6 - MIRI

- MIRI was assembled in the UK by a UK-led team / Webb is international project
- Show engineers at work

Here is the MIRI detector being checked over just after it arrived at NASA. It was built at Rutherford Appleton Laboratory in Oxfordshire by a UK-led team. The blue-capped European Space Agency engineers are seen here working with the white-capped NASA engineers to check that it has arrived clean and undamaged. Happily there wasn't even a spot of dust on it.

This is where a portion of Webb's light will end up. MIRI (and the other instruments) will see the invisible, to open up our understanding of the Universe. But to explain properly what I mean by that, we need to think about light.

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4. Colours past the end of the rainbow (slide 7 – rainbow; slide 8 – white; slide 9 – prism; slide 10/11 – end of the rainbow; slide 12 – types of light; slide 13 (KS3+) – electromagnetic spectrum)

Slide 7 – rainbow

- Sunlight / white light contains all the colours of the rainbow
- These colours can be separated to be seen as a *spectrum*, eg by a *prism*

Beautiful. Lovely colours of light. What do you need to make a rainbow? Sun <click> and rain <click>.

OPTIONAL DEMO: use water spray to create a rainbow
Each drop is tiny, but together they make a rainbow for us to see. What if I had a bigger raindrop?

DEMO: prism creates spectrum – use slide 8 if no other light source available
Where is the colour coming from?

DEMO: colour filter experiments (volunteer)

Conclude that the colour is already in the light, that the prism/filter are not *giving* colour.

- Top tip: be a bit careful of talking about “mixing” light as this could sound like colours are changed into another form when they are overlaid.

Slide 9 – prism

Use diagram to recap what we saw in the demos. Point out that the colours get separated because they refract (bend) differently when they enter and leave the prism (red taking the straightest path).

For KS3, introduce the idea that different colours have different wavelengths.

Sunlight contains all the rainbow colours, which can be separated using a prism/raindrop/filter.

- Top tip: avoid additive/subtractive mixing (ie mixing light/paint). It’s far too confusing/complicated and diverts from the story.
- Accuracy: colour exists only in the brain. Light has a wavelength, that is all. The wavelength we see in isolation as “yellow”, we call yellow. But our experience of “yellow” can be created in other ways too (eg a lemon’s yellow is mostly red + green). Be mindful of the way you speak, to avoid introducing misconceptions that may hamper future learning.

Slide 10 (KS2) or 11 (KS3) – the end of the rainbow

- There are other ‘colours’ we can’t see, off the end of the rainbow
- KS3 – different colours are due to different *wavelengths*
- KS3 – types of *electromagnetic radiation*

So, all the rainbow colours are laid out like this in the spectrum … but what’s at the end of the rainbow?

Slide 10 (KS2):

< click– gold coins >

Not gold coins! Something better – invisible colours. And I’m going to try to prove that they’re real. Starting with what happens if you go past the violet end of the rainbow spectrum.

Slide 11 (KS3):

It turns out that the colours we see are only one small part of a wider spectrum. And at the ends, past the colours we can see, are invisible colours. These colours have names. Those with extra-short wavelengths, past violet, are called …

< click – shorter wavelengths >

Ultraviolet, X-rays and Gamma rays. And those with longer wavelengths, past red, are called:

< click = longer wavelengths >

Infrared, Microwaves and Radio waves.

These might sound familiar, and if you haven’t heard this before then this is great because it means that science is a lot easier than you might have thought. All of these things are actually all the SAME thing. The light we see is the same thing as X-rays or radio waves, the only difference is the wavelength. They are all forms of *electromagnetic radiation*. Their different wavelengths mean they behave differently to each other, but at a basic level they are the same thing.

OPTIONAL Slide 12 – EM spectrum (unlikely to be required)

Option for if you want to talk about this in more detail to audiences with more prior knowledge.

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5. Ultraviolet light is real (OPTIONAL; slide 13 – UV torch; slide 14 – UV flowers)

Slide 13 – UV torch

- *Ultraviolet* light is real
- If you could see UV, it would give you additional information about the world
- KS3: recap idea of different wavelengths of light

If you go past violet on the rainbow, the first invisible colour you get to is called ultraviolet. Well, I guess I shouldn't really call it a colour as you can't see it, but you know what I mean.

I have a torch that gives out ultraviolet light. [Shine light onto non-fluorescent white surface, eg wall. Do not shine near eyes.] You can see violet light here because …

< click – torch emission >

… the torch also gives out quite a lot of violet light. But there is very bright ultraviolet there too. In fact, I need to be careful not to shine this in anyone's eyes as it is so bright. You can't see it, but it is there.

Although we can't see it directly, we can see its effects on things.

Demo: UV light

Shine the light onto something fluorescent – eg bleached white paper, washed fabrics, ideally held against the other surface to directly compare how bright each looks.

Do you see how bright [the thing] looks? Where is all that light energy coming from? It is absorbing the invisible ultra-violet light and then releasing that same energy as different colours which we *can* see.

KS3: absorbing the short-wavelength ultraviolet light and re-emitting it with a longer wavelength, so that the emitted light is at wavelengths within the visible spectrum.

Paper/washing-powder is designed to do this so that the fabric re-emits the sun's UV, making it look as though it is even more reflective of visible light than it really is – this makes it look 'whiter than white'.

Slide 14 – UV flowers (this slide can easily be cut for a shorter show)

Ultraviolet, invisible light is real. This is why we wear sunburn, to prevent it damaging our skin.

If you could see it, the world would look different. And bees can. I can't show you what the world looks like to them, but I can show you which parts of these flowers are reflecting ultraviolet light, by showing you photographs taken by a special camera. These first photos were taken by a camera that is showing us where all the different rainbow colours of light are reflecting from the flowers. I'm going to show you pictures showing where ultraviolet is reflecting.

< click – ultraviolet flowers>

The pictures are black and white - I can't show you them in ultraviolet because it is invisible! White shows where more ultraviolet is reflecting from the flower – these parts would look ultraviolet to the bee. Black bits are where no ultraviolet is reflecting. You can see these new patterns that are invisible to the human eye.

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6. Infrared is real (slide 15 – IR reflection; slide 16 – IR emission; live camera feed)

Slide 15 – infrared reflection (possum)

- *Infrared* light can be seen by special cameras

Infrared is the colour past red on the rainbow/spectrum. Its wavelength is too long for our eyes to detect it. Have you heard of it? (Kids may say heaters, remote controls).

Just like the UV torch, you can get IR torches or spotlights that are invisible to our eyes. These shine what's called near-infrared – light that is only just past the edge of our vision. Some night vision CCTV and animal camera traps use bright IR lights which light up the scene for the camera.

Just like the IR flower picture, I can't actually SHOW you infrared, so this picture is in black and white, with white showing where more infrared light was being reflected.

Brush tailed possum.

Can you see the pool of light from the infrared floodlight? The pathway (a safe route to cross a road in Brisbane Australia) is good at reflecting IR and looks bright. The possum isn't scared because it's eyes can't detect the bright infrared light any more than your eyes could.

The possum's tail is not so good at reflecting IR, so looks dark. His eyes reflect the light just like cats eyes reflect light.

In case anyone doesn't know what a possum looks like in normal light …

< click – possum in visible light >

… Here you go. You can just about see their dark tails at the bottom left of the picture here.

- If they ask: if people ask about animals seeing in the dark, note that they achieve this by being very effective at capturing the small amounts of visible light that is present, rather than by seeing in infrared.

They have big pupils, and often the back of the eye reflects the light back for a second chance to detect it (this is why cats eyes reflect light).

- If they ask: night vision goggles are like animal eyes in that they make best use of the little light there is. They also commonly use ambient IR light to boost the signal. Sometimes people use IR torches with these. They are commonly shown as green because the human eye is very sensitive to green light and this makes it easier for the user to see the resultant image.

IR image permission (does not require credit): by email from Prof Darryl Jones d.jones@griffith.edu.au
Visible light image permission CC BY 2.0 (does not require credit) as given at https://en.wikipedia.org/wiki/Common_brushtail_possum#/media/File:Brushtail_possum.jpg

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Slide 16 – infrared emission (cat)

- Everyday objects emit infrared, which swamps reflected signals
- Infrared cameras can tell us about objects' properties from their IR signal
- Brighter bits on the camera image = more IR received from that direction

Here is Louis the cat. This time there is no IR spotlight. But an IR camera will still see him because he is glowing. You know how when barbecue coals heat up, or metal is melted, then they glow? Some things glow but at lower energies / longer wavelengths, in colours we can't see. Things around room temperature glow (= emit radiation) nicely in infrared.

What do you think he will look like in IR? Which bits of him will be emitting more IR?

< click – infrared Louis >

[Discuss with group … realise it is the warmer bits; recap that the bright areas are where the camera is detecting more IR, but this time from emission rather than reflection]

Yes, his warm little face and his
<click – toasty toe beans >
… Toasty toe beans.

When you can feel that something is hot from a distance, it's because you are receiving warmth from its infrared glow. Your skin absorbs the infrared, heating it up, and you then feel that heat.

[KS3 optional for more physics: Skin is good at absorbing IR just as it is good at emitting it. Good emitters are always also good absorbers.]

There is no infrared spotlight here. Louis is emitting more IR than he is reflecting. This picture is dominated by where IR is being emitted. It's a different way of seeing, and it highlights different information.

I have the camera that took this picture, right here. I thought we could have a play with it.

DEMOS: camera activities 1
Black and white images, look around the room for warmer / cooler objects

- If they ask: the possum pic is in near-IR (just off the end of the visible spectrum), while Louis is shown here in mid-IR (longer wavelength, as used by the Webb telescope).

- If they ask: snakes detect IR at similar wavelengths to those detected by the camera. Their infrared organs give detailed feelings of warmth, rather than direct chemical reaction to light absorption as in true eyes. They create only a very poor ‘image’ from these sensations.

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7. Colour mapping images does not add information (slide 18 – coding in colours; slide 19 – coding visible image)

Slide 18 – coding in colours

- Colours on infrared images do not add more information, they just make it easier to read

We’ve been looking at IR images in black and white. But when you see IR emission images, they more often look like the one on the right. Can you work out what the colours mean? (Younger children – I’ll give you a minute to discuss this with the person next to you).

The answer is the colour is related to the INTENSITY/amount of IR light detected. So the white is where there is lots of IR being emitted, like his hot little face and toe beans.

< click – reveal answer >

The IR intensity is most likely related to temperature, but not directly (KS3: it will depend on how good an emitter the object is, and also any noise/absorption from the air between object and detector).

The colour hasn’t added any new information to the image, it’s just swapped shades of grey for different colours. But humans tend to be able to see differences more clearly when they are coloured in like this. What do you think? Can you see more detail in the coloured image? Do different things stand out now?

- If they ask: the camera picks up a range of wavelengths but only records the total brightness from these. The colour is not related to the exact wavelength, only to the total amount of light detected between two wavelengths.

Slide 19 – colour coding visible image

- Colour choice for colour-mapped images is arbitrary
- Adding colour does not add information

Let me show you how this colour coding – or colour mapping – works using a visible image. Here is a picture of some toys in visible light. First, we make it so the picture just shows the intensity of visible light …

< click – image goes black and white >

The black and white image has lost the detailed wavelength information that told us exactly what colour every part of the image was. Now it just tells us how much visible light in total is coming from each part of the picture. This is like the black and white infrared image we got, which didn’t tell us exactly which wavelength of infrared was being received, but just the total intensity over a range of wavelengths.

Then we colour it like we did for Louis.

< click – colourised image appears >

Just like before, the areas of the picture that have the most intense light detection are coloured white/yellow, and those with the least are blue/black. This has not added any information to the image, but just makes it easier to see.

Of course, you could use any colour scheme you liked for this, depending on what features you wanted to talk about. It's like using different Instagram filters. All these pictures contain the same information, but the different colour schemes help draw our eye to different features.

< click x 3 – differently colour mapped versions >

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8. Infrared behaves differently than visible light (live camera feed, slide 21 – Webb telescope)

No slide – live camera feed

- Words: *opaque*, *translucent*, *transparent*, *reflective*, *absorb*
- Materials that are opaque to visible light can be transparent / translucent to IR
- Some materials reflect IR

Here is our camera feed again, but this time let's use colour. Which colour scheme do you like? [Switch through different options. Letting children choose helps reinforce that the choice is arbitrary.]

We know the camera can see IR (relating to the temperature of things)
This means we can use it to find out about the properties of IR light. How is it like visible light, and how is it different?

Demo: camera activities 2 - testing different materials

So what does this all mean for the Webb telescope? Well these differences between visible and infrared light explain a lot about why it is designed as it is, and why astronomers want to have an infrared telescope at all.

- Top tip: unfortunately, remote controls and IR flashlights use near-IR and so cannot be seen by the camera. You could however set up a hacked webcam or use your mobile phone if you wanted to do things using these wavelengths. But remember MIRI is mid-IR so this would be a bit of a diversion.

Slide 21 – Webb telescope

- The properties of infrared have been considered in the design of the telescope

For a start, the gold on the mirror is very reflective to infrared. This ensures the telescope can capture as much light as possible.

And the reason why the mirror is huge is because infrared naturally gives a fuzzier picture than visible light (KS3: because of its long wavelength), so you need a mirror this size to give similar resolution to Hubble.

The sunshield also reflects infrared – I'll come to that a bit later.

But why IR? For a start, there are things in space which are opaque to visible light, but transparent to IR. Just like the bin bag. And if you could peek inside them, you could discover secrets of how our planet was formed, and about the whole history of the Universe.

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9. Why build an infrared telescope (slides 22 to 25 – astronomy images)

Whizz through these fairly quickly, there is not time to go into lots of detail about them. Remember what the main messages are:

- There are interesting space things that you can only see with infrared
- Webb will be much better than previous infrared telescopes

Slide 22 – Eagle Nebula / Pillars of Creation

I showed you this before, from the Hubble telescope. Great clouds of dust that visible light cannot pass through. And we do want to see inside, because new stars and planets are forming in there.

This picture has false colour, this time related to what wavelength of light has been detected. They have chosen wavelengths of light associated with particular atoms – blue for oxygen, red for sulfur, and green for nitrogen and hydrogen.
But what if we used infrared?

< click – Hubble infrared image >

This image picks out more stars, and lets us see through the dust, which now looks translucent. We can see baby stars forming inside the nebula.

This infrared image is from Hubble, which can only see near-IR – that's only just a little further along the light spectrum than our eyes can see. Two different wavelengths are shown, the one closest to visible light in blue, with yellow for a little further into the near-IR band. Remember near-IR behaves more like visible light, and you can see here that the dust clouds are still blocking some of the view.

How amazing would it be to have a higher resolution IR image using mid-IR - the same wavelengths that our camera sees. We'd be able to see even more clearly through those clouds.

- If they ask: The pillars are about 1/10 the width of the full moon in the sky, in Serpens
- 1100 nm infrared light is depicted in blue, while 1600nnm light is depicted in yellow
- Additional info: https://www.nasa.gov/feature/goddard/2017/messier-16-the-eagle-nebula

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Slide 23 – protoplanetary disk

What might be inside the nebula …
This is a PAINTING of the formation of a solar system with the star in the middle. Our own solar system once looked very much like this. There is so much we don't know about how this process happens, and Webb can help us peek into those dusty clouds to catch different solar systems at different stages of formation.

Slide 23 – Black Eye galaxy

On a MUCH larger scale, here is a huge galaxy containing billions of stars. It's a really weird one because the stars and gas on the outside are rotating the opposite direction to those in the middle. Maybe it is two galaxies that merged? Maybe we could unravel this mystery if we could only peek through this dark dust that is obscuring so much.

https://www.nasa.gov/feature/goddard/2017/messier-64-the-black-eye-galaxy

Slide 23 – Pinwheel Galaxy

Here's another galaxy in visible (Hubble again). Now let me show you the best infrared view so far, from the Spitzer Space Telescope, which specialises in infrared

< click – to infrared image. Click back and forth a few times >

In IR you can see new, delicate structures. But it's poor resolution of the IR image compared to Hubble (note the fuzzy stars).

Wouldn't it be great to be able to see all these structures with the detail that Hubble offers.
Spitzer sees similar parts of IR as Webb. But it only has a 85cm mirror. Remember Webb's mirror is 6.5m!

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10. Why and How Webb is kept cold (slide 26 – L2; slide 27 – Webb (sunshield); slide 28 – Space Fridge

Slide 26 – L2

- Infrared interference from Earth, Moon and Sun would warm the telescope
- Warm telescope emits infrared radiation which is collected by the detector
- Being at L2 means that Earth, Moon and Sun can all be blocked by sunshield

But there's a problem

You know how we could see everything in the room so clearly with the camera? Webb is looking for much, much dimmer light sources.

If we put Webb where Hubble is – orbiting the Earth just a few hundred miles up – then it would absorb sunlight reflected from the planet and warm up. The telescope itself would glow in infrared, and its own radiation would swamp its delicate detectors. It'd be as if the inside of your eye was glowing with light.

Astronomers like me go out into the countryside to find the darkest spots for our telescopes, so we can see fainter objects in the sky. Similarly, Webb is going to go off on a journey to escape the warmth of the Earth and Moon.

It will not even be orbiting Earth, instead it will orbit the Sun. After launch, it will travel 1.5 million kilometres over 30 days to reach a weird place in space called L2.

< click – Webb's orbit >

Here is a diagram to show where it will go. This is not to scale, but it's to give you an idea of where Webb is compared to the Sun, Earth and Moon. Here is Earth in blue, with the Sun over in that direction. The Moon goes around the Earth. Webb will be the other side of us from the Sun.

L2 is further from the Sun than Earth is. That would normally mean that objects here should orbit the Sun more slowly than Earth, as they feel less gravity from the Sun. BUT in this exact position, an object gets an extra little tug from Earth's gravity. This means that it orbits at the right speed to follow the Earth around the Sun, staying always the opposite side of it. [I'd recommend lots of hand gestures to help try to explain this!].

Demo: where is L2 (includes demonstrating Webb's orbit around L2)

Slide 27 – Webb (sunshield)

Sunshield – remember how Mylar reflected IR in the demo earlier? These membranes are made of a material called Kapton, coated with aluminium. Each is as thin as a human hair.

109°C on sunward side, -220°C on dark side.

Multi-layered so that heat can't conduct through it.

KS3: The only way to get through is to be absorbed (by this reflective material), conduct to the other side of the membrane, radiate out across the gap, get absorbed by the next membrane (of highly reflective material) and repeat this over and over again. More likely, any IR gets bounced along and out of the gaps at the side. Meanwhile any heat that does get to the far side is similarly radiating out into space, and so does not build up.

Heat generated by the telescope systems is released through the sheets to divert it away from the instruments.

Slide 27 – Space Fridge

The sunshield is enough for the other instruments, but because MIRI detects longer-wavelength IR it needs to be particularly cold. For this reason MIRI has an active cooling system.
It works very much like a home fridge. It moves heat from one place to another. Home fridges take heat from inside and dump it outside into the room. MIRI's fridge takes it from MIRI and dumps it on the sunny side of the telescope.

Fridges control heat transfer by pressurising and depressurising gas as it moves in a loop. Let me show you why this works.

Demo: depressurising gas / pressurising gas (watching each with infrared camera)

This is all an amazing feat of engineering and human endeavour. But it's even more clever than that – it also has to fit inside a rocket.

[Good space fridge info at https://jwst.nasa.gov/cryocooler.html]

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11. Project progression (slide 29 – rocket; slide 30 – progression; slide 31 – current situation; slide 32 – launch date)

Slide 29 - rocket

- Webb is a huge challenge!

On top of all the challenges to keep it focussed and cool, it has to squeeze inside an Arianne 5 rocket.

The mirror folds, the sunshield is neatly stowed. And it will have to open itself up, perfectly, when far from Earth with nobody to give it a nudge if something sticks, or repair a tear in the sunshield.

And best not think about the dangers of launch! So many years work, sat essentially on top of a large, controlled bomb. But Ariane 5 rockets are good, they have proved exceptionally reliable for the past twenty years or so.

Slide 30 – project progress

- Webb is a huge challenge! Success is not predetermined

So how is it all going so far? Well, the launch date and budget have slipped … just a little. This is something people have never done before, it is hard to predict how these enormous projects will develop.

The US government just recently had to agree whether to increase the budget again – it's difficult as so much has already been invested, and so many people are waiting for its results … But it's also a lot of money.

Slide 31 – project progress

- International collaboration, lots of teams/people involved.
- Nearly there?!

This is a really simplified overview. Once the sunshield is done (it had problems with tearing when they test deployed it), they still need to integrate everything and do some more testing before it'll be ready to go.

Slide 32 – launch date

- This is a real, ongoing project

[Depending on age(s) of audience:] This telescope has been being planned/built for your whole lifetime [planned from 1996, built from 2002].

With a launch date of 2020 and 10yr lifespan, it will last until about 2030. It will be one of the most important instruments available to astronomers during this time.

[Relate to their own possible careers, eg:
If they are 8yr old, they will be 20yr by its demise. It will change what they learn / use data in project.
If they are 10yr old, they will be 22yr by its demise. They could use it during a PhD.]

I can't wait to find out what it discovers.

SECTION 4: Cheat Sheet (example)

It is recommended that each presenter create a 1-2 page cheat sheet for their own use. This can help as a prompt for what comes next, a reminder for awkward facts and figures, and/or to help focus. What works best will be highly personal, so do make your own. The below is only for example! You may prefer to annotate the slides to print from Powerpoint. Be sure to use a font large enough that you can sneakily read it during the presentation if needs be.

1. **Introduction**

2. **Telescopes catch light**
   - Light enters eye, more light = more info

3. **Webb's (invisible!) light goes to detectors like MIRI**
   - Light rays < don't mention size here
   - "Uncrewed" not "unmanned" – compare to Earth-based
   - "Invisible light" (don't mention infrared yet)

4. **Colours past the end of the rainbow**
   - **DEMO – water spray / DEMO – prism** (filter wall-side to start)

5. **Ultraviolet light is real**

6. **Infrared light is real**
   - Reflected (brush tail possum, Brisbane)
   - Emitted (toe beans)

7. **Colour mapping images does not add information**
   - Louis (click for 'answer'), then toys

8. **Infrared behaves differently to visible light**
   - **DEMO – black/white camera – look for hot/cold**
   - Gold mirror (is on next slide)

9. **Why infrared astronomy**
   - Eagle – 1. O blue, S red, N/H green   2. blue is nearest-IR   1/10 moon
   - Black eye – weird rotation
   - Pinwheel – Spitzer 85cm mirror

10. **Why and how Webb is kept cold**
    - **DEMO – L2** 30d / 1.5 million km
    - Sunshield: human hair, 190 vs 220 °C
    - Fridge > link to fitting inside rocket

11. **Webb project progression**
    - Arianne 5, last 20yr very reliable
    - March 2020