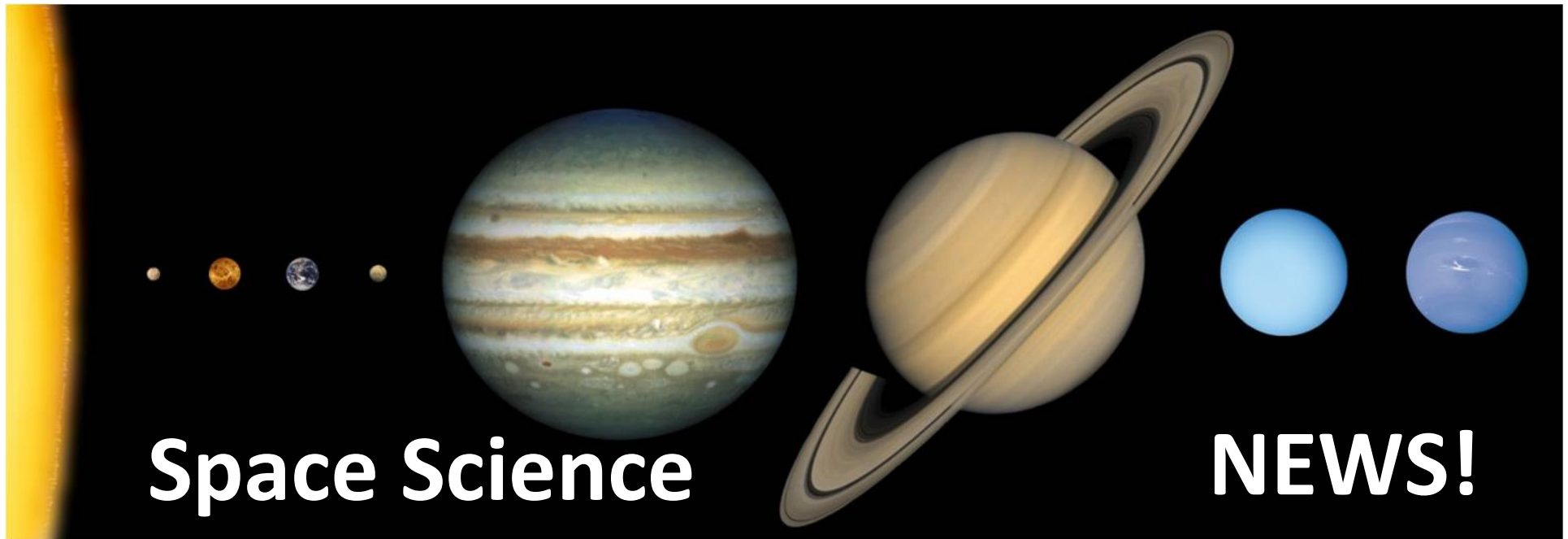


Earth Sciences 2150 – Fall 2023

Solar System and Planetary Science



**The James Webb Space Telescope:
Amazing Technology and Amazing Images**

EASC 2150: The Solar System

The Plan for Today

What is the JWST and What is it Doing Out There?

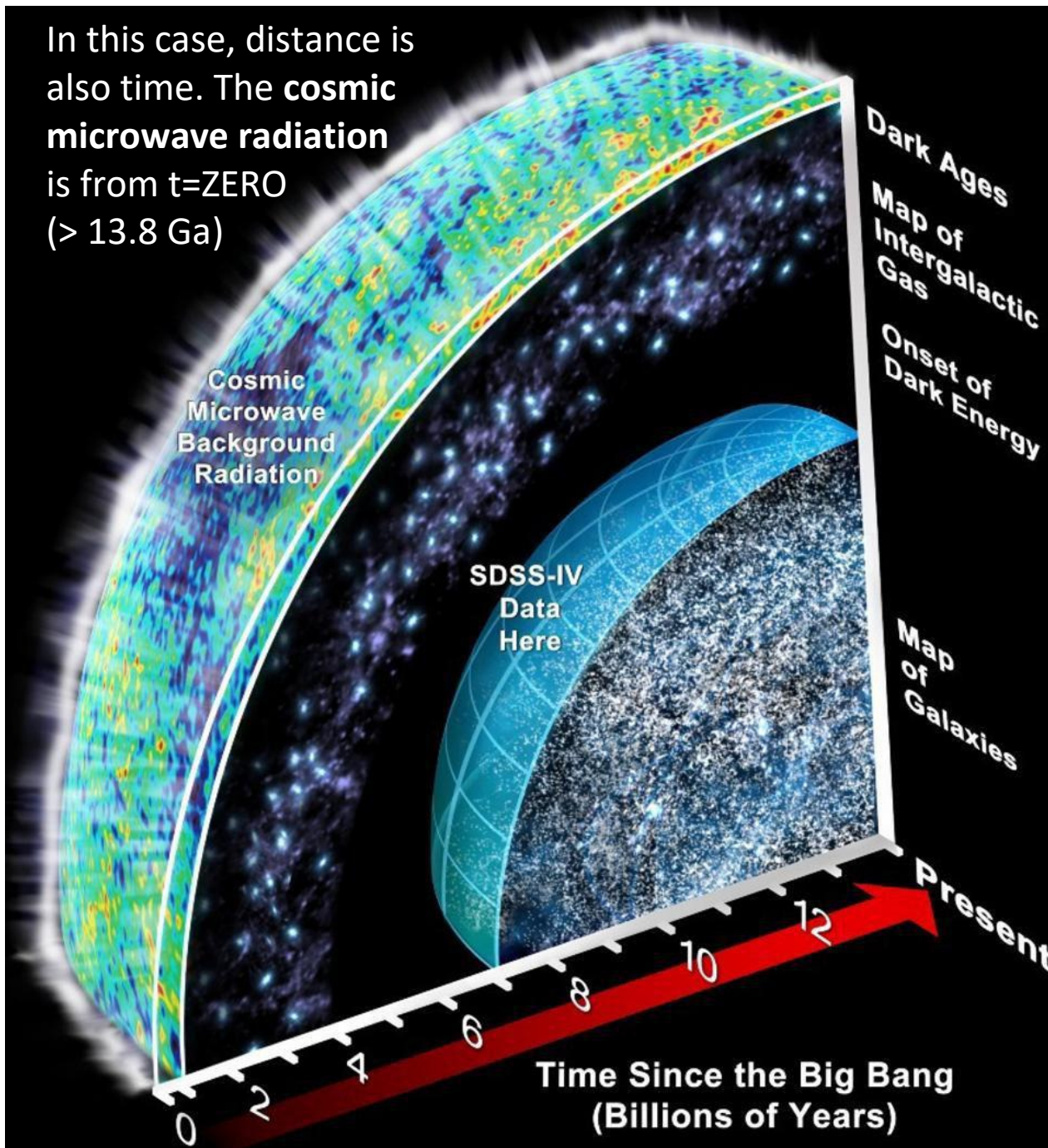
- Orbital telescopes have made huge contributions to our knowledge, notably with respect to “exoplanets” – those in other solar systems. But they have their limitations.
- The JWST is a more powerful space telescope placed far away from the Earth, to avoid ‘interference’ by Human and other natural radiation sources. It is a technology triumph!
- The JWST has a number of objectives, including better understanding of our own Solar System, but its primary objectives are much wider – getting information that will contribute to *cosmology* – and perhaps even constrain it.
- The JWST will also target “exoplanets” as part of **SETI**.

The Rather Bizarre World of Cosmology



“Alice in Wonderland” is my favourite metaphor for this!

- The field of cosmology is one of the most baffling in science. It involves concepts that are hard to conceive of, let alone grasp, and at times it verges on the mystical. How did the Universe begin and why does it exist? Does it involve more than four dimensions?
- **The JWST will look outward in space and backwards in time.....**



- When we look at the distant areas of the universe, we are also looking back in time, because the light and other EM radiation left their sources billions of years ago....

- The signals are very faint, and also have **changed** from initial parameters because the sources move fast. They are not **visible** light....

A portrait of the James Webb Space Telescope

INSTRUMENTS

Spectrometers and other instruments

BACKPLANE

OPTICAL TELESCOPE (OTE)

Primary mirror made of hexagonal Be panels

'aperture'

Secondary Mirror

MOMENTUM FLAP

SOLAR ARRAY

EARTH-POINTING ANTENNA

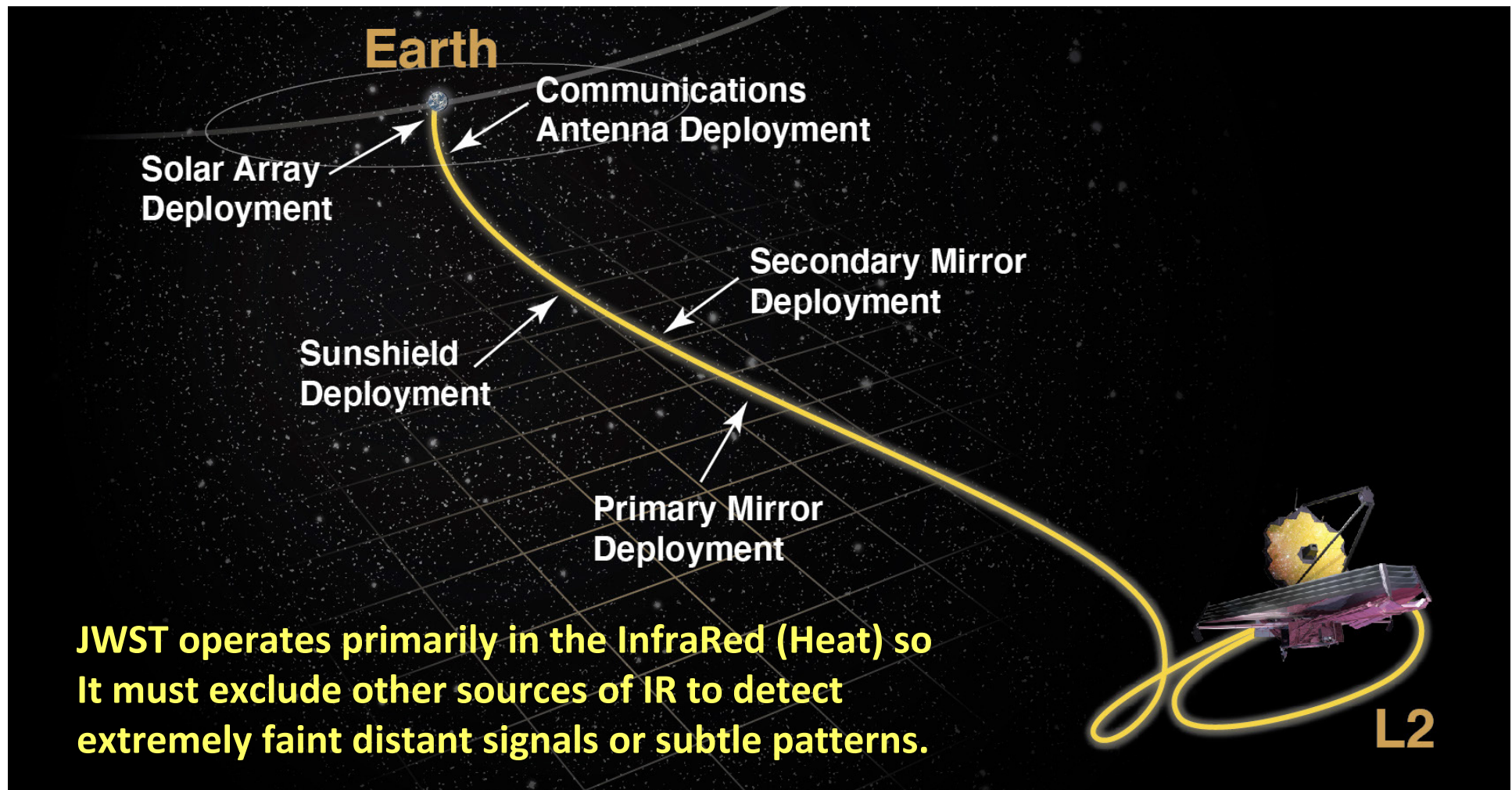
SPACECRAFT BUS

STAR TRACKERS

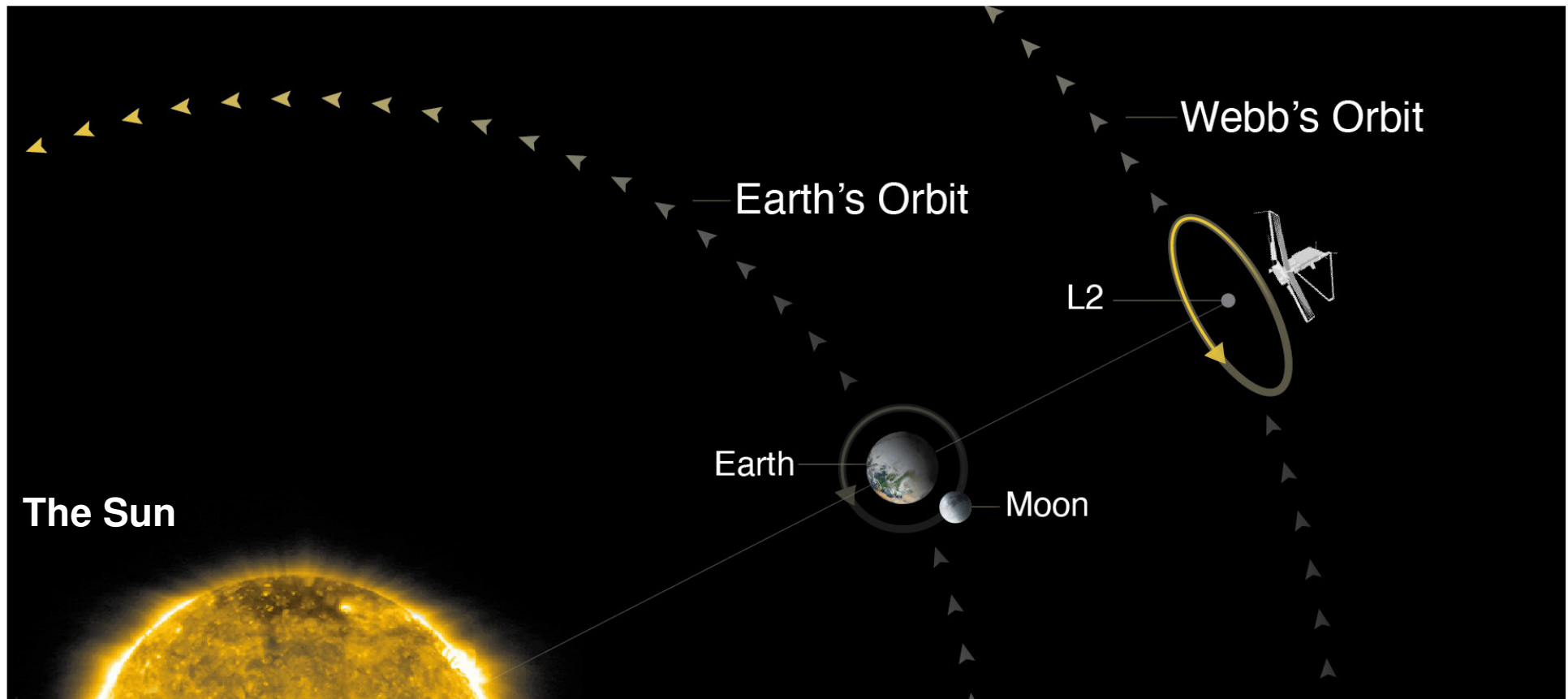
Sunshield

From NASA

- The telescope is a reflecting system, with the largest mirror ever deployed in space. It sits behind a complex protective "Sunshield".

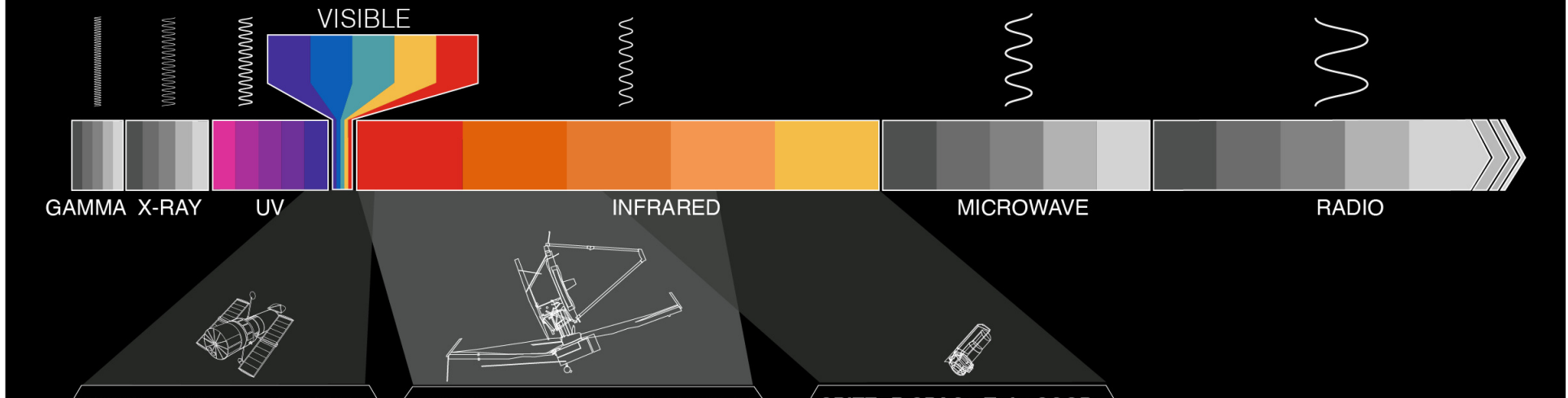


- JWST is not in near-Earth orbit. Launched on Christmas Day 2021, it travelled to a location in space called “L2” – a place of gravitational stability in the –Sun-Earth-Moon system. It is distant from terrestrial sources, and protected by its sunshield. This allows its operating temperatures to be close to absolute zero (-273.15°C).



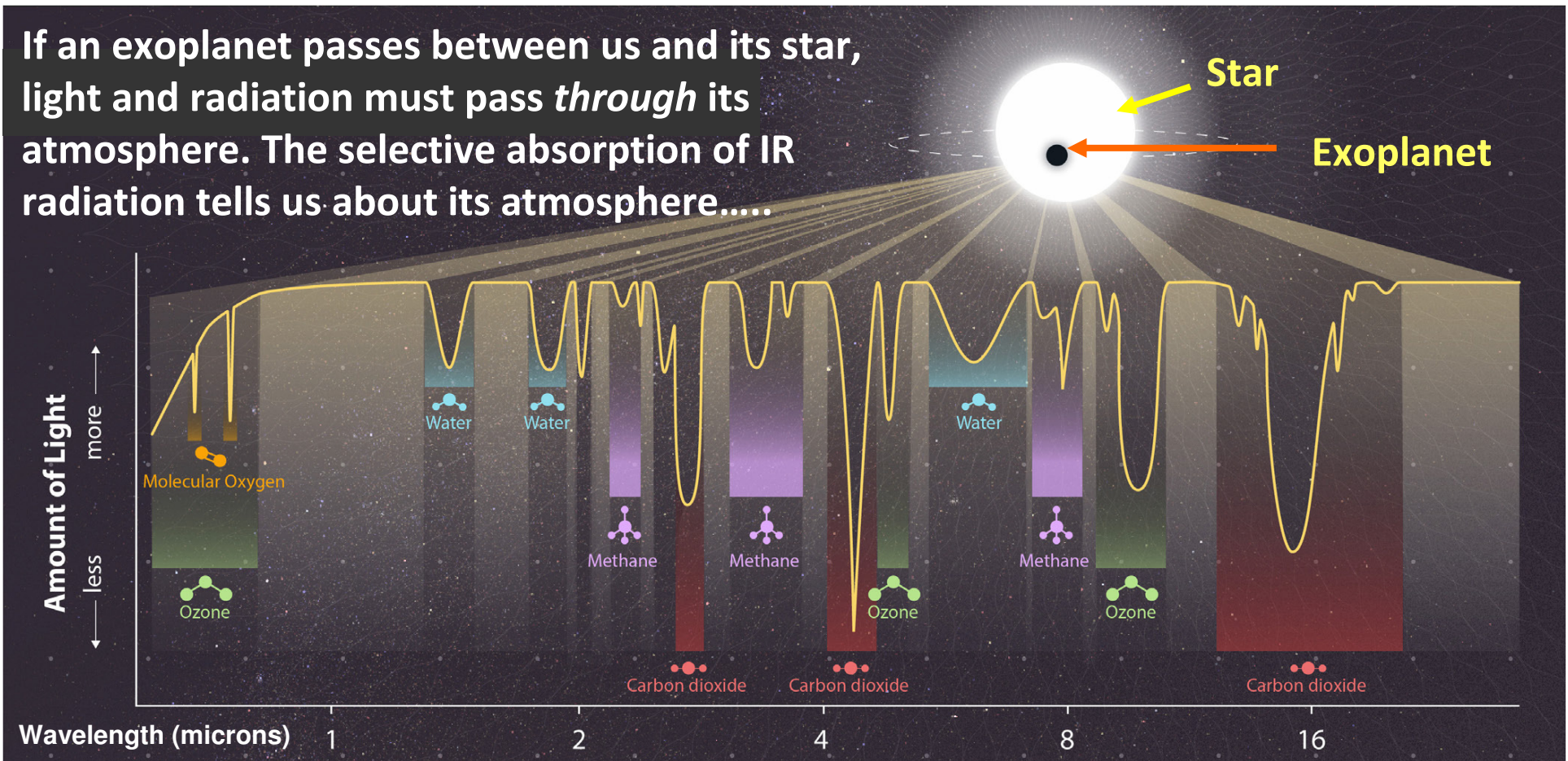
- **Being at L2 means that it can stay in one place with minimal fuel.**
- The telescope is about 1.5 million km from Earth, and will always have one side in sunlight to power instruments. It needs to orbit L2 to avoid shadows from Earth/Moon and maintain thermal stability.
- **It requires fuel to maintain its orbit – and no refuelling is possible!**
- It can image half the 'sky' at one time, but over a year it sees all, because it orbits the Sun, but always beyond Earth and the Moon.

ELECTROMAGNETIC SPECTRUM



- The JWST will focus on the infra-red – this longer-wavelength radiation is better able to avoid dispersion and absorption by dust and gas. So it is easier to see distant regions. But because dust/gas tends to radiate in the infrared, we can study it if we want to.....
- **But there is another reason. As we will discuss, radiation from moving objects is “changed” as they recede from us. We now get IR from the distant universe instead of visible or UV radiation, but we can reprocess this to understand original characteristics.**
- We can see the first stars and galaxies of the earliest Universe....

If an exoplanet passes between us and its star, light and radiation must pass *through* its atmosphere. The selective absorption of IR radiation tells us about its atmosphere.....



- **There is no end to the insight that spectroscopy can give us. For stars in very distant galaxies, we will look back in time; what were stellar populations like in the earliest times of the Universe?**
- **For regions that are closer, this will allow us to see how starlight is affected when it passes through the atmospheres of exoplanets.**
- **JWST soon found CO₂ in an exoplanet atmosphere – no surprise.**

NASA's View of the Mission Objectives

(but note that NASA is only one of the sponsors.....the European and Canadian Space agencies also play roles.)



Search for the first galaxies formed in the early universe



Observe the formation of stars, from young stellar nurseries to the formation of planetary systems



Study galaxies near and far to inform the evolution of galaxies

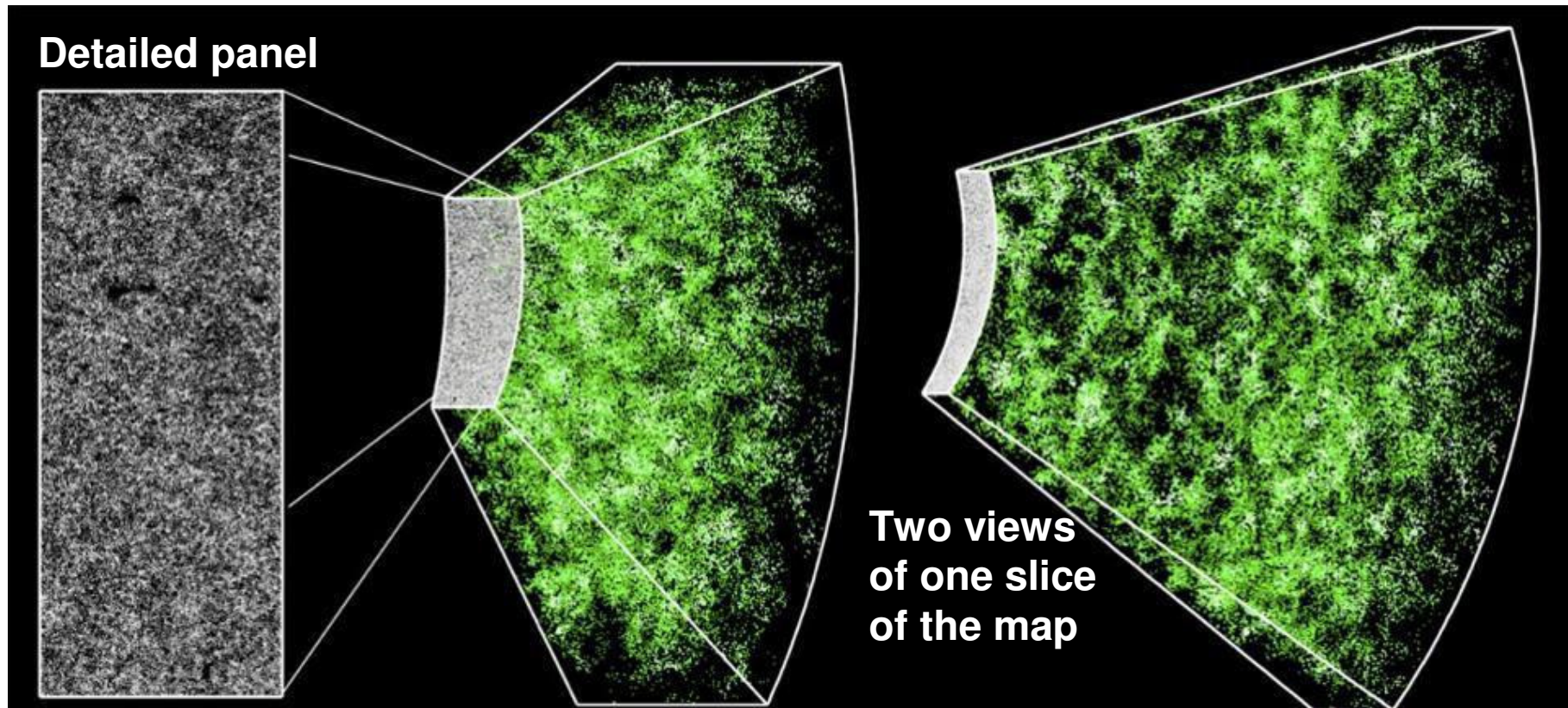


Measure physical and chemical properties of planetary systems, including our own solar system, and investigate the potential for life in those systems

The Unexpected and Unknown

Webb also has the capacity to reveal completely unexpected aspects of our universe, as Hubble has done. Webb's observations, which are designed to answer specific scientific questions, forge additional questions that can be addressed in future observation cycles and by future missions and observatories, such as the Nancy Grace Roman Space Telescope.

JWST and the Structure/History of the Universe



- These images from a '4D map of the Universe' show that galaxies in it are not evenly distributed – on clusters, strands and voids.
- Where (and what?) is the mysterious “dark matter” that modern observations of the Universe demand? Why can't we see this?
- Exactly when did the first galaxies (and stars) begin to form?
- Provide insight into a variety of other cosmological puzzles....

See the Difference!

Image from Hubble ST
(Visible Spectrum)

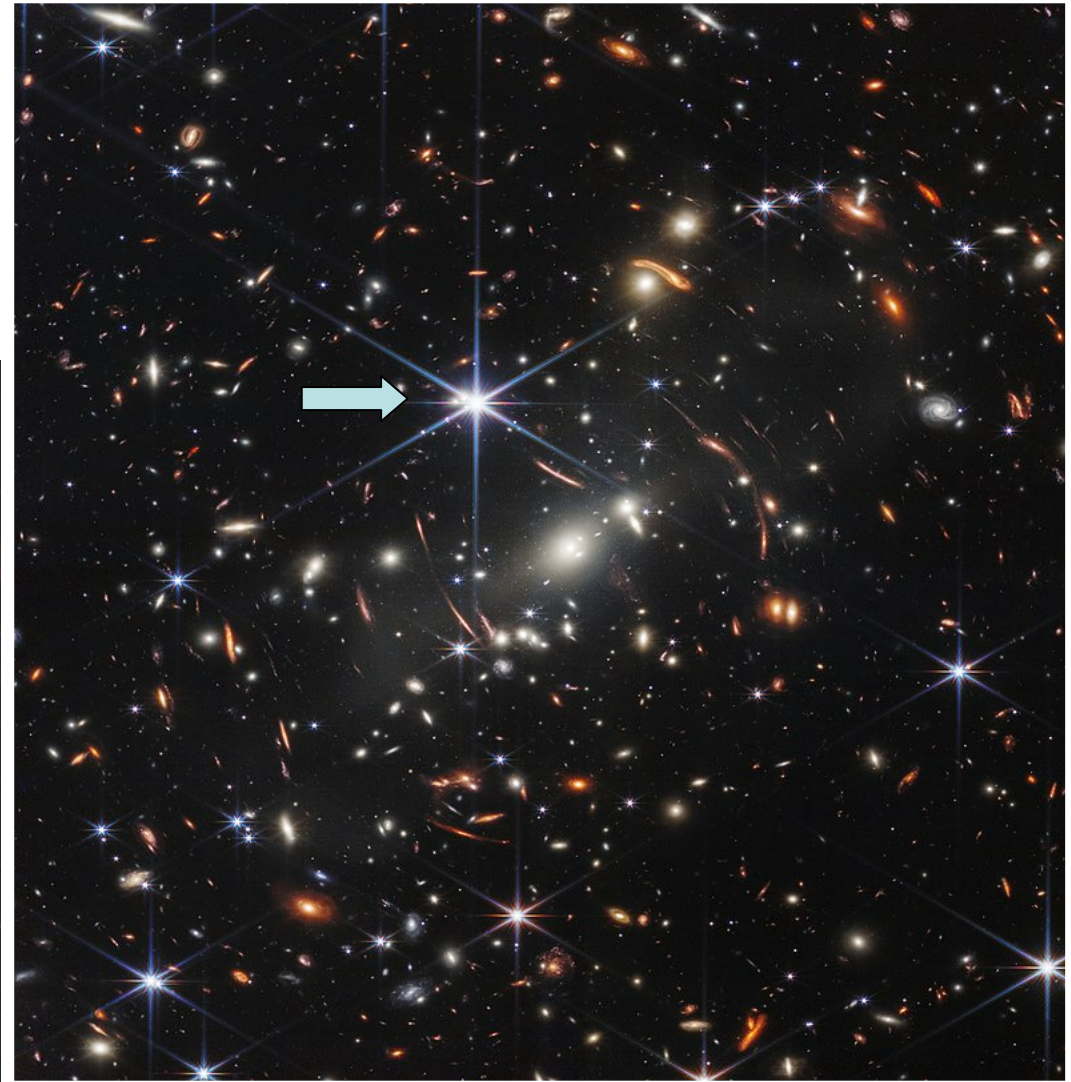
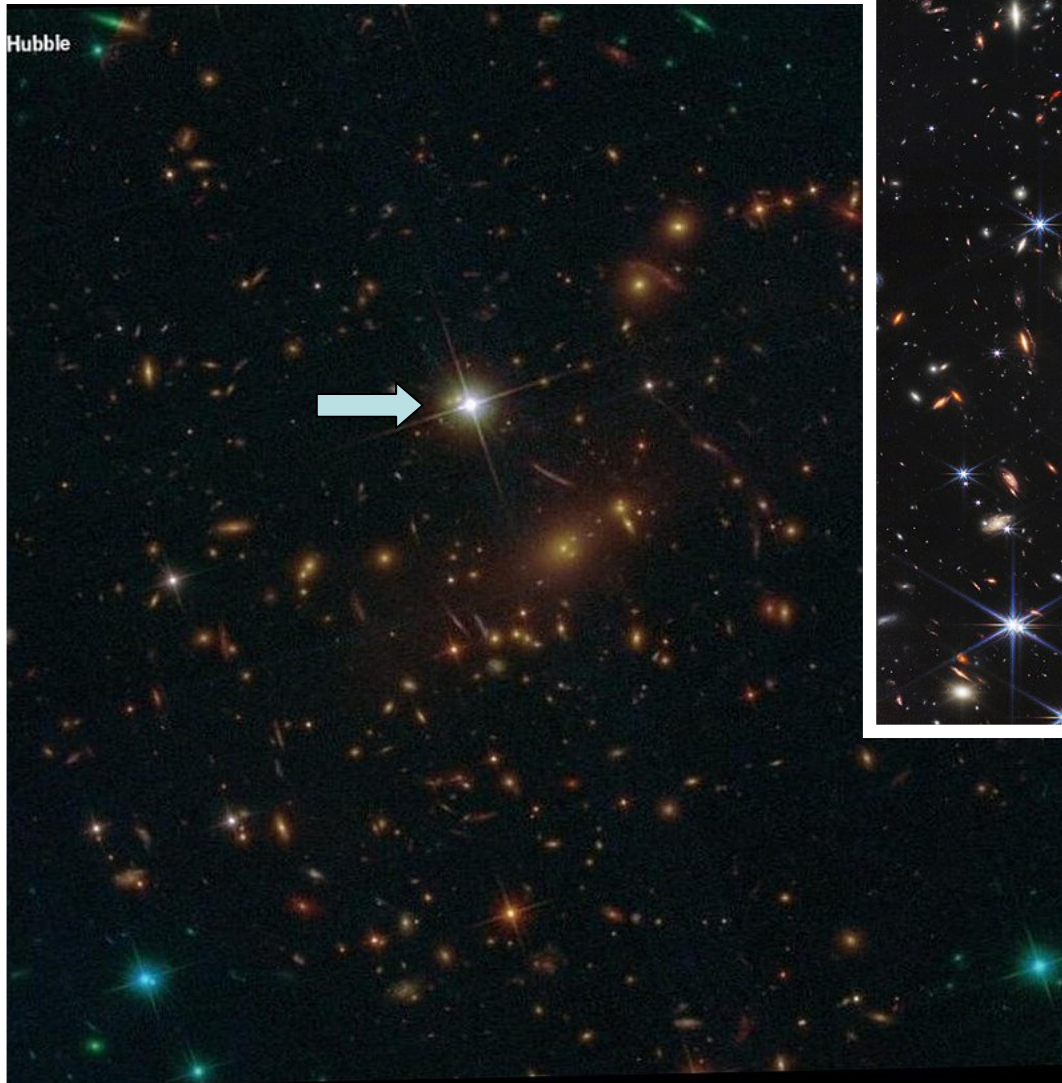
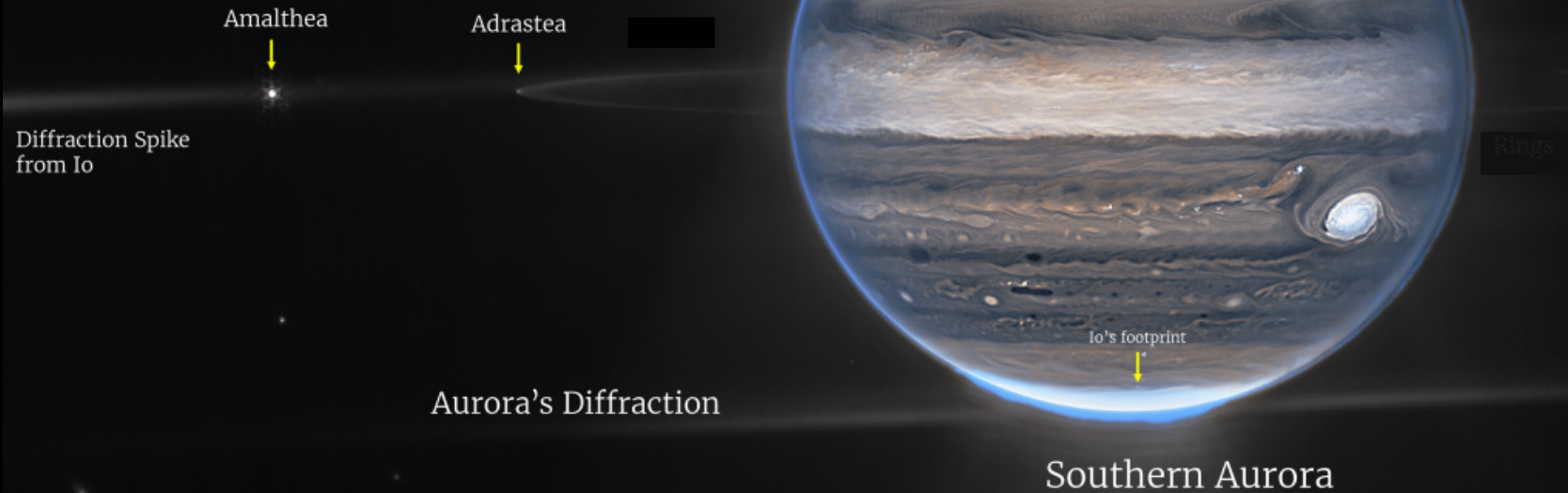


Image from JWST
Translated IR to Visible

Jupiter in the Infra-Red: Testing the Instruments



- The image is processed Infra-Red, which is then ‘mapped’ to visible light using false-colour assignment. The larger image shows two of Jupiter’s minor moons, and also the “Rings of Jupiter”.
- This is not a primary function, but Solar System science will be advanced by this remarkable imaging capability..... Can you see the rings in this image of Jupiter (they are very faint).

Saturn – June 25, 2023.



- This is a near-IR image, translated to see. The planet itself is dark, because it has methane in its atmosphere, which has strong IR absorption. But the rings of Saturn are largely icy materials and these reflect almost all radiation. The structure of the rings is seen in exquisite detail, including the ‘Cassini Gap’.

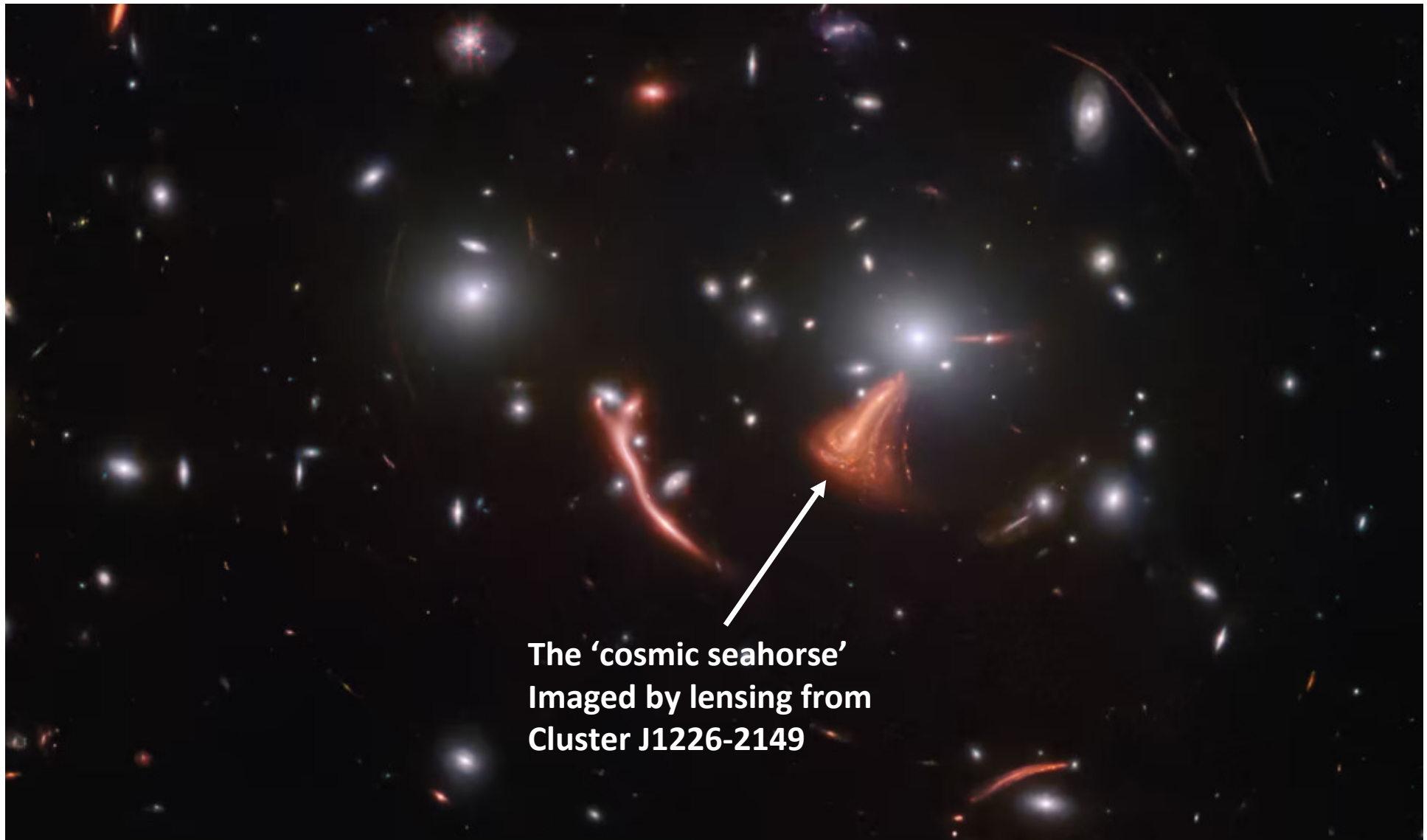
**Uranus and some of its
Moons; and its rings,
which appear bright in the
Infrared.**



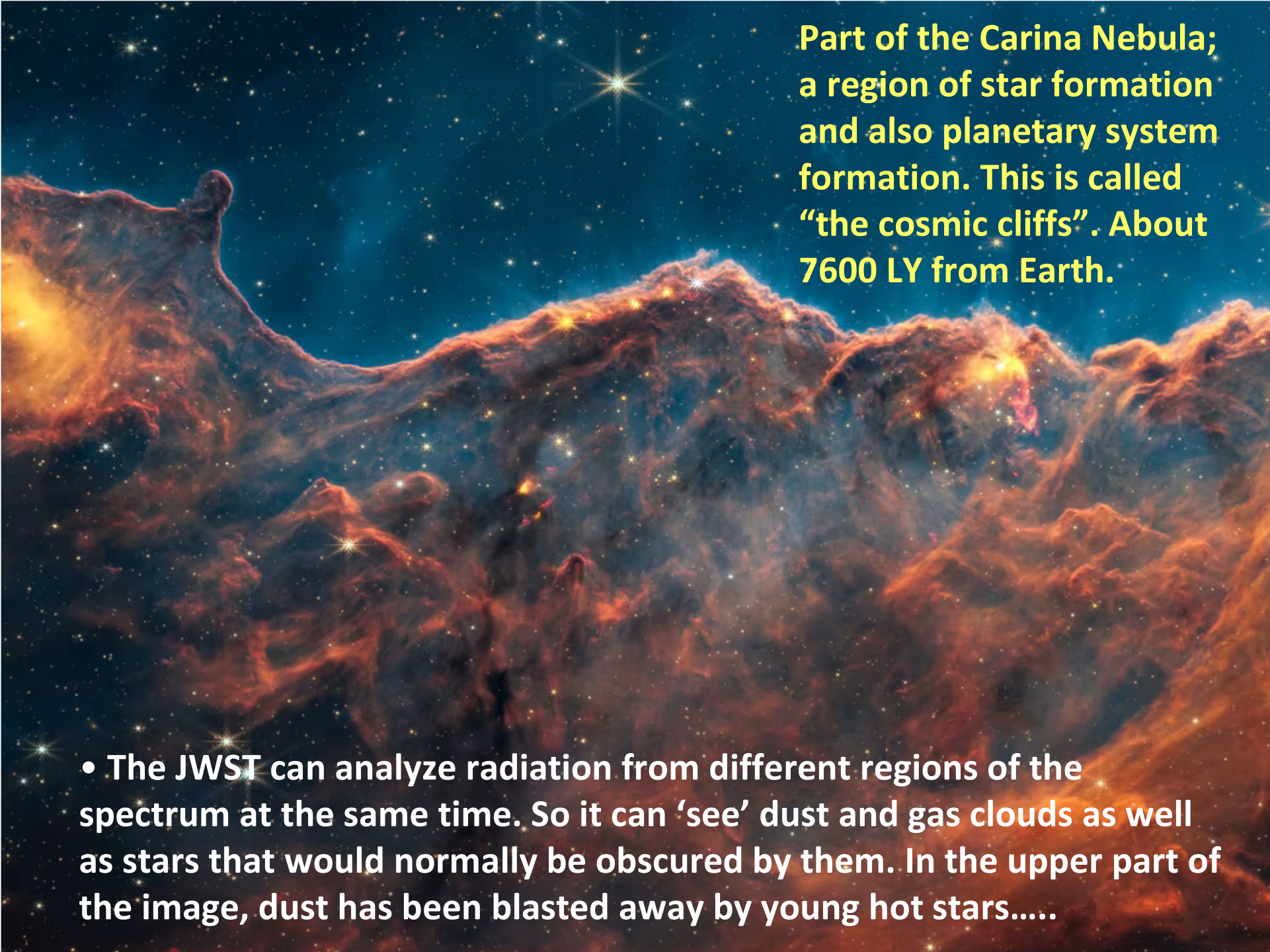
- **How is it that the JW telescope can take a picture that makes it look as if we are looking DOWN on the rings of Uranus?**



- Multiple distant galaxies imaged. Only the 'six-pointed' stars are in our own galaxy (artifact of the hexagonal mirror panels?). The spiral galaxy is analogous to ours, but is 1 billion light years away – when the light left it, most organisms on Earth were single-celled. Other galaxies are far more distant, and we would not even see them with visible light.



- “Gravitational Lensing”. The cluster of galaxies at right centre has ‘bent’ and ‘amplified’ radiation from even more distant sources, so we can look at star formation in the early times of the Universe. The cluster J1226-2149 is 6.3 Billion LY from Earth. Our Solar System did not exist at that time.



**Part of the Carina Nebula;
a region of star formation
and also planetary system
formation. This is called
“the cosmic cliffs”. About
7600 LY from Earth.**

- **The JWST can analyze radiation from different regions of the spectrum at the same time. So it can ‘see’ dust and gas clouds as well as stars that would normally be obscured by them. In the upper part of the image, dust has been blasted away by young hot stars.....**

**The “Tarantula Nebula” -
A region of star formation
about 161,000 LY from us.**

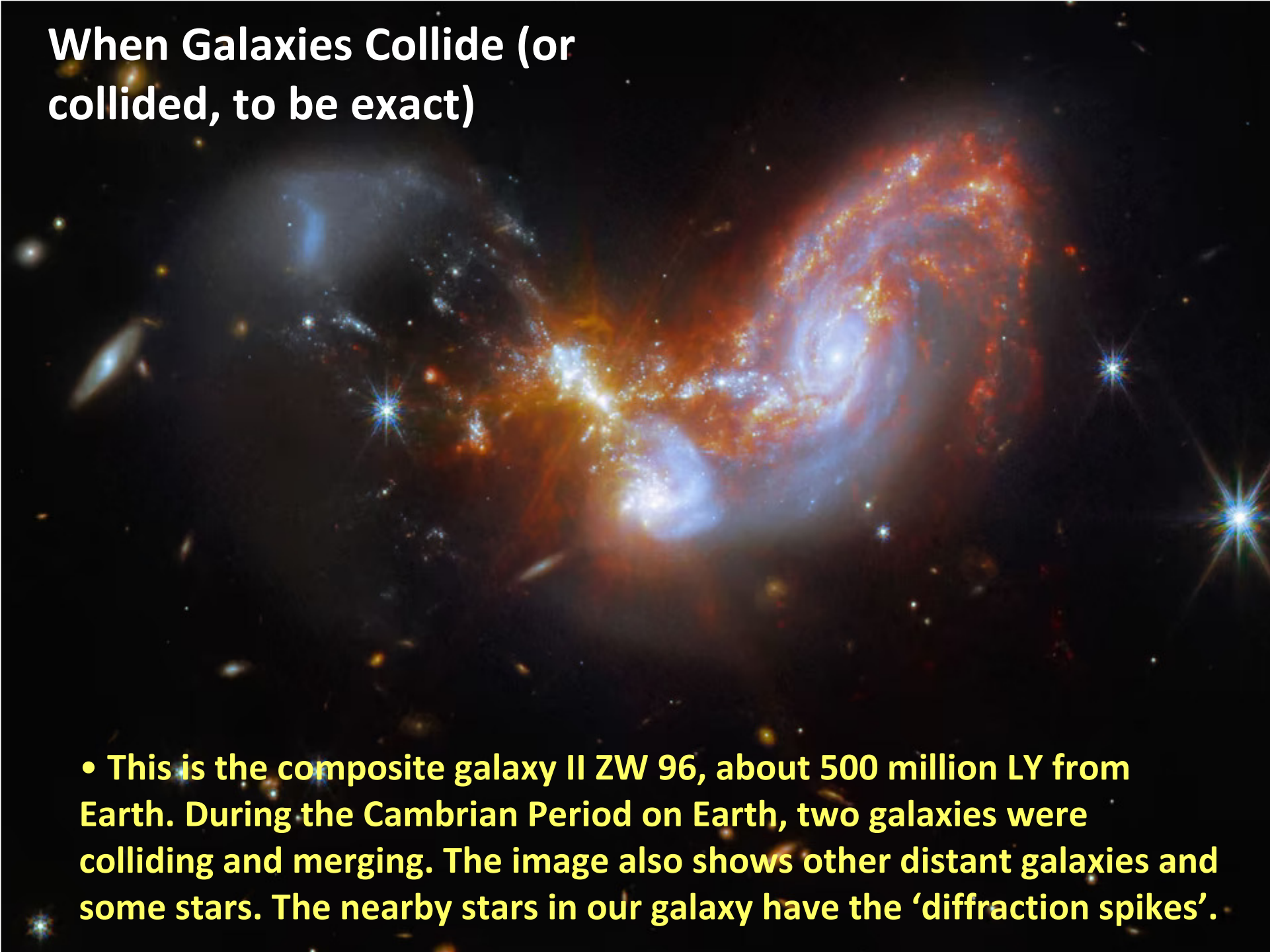
- **A now-famous image from the early testing of the instrument. The blue stars will not live long and will ‘seed’ the area with heavy chemical elements. Dull red and orange stars are ‘newly-formed’.**



Wolf-Rayet 140 (about 5000 LY away)

- This is a binary star system; two large stars orbit one another every 8 years. Their gravitational influences when they come close create concentric shells of 'cosmic dust' around them, which then move outward slowly and disperse. JWST will watch this in 'real time'.

When Galaxies Collide (or collided, to be exact)

- 
- This is the composite galaxy II ZW 96, about 500 million LY from Earth. During the Cambrian Period on Earth, two galaxies were colliding and merging. The image also shows other distant galaxies and some stars. The nearby stars in our galaxy have the 'diffraction spikes'.

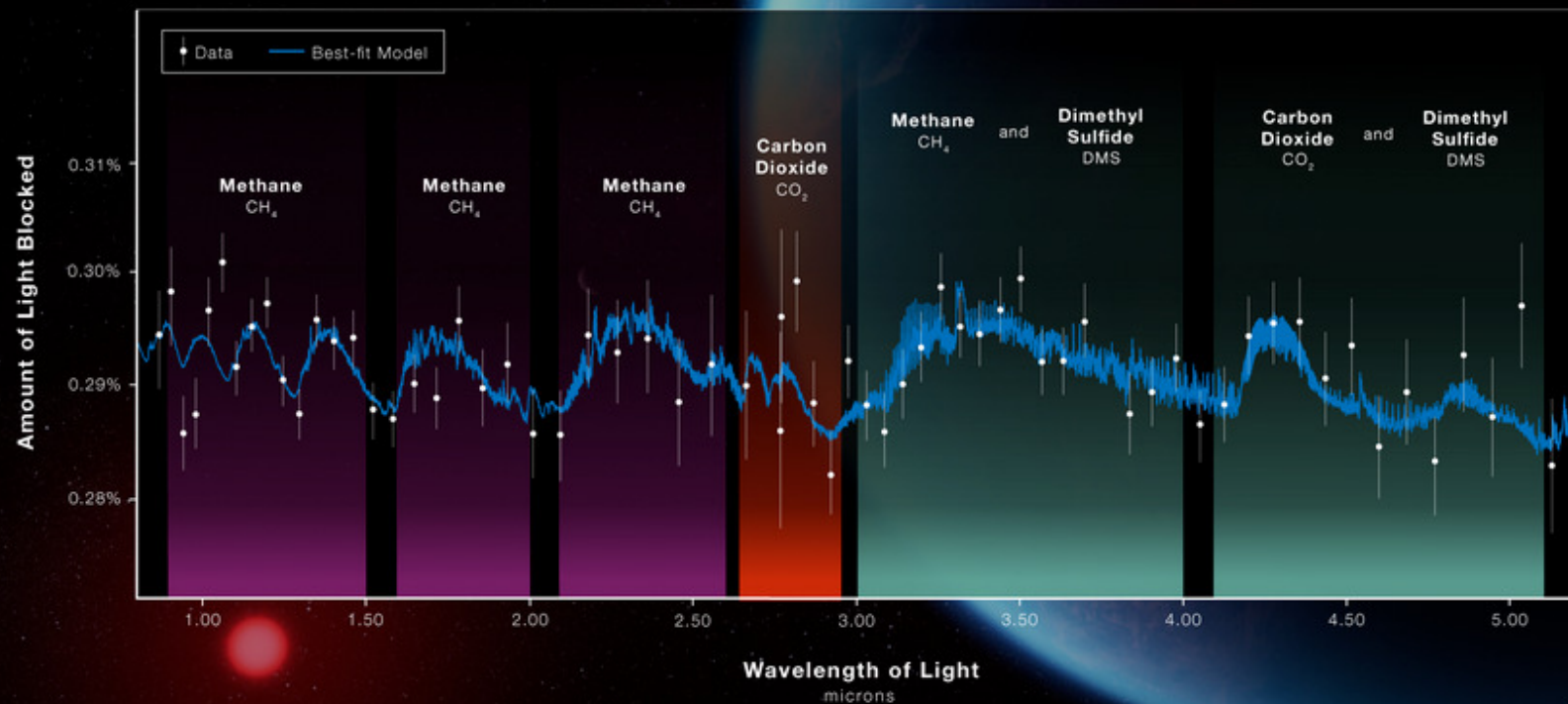
Hot off the press: JWST finds methane and CO₂

Artist's impression of K2-18b, an exoplanet associated with a small red star (120 LY). This is about 8.6 times more massive than Earth, of a type dubbed 'mini-Neptunes'. The term 'Hycean Planet' is now in vogue – these may be covered in vast water oceans beneath Hydrogen-rich atmospheres. Nothing like this exists in our Solar System.



- There is speculation that Hycean Planets might be potential sites for primitive life to exist, but this idea is controversial. It would definitely be “life as we do not know it.....”

How do we understand the atmosphere of K2-18b?



- The light from the star encounters the atmosphere of the planet. CO₂ and Methane are indicated by absorption patterns. There was also *possible* evidence of **Dimethyl Sulphide** – generated by marine photosynthesis (algae) on Earth. But more work is needed to be sure.
- Another study released on Sept 11 assessed whether an alien JWST in another star system could detect ‘biosignals’ in *our* atmosphere....

**“Full speed ahead - Warp Factor 10, Mr. Scott.....”
Wouldn't that be wonderful if it were really possible?**



The USS Enterprise supposedly takes short cuts through space by warping space and time.....The concept of 'hyperspace' and faster-than-light (FTL) travel is popular in SF. It is a plot device. As we will discuss much later, there are some fundamental problems with energy for even slow interstellar travel.

What are the chances we might ever get to visit such places, even within our own stellar neighbourhood? The chances are not so good, it seems, even if the Universe is “curved”. The James Webb telescope is perhaps the next best thing.....

More Information?

Much (but not all) information in this item came from NASA's website. There are already many images on the internet from early work and testing of the instrument.

(see the links below if you are interested)

<https://www.theatlantic.com/photo/2023/07/james-webb-space-telescope-photos-anniversary/674681/>

https://www.nasa.gov/mission_pages/webb/news/index.html

<https://www.livescience.com/space/exoplanets/james-webb-telescope-could-detect-life-on-earth-from-across-the-galaxy-new-study-suggests>

Some Light Musical Relief?

- It does not take too long for contemplations of the wider Universe to give most of us a headache.

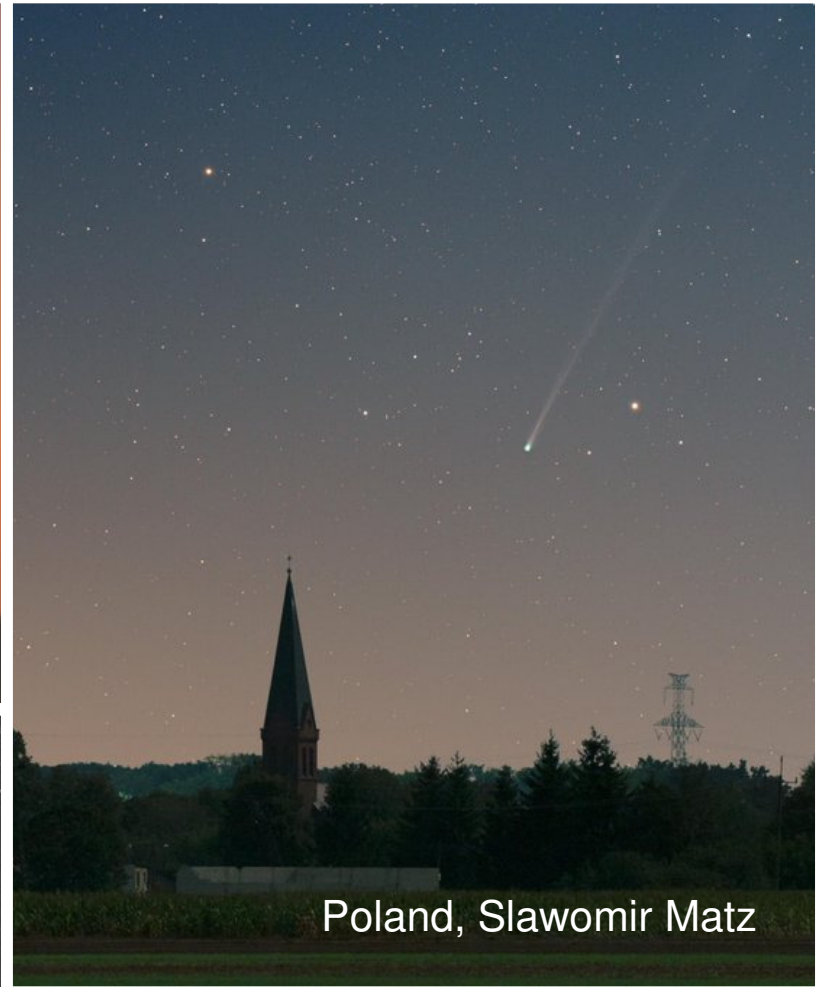
Back in the long-vanished 1980s, the British Comedy Group “**Monty Python’s Flying Circus**” released their famous “**Galaxy Song**”, in their movie “The Meaning of Life”. Although their comedy routines have not stood the test of time, the music and lyrics have.

There are many versions on the internet – some I can’t use.....but here is an educational treatment that fits.

<https://www.youtube.com/watch?v=vly76M4xo>



Alberta, Alan Dyer



Poland, Slawomir Matz



Telescopic, Michael Jaeger