JAMES WEBB SPACE TELESCOPE

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Shawne

Introduction
Mission Goals
JWST's Launch and Orbit

Jackson

Building the Telescope
Primary Mirror
Sun Shield
Instruments

Erika

Astronomical Spectroscopy
Infrared Imaging

Mission Goals for the Webb Telescope

Explore the Early Universe

Study Galaxies Over Time

Star Lifecycles

Other Worlds - Planets and exoplanets

The report "HST and Beyond" (1995) proposed the concept of what would become the James Webb Space Telescope. [1]

Partners

NASA – North American Space Agency

CSA – Canadian Space Agency

ESA – European Space Agency

Canada’s contribution:

NIRISS (Near Infrared Imager and Slitless Spectrograph)

FGS (Fine Guidance sensor)   [2]

Challenges

How to construct a mirror of the size needed and get it 1.5 million miles from Earth

How to block out heat radiation from the sun and Earth and maintain the optimal operating temperature of 40^{o} K.

WEBB’S INNOVATIVE CONSTRUCTION

THE PRIMARY MIRROR

The primary mirror has iconic golden, hexagonal segments.

Three other mirrors in Webb's optics operate simultaneously.

The 18 hexagonal primary mirror segments have to be aligned.

The primary mirror gathers light and focuses it onto the **round convex secondary mirror.**

The secondary mirror reflects the light back to the **concave rectangular tertiary mirror**.

The tertiary mirror reflects light to the **flat fine steering mirror** from which light travels into Webb's instruments. [3]

WHY HEXAGONS?

Hexagonal shapes allow for an approximately circular mirror.

They allow for "high filling factor” and six-fold symmetry."

The segments fit together without gaps.

Symmetry is good because there need only be three different optical prescriptions for 18 segments in total, six of each.

Finally, a roughly circular overall mirror shape is desired because that focuses the light into the most compact region on the detectors. [3]

THE HUBBLE PRIMARY MIRROR VS THE JWST PRIMARY MIRROR

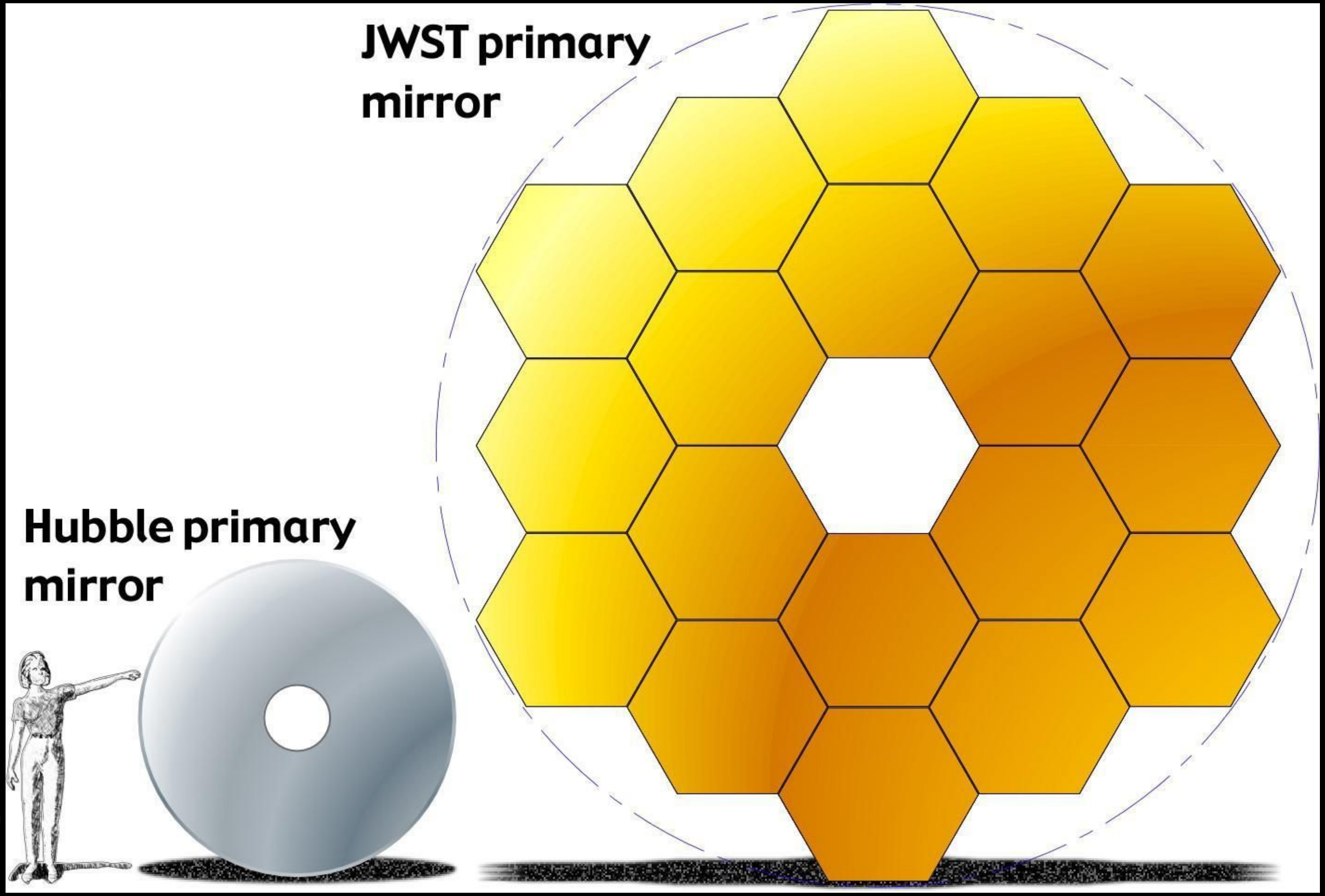


Figure 1: Primary Mirror. science.nasa.gov/mission/webb/webbs-sunshield/.

KEEPING THE MIRROR COLD

To see stars and galaxies in the early universe, astronomers need to observe their infrared light.

Webb needs to be very cold ("cryogenic"), with its mirrors at roughly -220 degrees C (-364 degrees F).

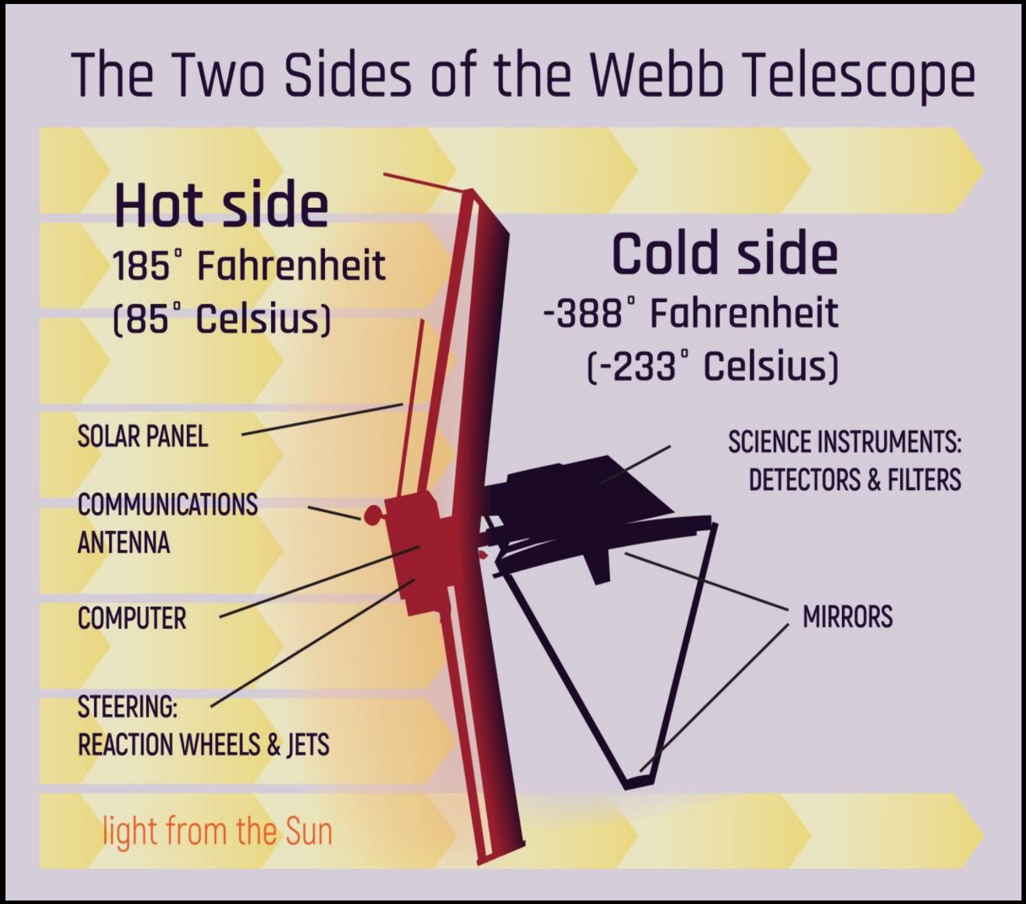
Warm objects emit heat in the form of infrared light.

Unless the mirror and instruments are kept very cold, the faint infrared light from distant galaxies would be lost in the infrared glow of the instruments.

The mirror must be able to withstand very cold temperatures and also hold its shape.

Webb’s location in deep space helps to keep it cold.

The sun shield shades the mirror and instruments from the sun and Earth as well as keeps them separated from the warm spacecraft bus. [3]



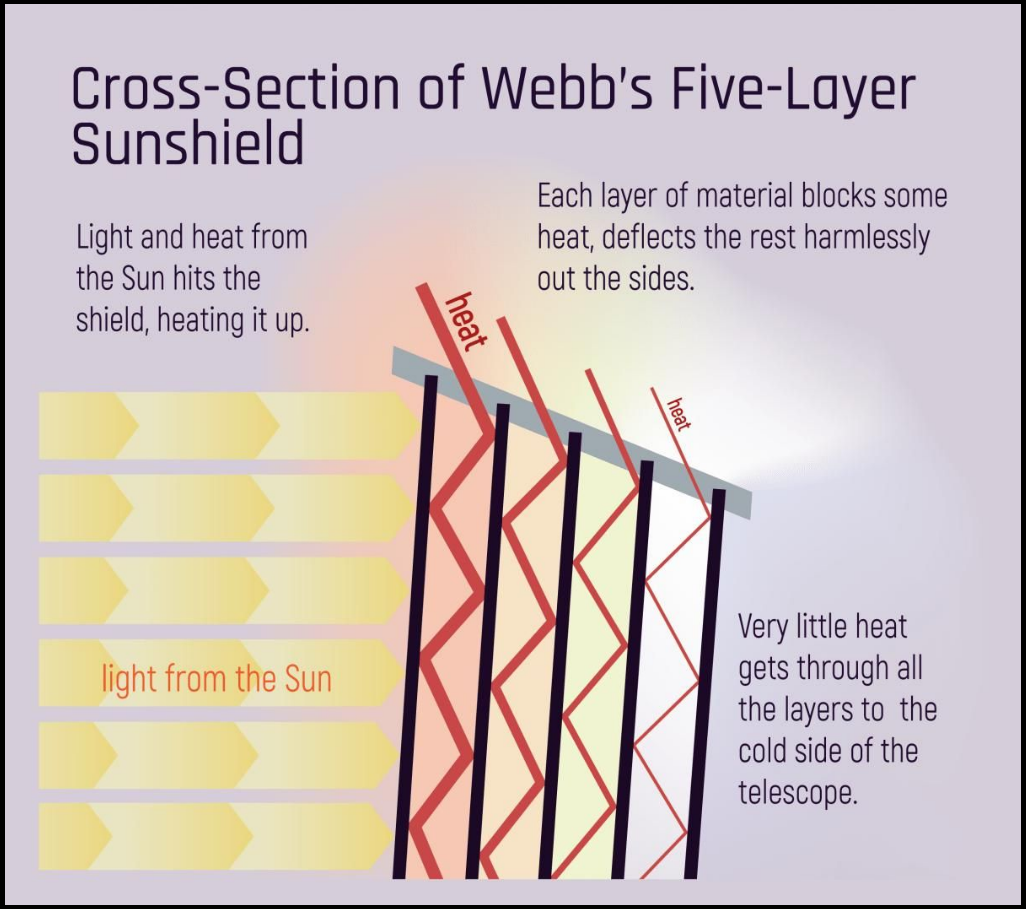


Figure 2: Sun sheild. Retrieved from https://science.nasa.gov/mission/webb/webbs-sunshield/

Webb Telescope Launches and Heads for Orbit Around L2

Figure 3: Launch of Ariane5 Rocket retrieved from
https://science.nasa.gov/mission/webb/multimedia/images/#Webbs-Road-To-Launch

After Launch – Activation of Instruments

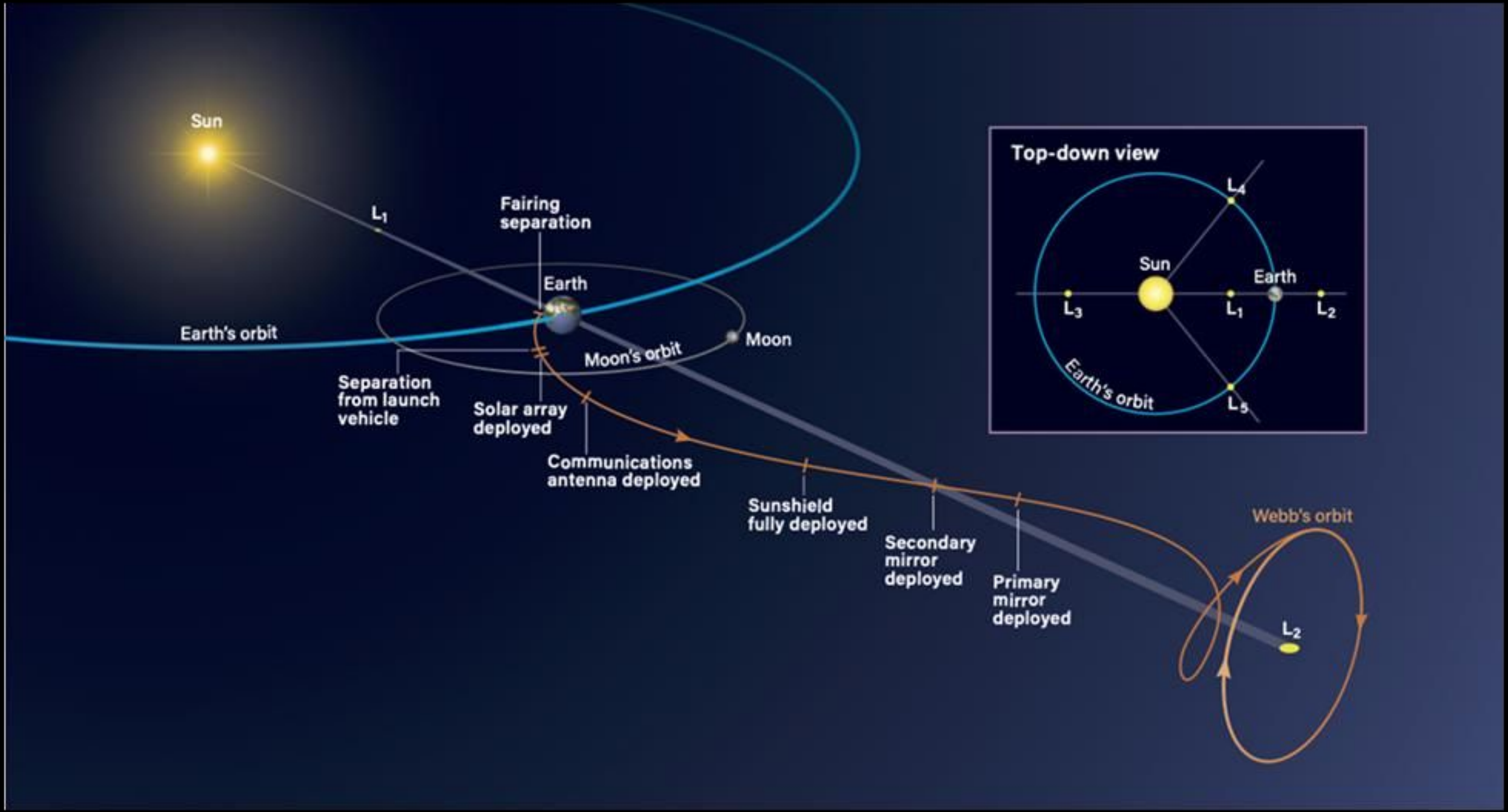


Figure 4: Journey to orbit. Retrieved from Astronomy Magazine
https://astronomy.com/magazine/news/2021/10/the-james-webb-space-telescope-lives

Webb Telescope Orbit

JWST orbits the sun at about 1.5 million km from Earth

As the Earth revolves around the sun a point called L2 (LaGrange Point 2) moves in sync with the earth.

JWST revolves around this point in an orbit nearly the size of the moon's orbit. [4]

Webb Telescope Orbit

Advantages

- The telescope can keep its sun shield always aligned blocking heat radiation from the earth and the sun.
- The telescope is never in Earth's shadow so it can operate continuously.

Disadvantages

- The telescope is so far away that it cannot be physically serviced (as Hubble was).
- Periodically the telescope must correct its position. This requires fuel (hydrazine) so the useful life of the telescope depends on how long the fuel supply lasts. [4]

The good news is that the initial launch was so efficient that the telescope has more fuel than projected and that the original projected life span of five to ten years has been extended.

Location of Webb’s Orbit

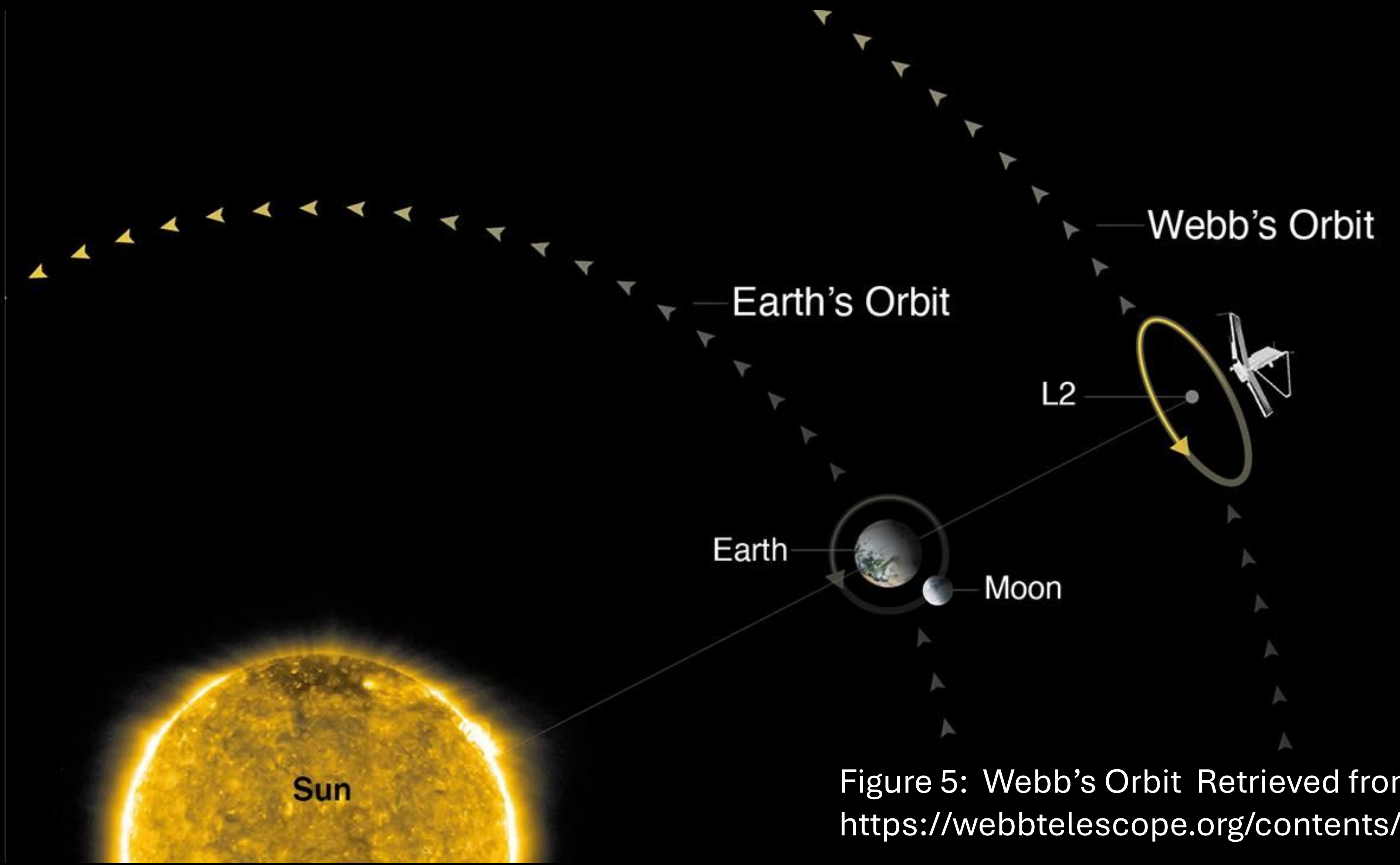


Figure 5: Webb’s Orbit Retrieved from https://webbtelescope.org/contents/media/images/4201-Image

Webb Orbits the Sun

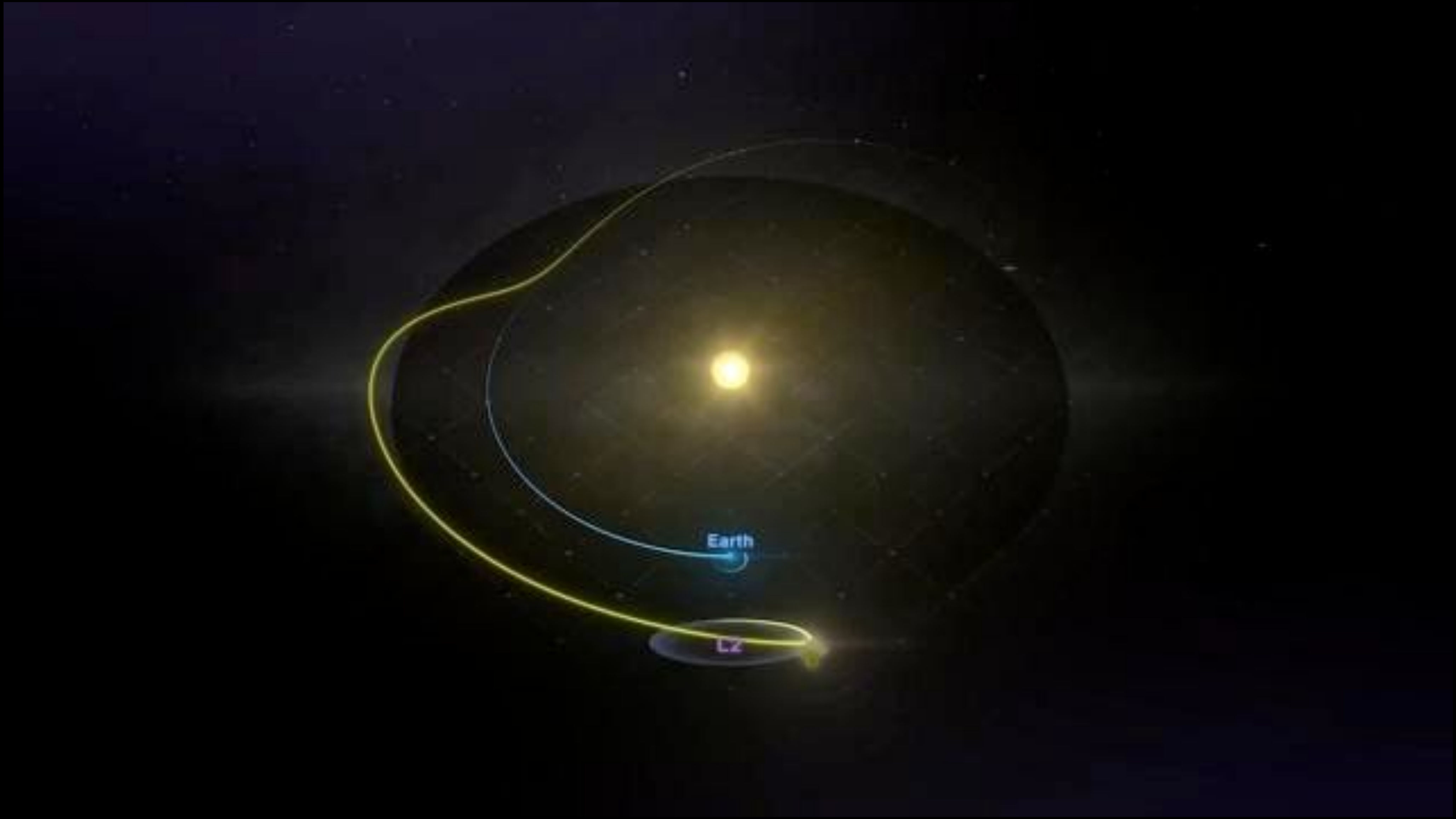


Figure 6: Space Telescope Science Institute. Retrieved from https://stsci-opo.org/STScI-01G5AKENDK9ZPVZHPNW2YSX4R7.mp4

How does James-Webb get such beautiful images of distant stars and matter?

Infrared light, and a ton of editing!

Figure 7: Deep Space
https://webbtelescope.org/contents/media/images/2022/035/01G7DCWB7137MYJ05CSH1Q5Z1Z

Astronomical Spectroscopy

$$\upsilon = \frac{c}{\lambda}$$

Frequency (υ)= speed of light (c) divided by the wavelength (λ). [5]

__Wavelength__ = the distance between peaks

__Frequency__ = How many peaks appear over a specified time

__Energy__ = How much energy that photon is carrying

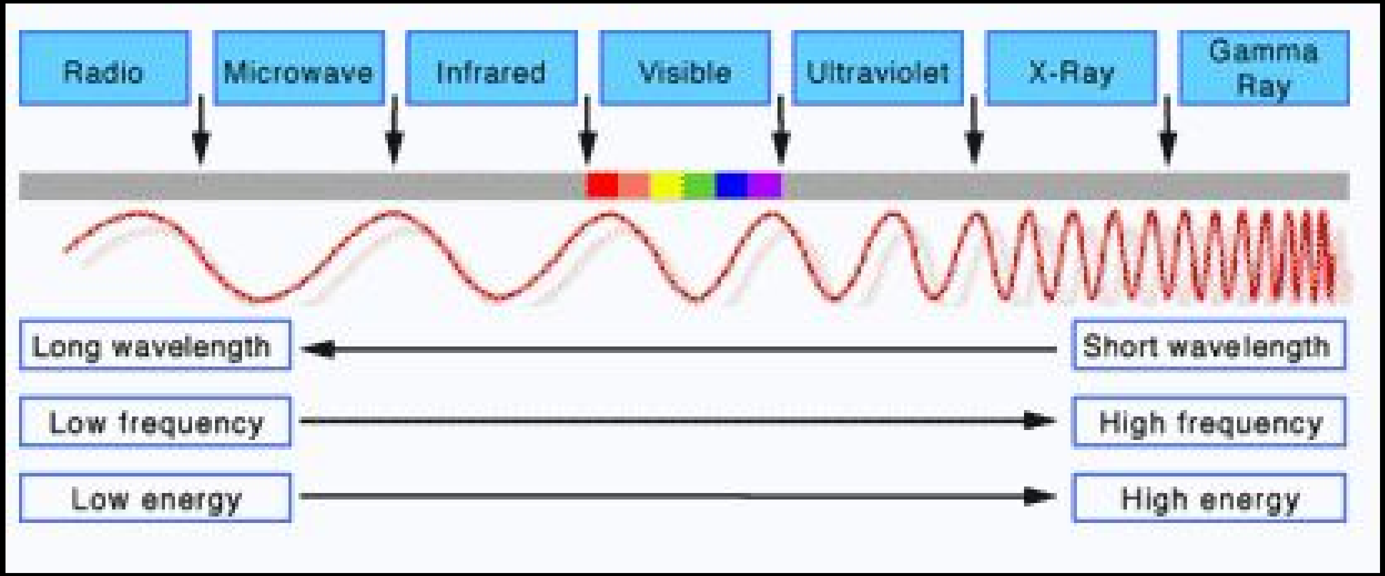


Figure 8: Electromagnetic spectrum https://www.solpass.org/science4-5/light/light-standards.html

Infra red region of the spectrum

WHY its good for astronomical spectroscopy?

EVERYTHING emits infrared radiation!

- *Cooler objects do not give off visible light.*

- *IR radiation can pass through dust*

- *We can see further back in time because of redshift [6]*

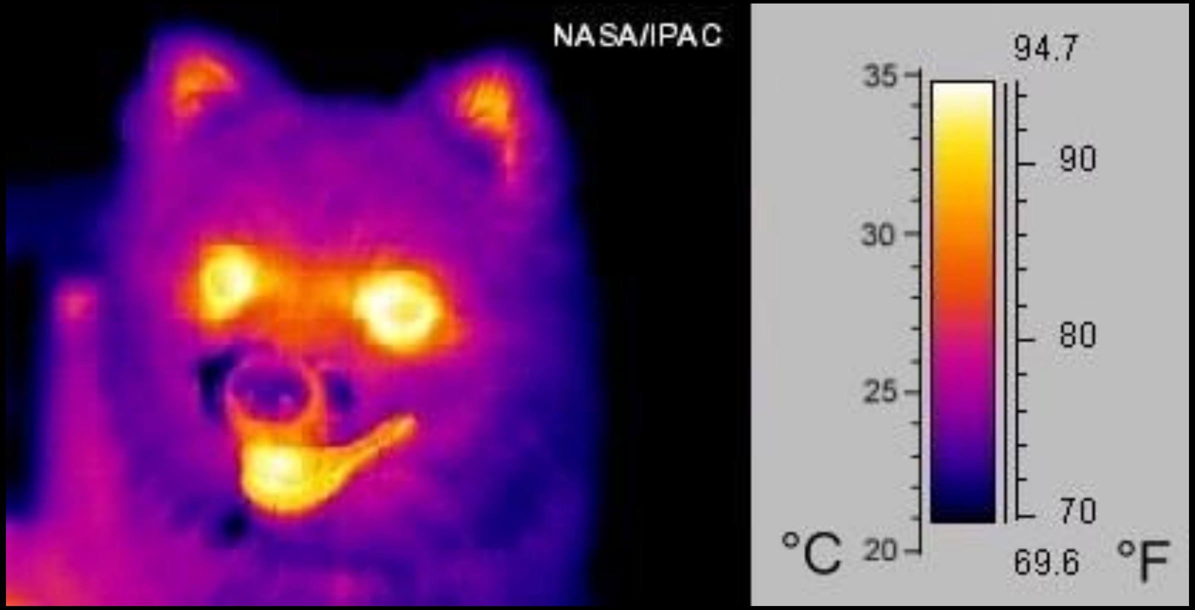


Figure 9: Infrared radiation emitted from Doge https://energyeducation.ca/encyclopedia/Infrared_radiation

But how does IR radiation tell us what type of matter we are looking at?

Absorption and Emission spectra.

Each element on the periodic table will show a unique fingerprint, because they only absorb and emit energy at very specific energy levels. [7]

$$E = h\upsilon$$

Energy of a photon (E) = frequency (υ) times Planck's constant (h)

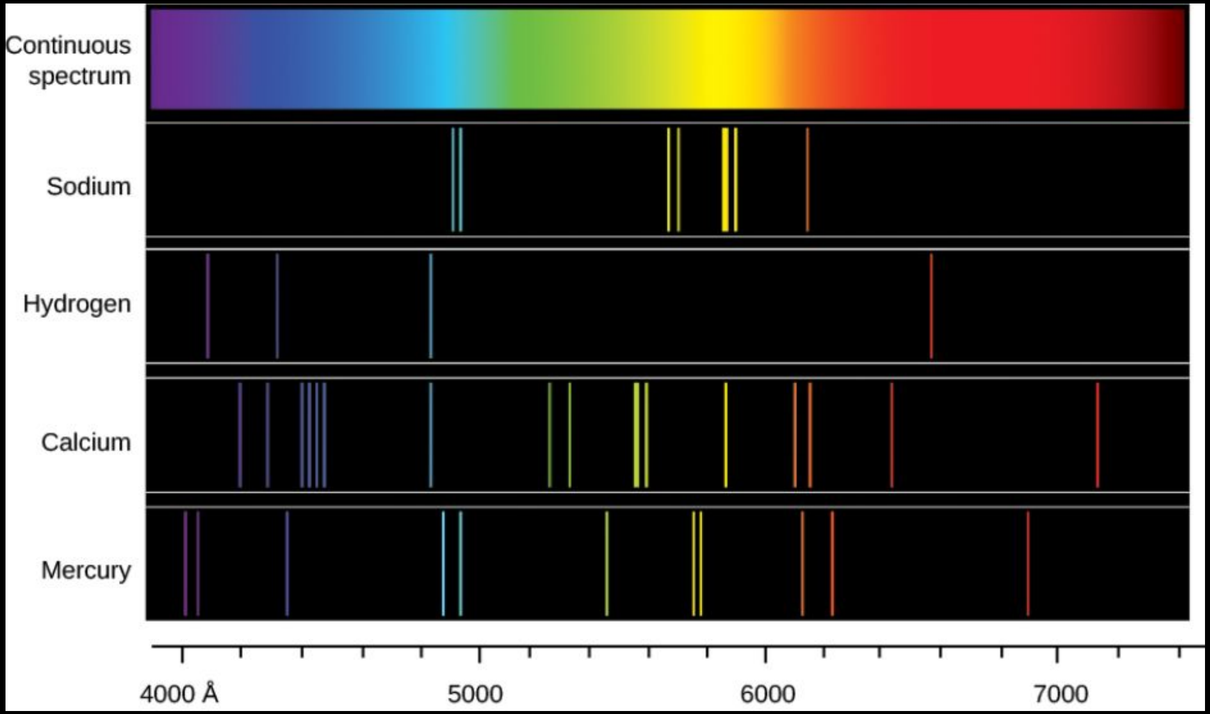


Figure 10: Emission spectrum, Astronomy Text [6]

Bohr Model of Hydrogen atom

Photons and Electrons exist and very specific (Quantized) energy levels, which correspond to specific wavelengths and frequencies. [8]

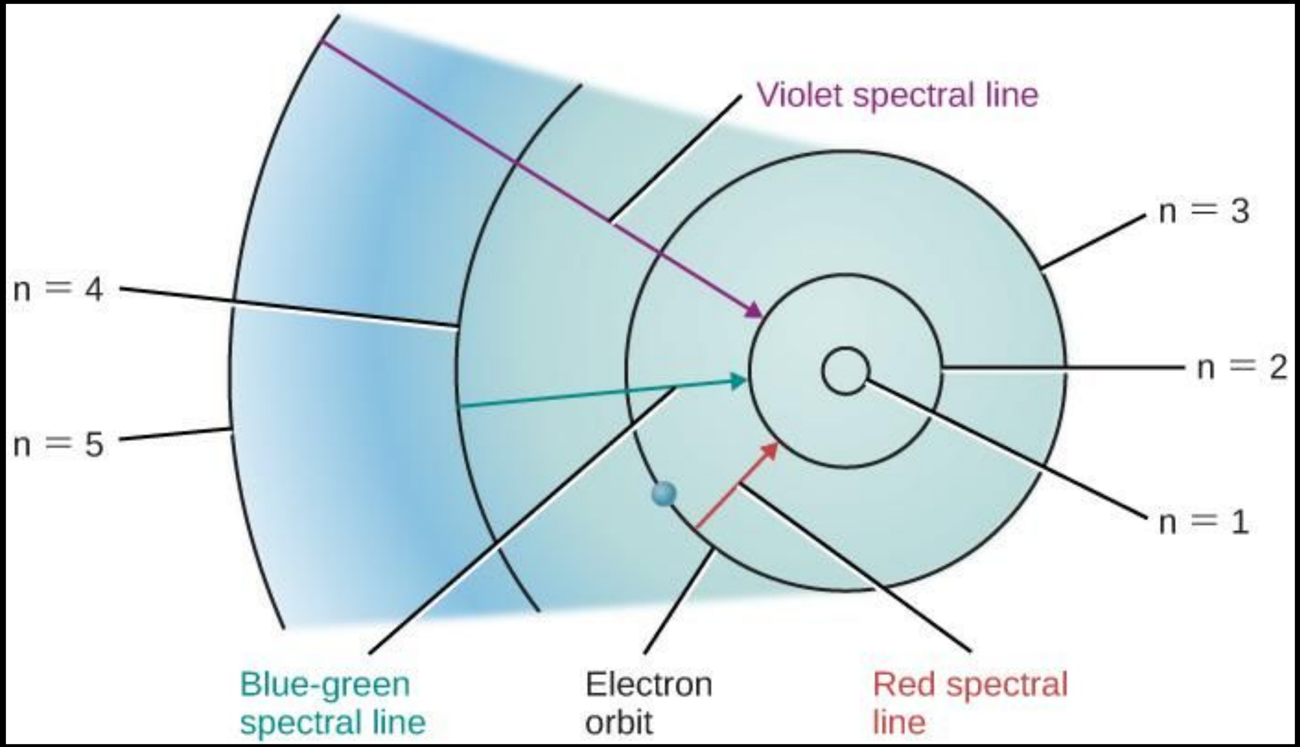


Figure 11: Bohr model of a hydrogen atom , astronomy textbook [6]

One of James-Webbs missions:

- To study the atmospheres of exoplanets, looking for the building blocks of life. [9]

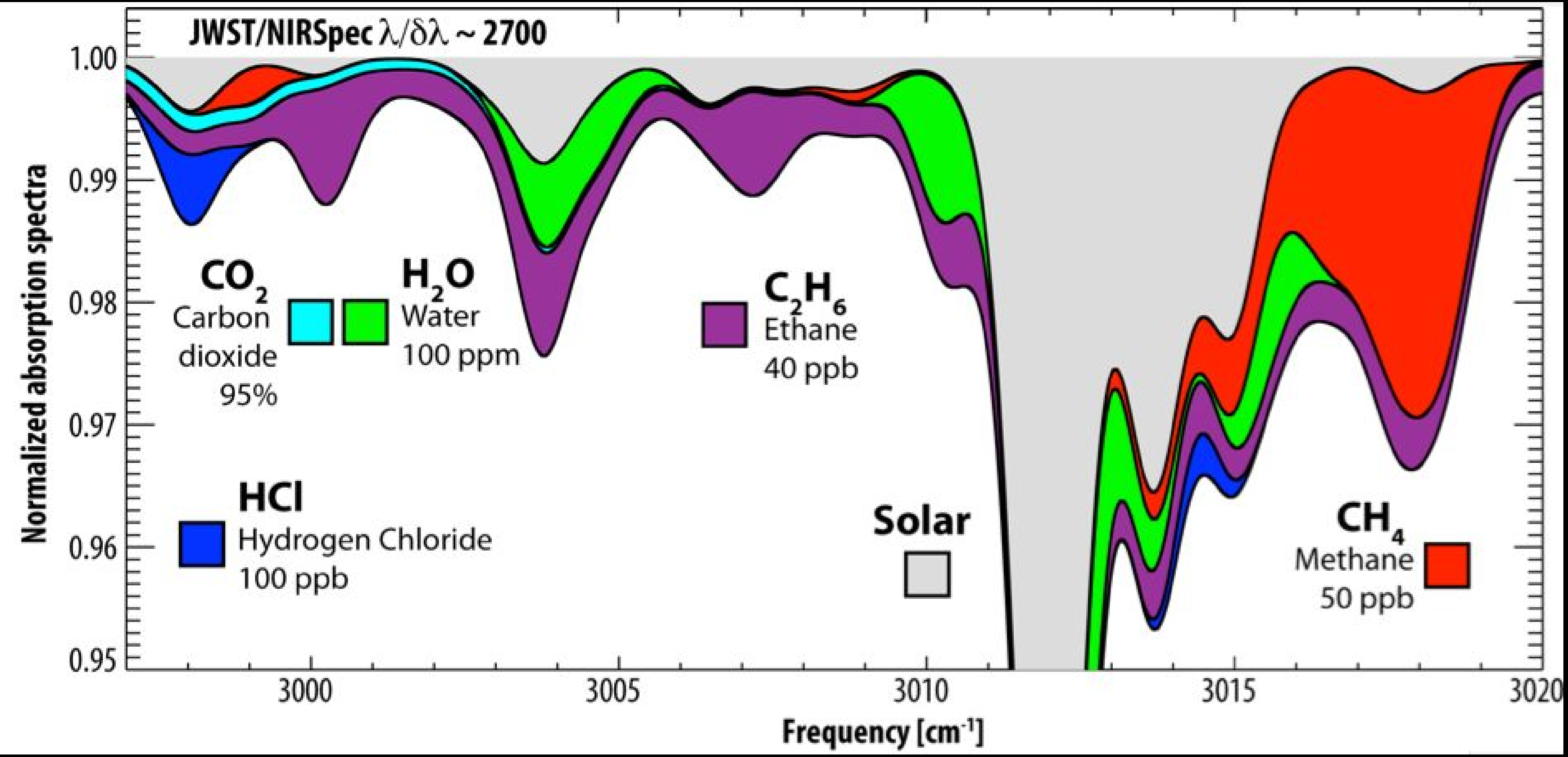


Figure 12 : Infrared Absorption Spectrograph
https://science.nasa.gov/mission/webb/other-worlds/

Using the invisible IR data to make a beautiful visible image:

Figure 13 : Actively Forming Star System Lynds 483 (NIRCam Image) https://webbtelescope.org/contents/media/images/2025/111/01JM03BFKHQ4TXFENM7XQHY405

Compounding all the IR data to make a beautiful visible image:

1. Import Raw data files
2. Define the images (increase brightness and contrast)
3. Remove artifacts (interferences)
4. Use separate coloured filters to get information about visible colours
5. Editing for composition [10]

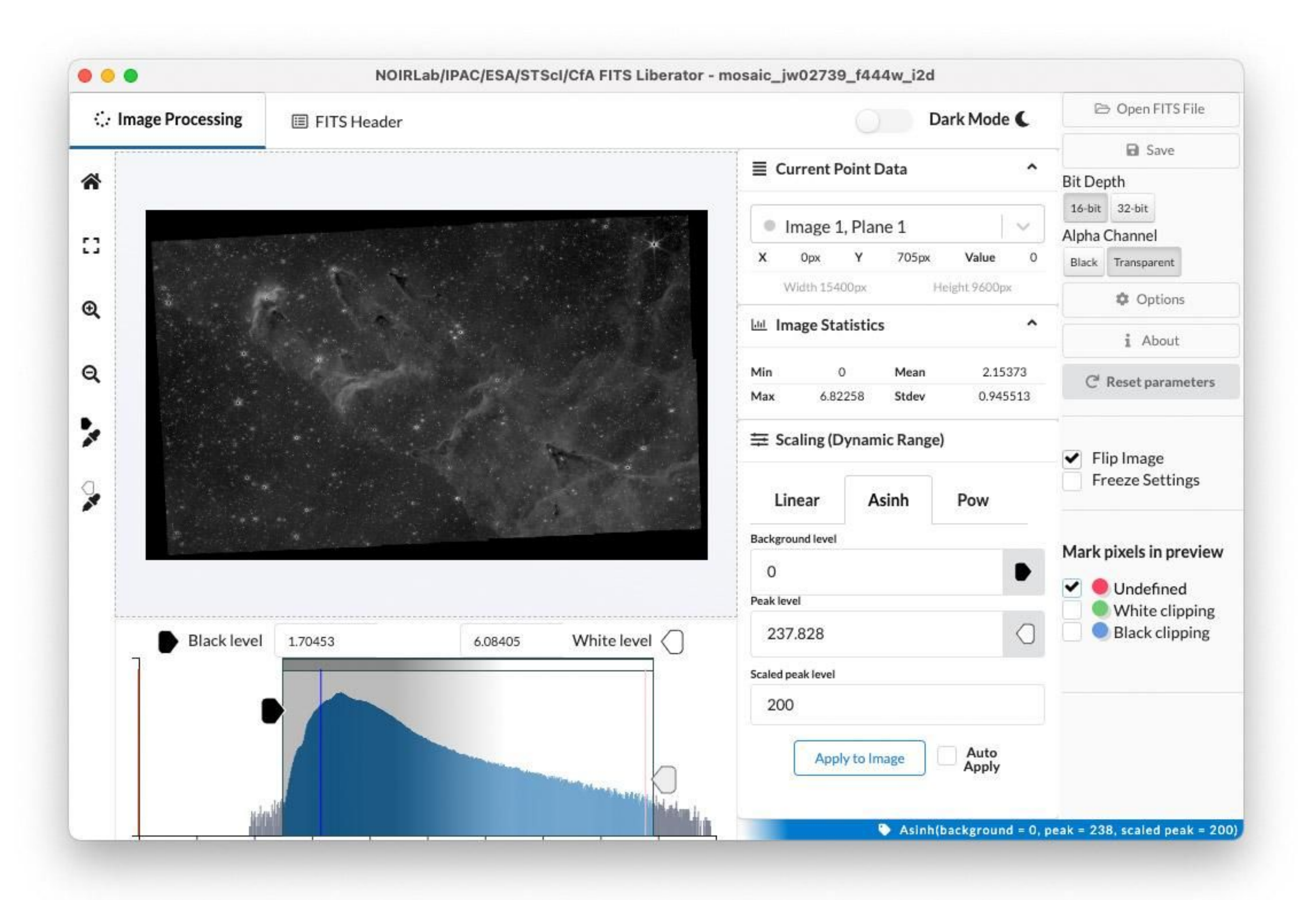


Figure 14 : Raw Data https://webbtelescope.org/contents/articles/how-are-webbs-full-color-images-made#:~:text=They%20can%20either%20layer%20the,the%20colors%20are%20knitted%20together.

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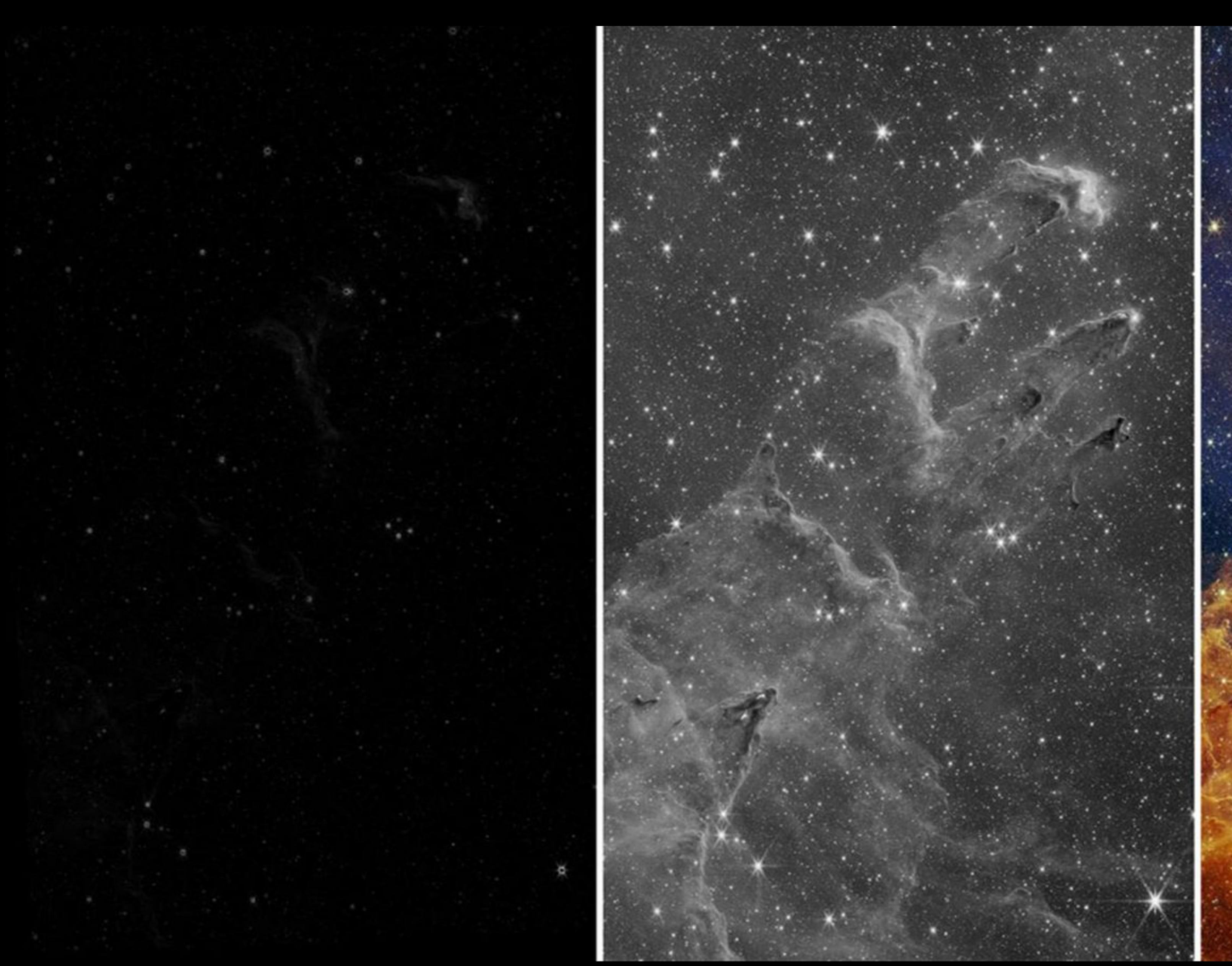

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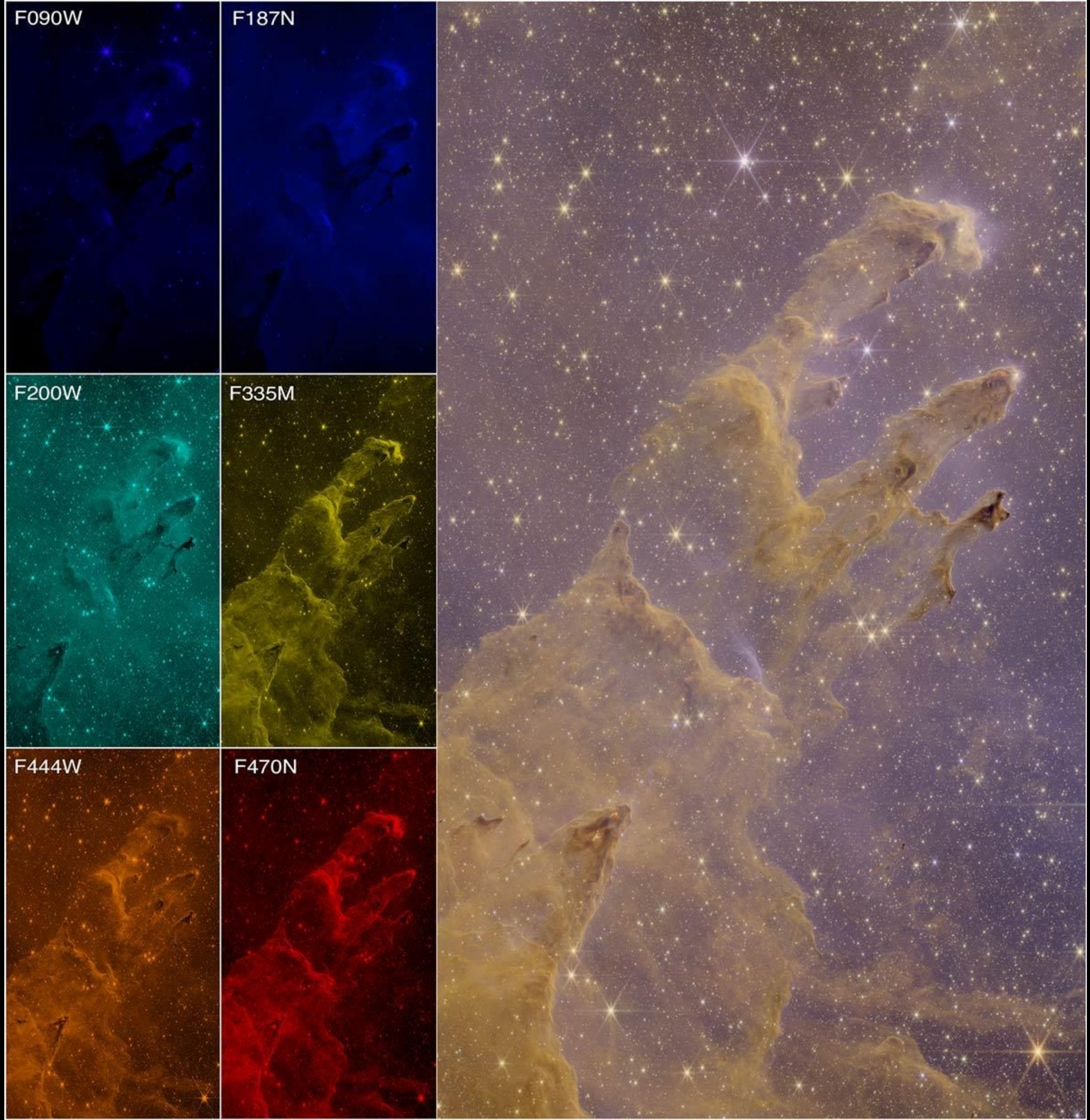

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Figure 17 : Editing for Composition https://webbtelescope.org/contents/articles/how-are-webbs-full-color-images-made#:~:text=They%20can%20either%20layer%20the,the%20colors%20are%20knitted%20together.

Figure 18 : Pillars of Creation (NIRCam and MIRI Composite Image) https://webbtelescope.org/contents/media/images/01GK2KKTR81SGYF24YBGYG7TAP?Topic=04-nebulas&keyword=pillar&itemsPerPage=15&page=1

Additional info:

This image shows how different filters for different wavelengths are used to look at the different gasses present in the accretion disk around a black hole.

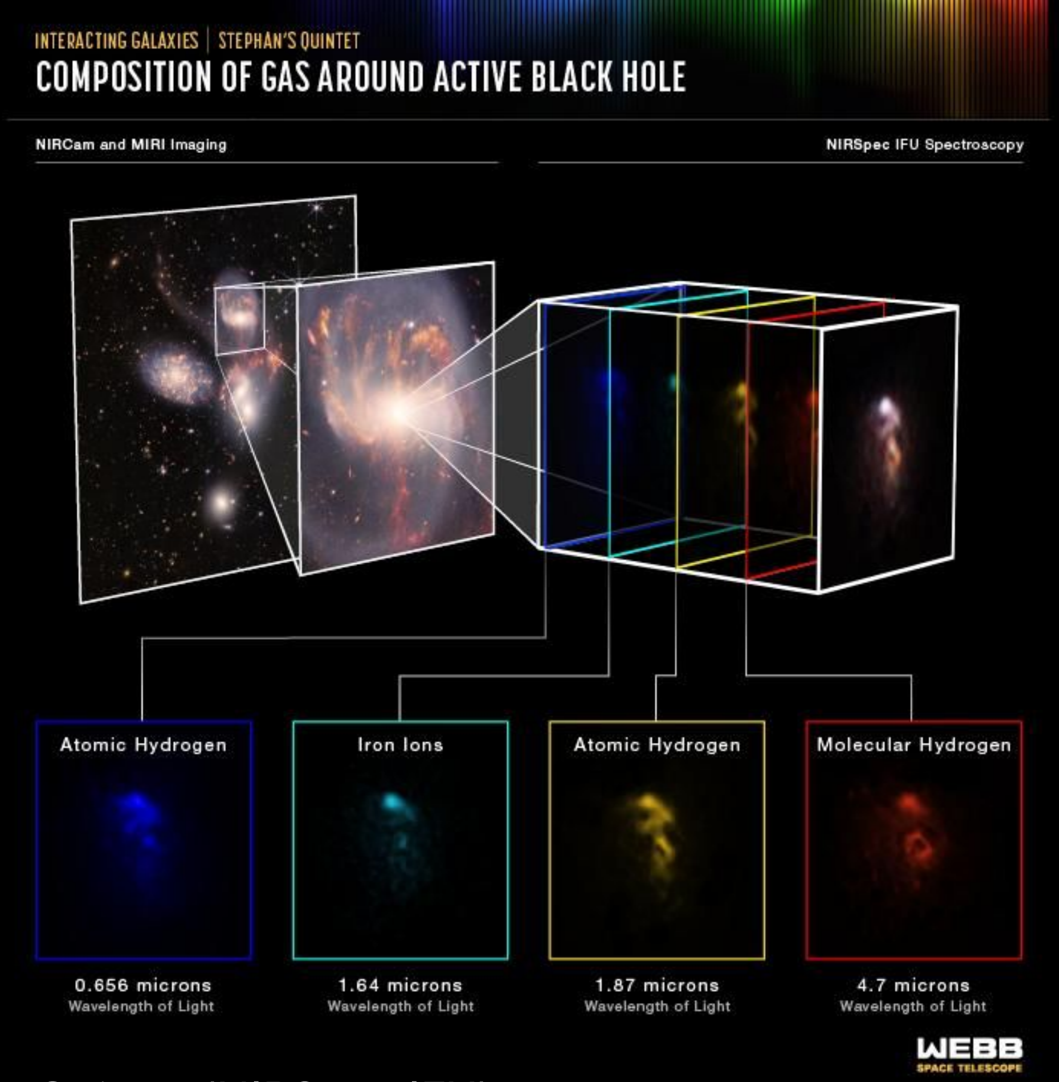

Figure 19 : Stephan's Quintet (NIRSpec IFU)
https://webbtelescope.org/contents/media/images/2022/034/01G7FJFCNKGARKRFM13FWQ881E?Collection=First%20Images&itemsPerPage=15&page=1

Astronomical Spectroscopy

By studying the amount of Energy we receive at different wavelengths/frequencies we can learn things about stars and matter. [6]

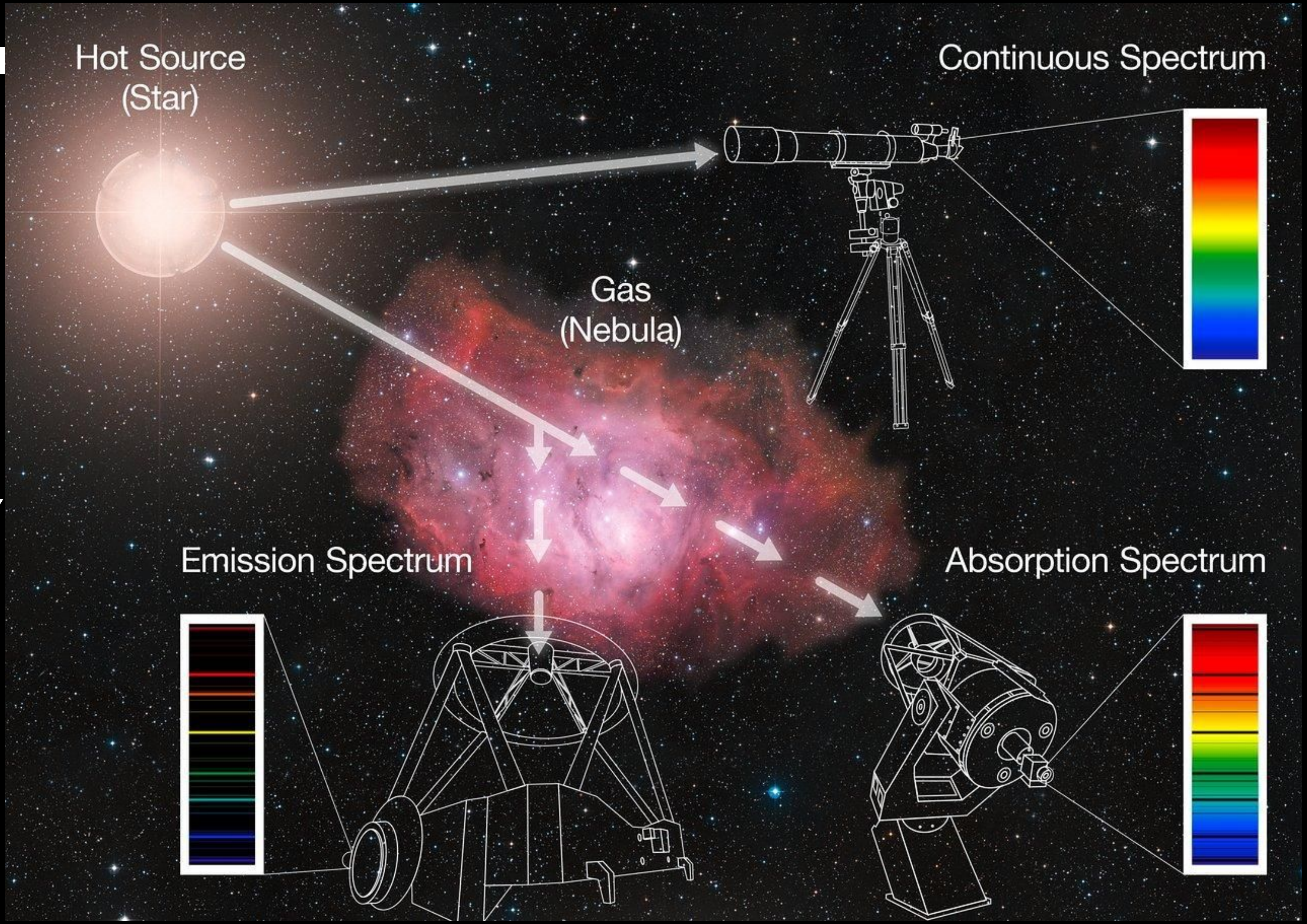

Figure 20 : Astronomical Spectroscopy
https://www.eso.org/public/teles-instr/technology/spectroscopy/

4 Different IR instruments on James Webb

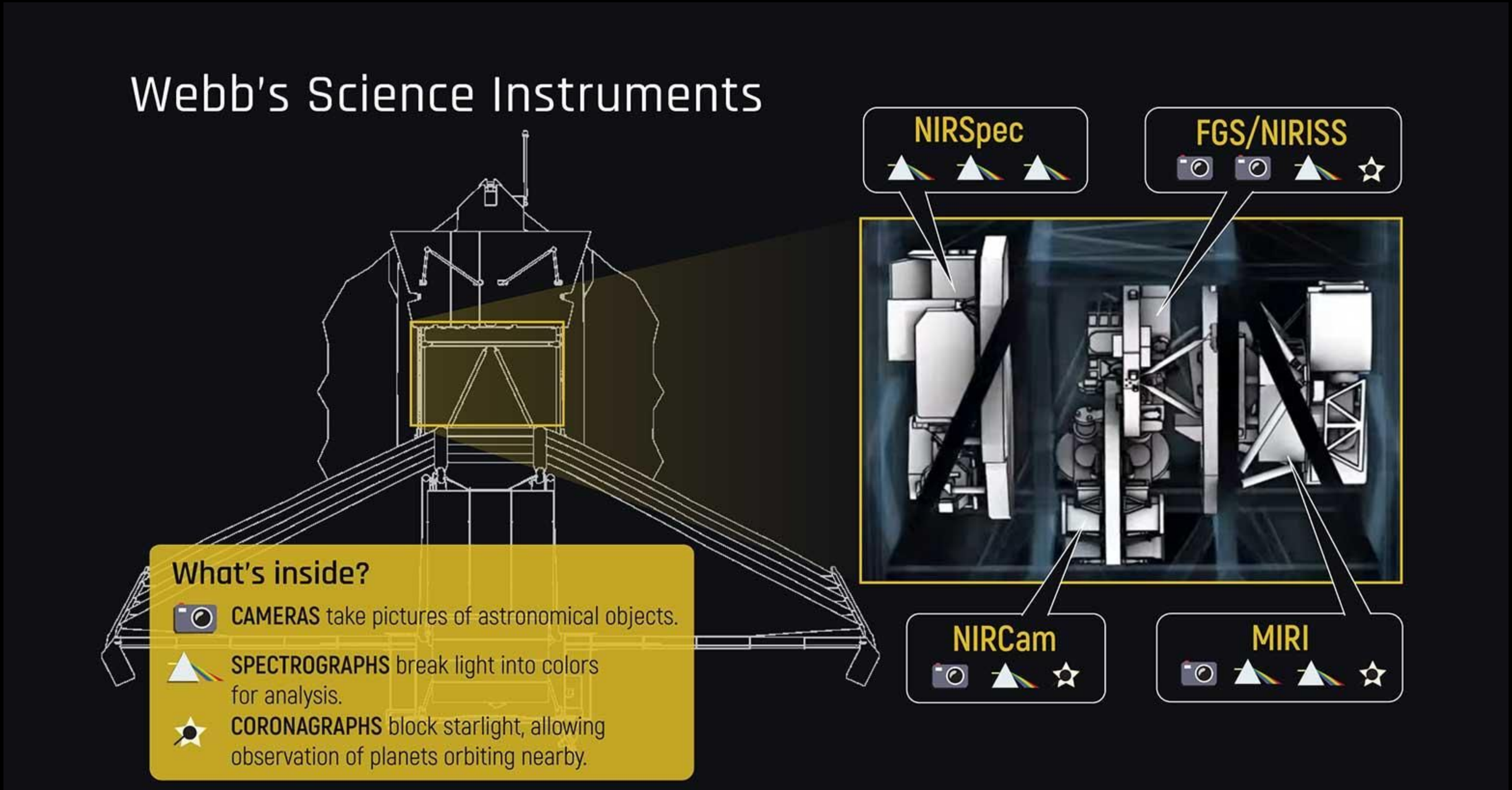

Figure 21 : 4 different IR instruments https://webbtelescope.org/contents/articles/whats-in-webbs-toolkit

Additional information about the 4 Different IR instruments on James Webb

NIRSpec

- Near infrared -> near to the red side of the visible spectrum
- Microshutter array: tiny shutters, the shutter doors left open are those to be aligned with the celestial objects on the schedule to be observed

NIRCam

- Near infrared -> near to the red side of the visible spectrum
– coronograph and time series imaging allows for tracking of planets orbiting stars [12]

MIRI

– Mid infrared instrument -> further away from the visible part of the spectrum, towards the microwave part of spectrum

FGS/NIRISS

- Fine Guidance Sensors/Near-Infrared Imager and Slitless Spectrograph
- this instrument is 2 separate things together. FGS is for telling the sensors where to look, and the slitless spectrograph gives full spectrum data.

[11]

Additional Information

Canadian Contribution

The FGS (Fine Guidance Sensor) is the most sophisticated guidance sensor of any telescope ever built. To take clear, high-resolution images, space telescopes use guidance systems to lock on to guide stars near the celestial object they are observing.

Using the position of these stars as a reference, a guidance sensor sends signals to other parts of the telescope to make necessary adjustments to compensate for any movement. [2]

Figure 22: Canada's Contribution retrieved from https://www.asc-csa.gc.ca/eng/satellites/jwst/canada-role.asp

THE PRIMARY MIRROR

- The James Webb telescope is famous for its primary mirror, with its iconic golden, hexagonal segments. However, there are three other mirrors in Webb's optics that all operate simultaneously to bring light to Webb's instruments. The 18 hexagonal primary mirror segments have to be aligned the way they are, in order to act as one large **concave primary mirror.** First, this mirror gathers light and focuses it onto the **round convex secondary mirror** that lies at the end of Webb's long folding booms. The secondary mirror then reflects the light back to the **concave rectangular tertiary mirror** which, in turn, reflects it to the **flat fine steering mirror** from which light travels into Webb's instruments. [3]

WHY HEXAGONS?

The primary mirror's hexagonal shape allows for an approximately circular, segmented mirror with "high filling factor and six-fold symmetry." High filling factor means the segments fit together without gaps. If the segments were perfectly circular or had more than six sides, there would be gaps between them. Symmetry is good because there need only be three different optical prescriptions for 18 segments in total, six of each. Finally, a roughly circular overall mirror shape is desired because that focuses the light into the most compact region on the detectors. An oval mirror, for instance, would give images that are elongated in one direction. A square mirror would send a lot of the light out of the central region (which is why hexagons are used instead of squares, even though squares tessellate). [3]

KEEPING THE MIRROR COLD

One challenge is to keep Webb's mirror cold. To see the first stars and galaxies in the early universe, astronomers need to observe the infrared light given off by them, and use a telescope and instruments optimized for this light. Warm objects emit heat in the form of infrared light. This means that if Webb's mirror was the same temperature as the Hubble Space Telescope's, the faint infrared light from distant galaxies would be lost in the infrared glow of the mirror. For this reason, Webb needs to be very cold ("cryogenic"), with its mirrors at roughly -220 degrees C (or -364 degree F). The mirror as a whole must be able to withstand very cold temperatures, and also hold its shape. To keep Webb cold, it was sent into deep space, far from the planet Earth. Sunshields shade the mirrors and instruments from the Sun's heat, as well as keep them separated from the warm spacecraft bus. [3]

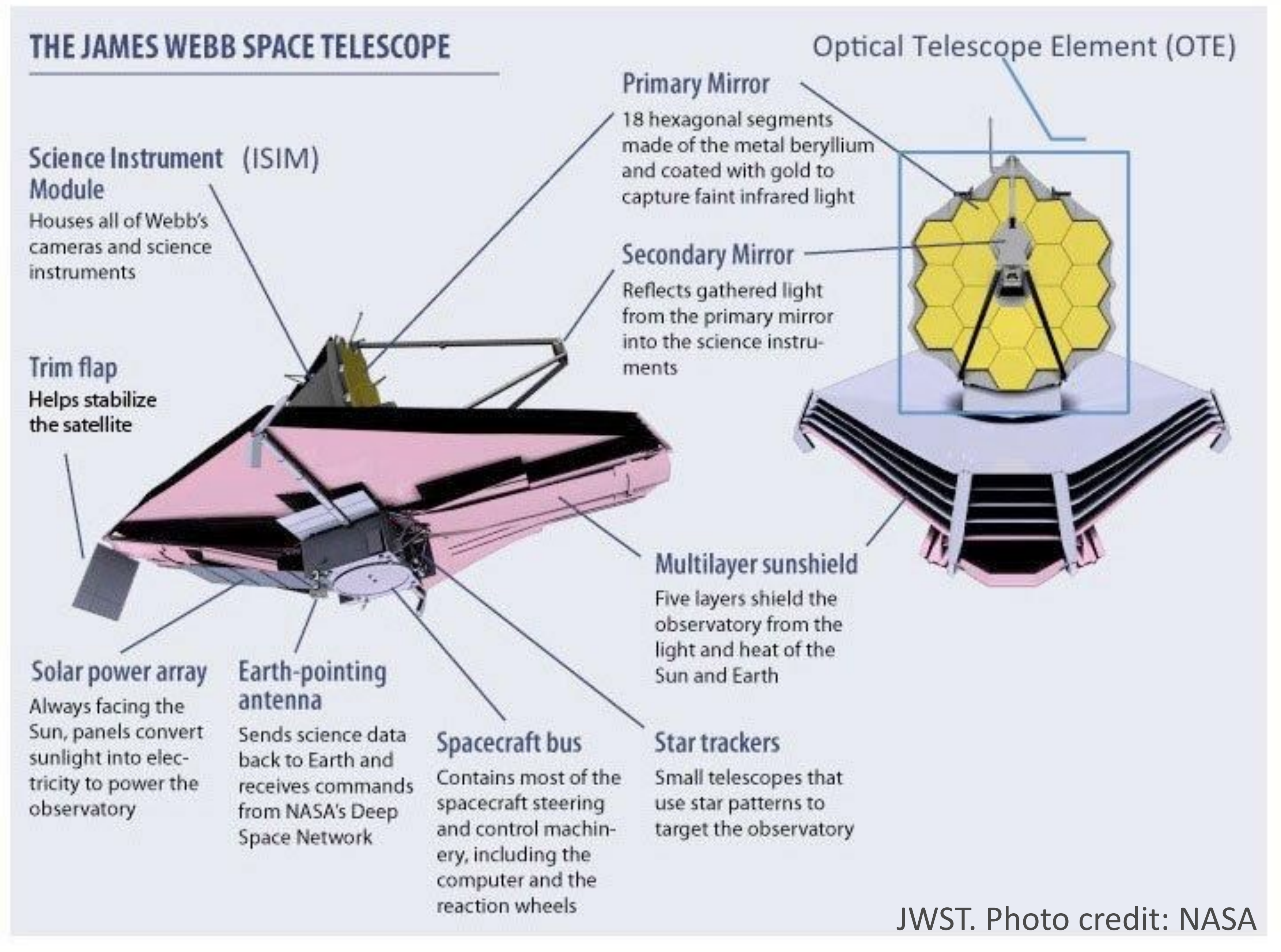

Figure 23 : JWST Instruments retrieved from https://dug.com/james-webb-space-telescope-preps-for-launch/

The Launch and Final Orbit

The telescope was launched on December 25 2021 from Kourou, French Guiana in an Ariane5 rocket that carried the telescope to its orbit.
The sun shield, the size of a football field, and the primary mirror, diameter of 6.5 metres, were folded into the rocket along with the assembled instruments.

The Webb compartment separated from the rocket 30 minutes after launch and began activating components . Before actually operating the instruments, they needed to be tested and calibrated and the segments of the primary mirror needed to be aligned. [13]

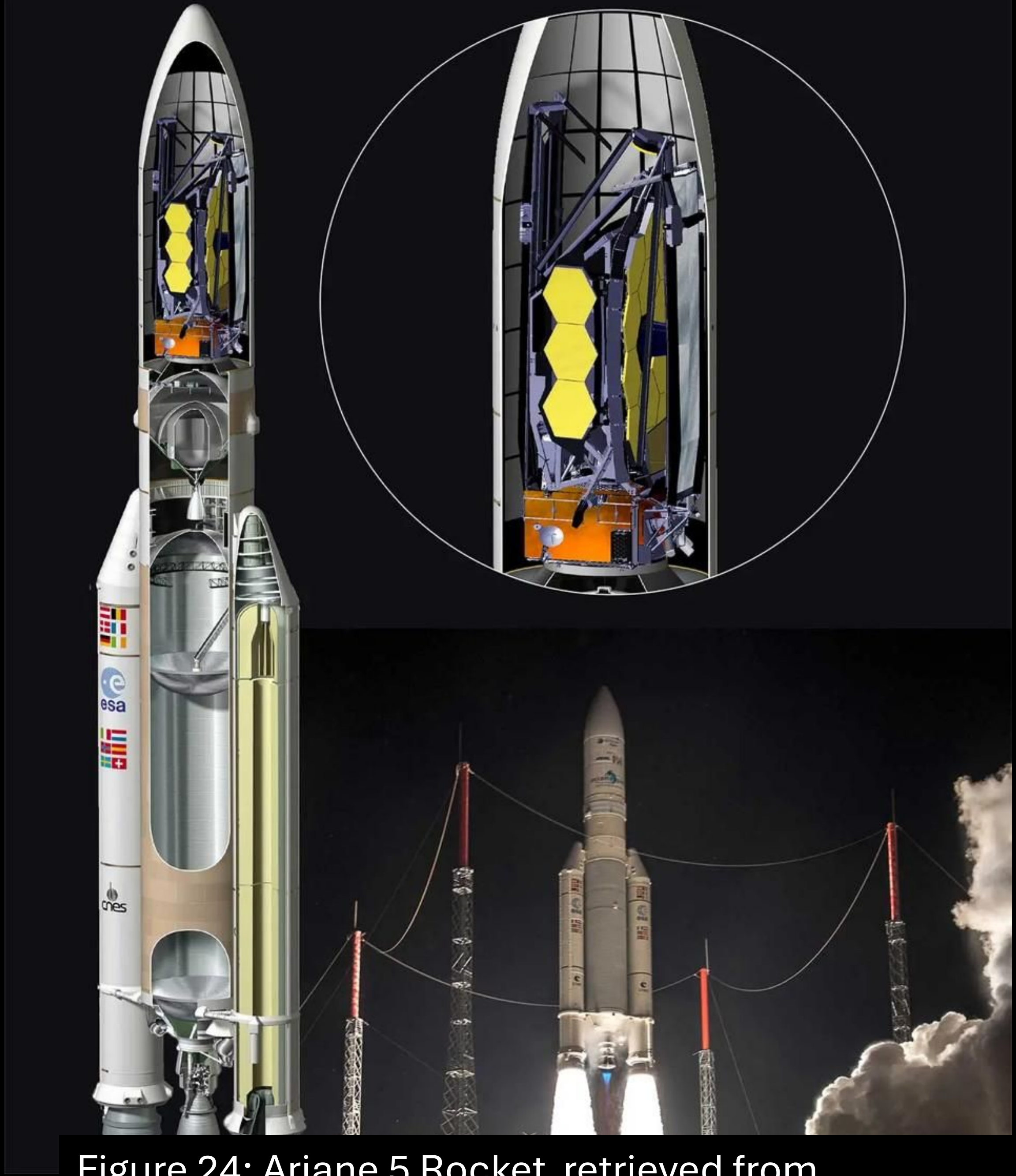

Figure 24: Ariane 5 Rocket retrieved from https://science.nasa.gov/mission/webb/launch/

Webb Deployment Timeline

1st hour: Webb separates from Ariane rocket. Solar array deployed immediately after.

1st day: High gain antenna deployed and trajectory correction.

1st week: Deploy for and aft sunshield pallets. Deployed telescope and spacecraft bus and tower. Full sunshield unfolding and tensioning done on day 6. Secondary mirror deployed.

1st month: Initialized flight flight software and did mid-course correction.

2nd month: Turned on and operated Fine Guidance Sensor, NIRCam and NIRSpec. Took and image to make sure light gets through telescope.

3rd month: Primary mirror segments aligned. Turned on and operated MIRI. Took first science-quality images. Webb completes initial orbit around L2.

4 to 6 months: Optimized telescope image in the NIRCam. Optimized image for other instruments. Tested and calibrated all other instruments

July 12, 2022. JWST begins its Science Mission. [14]

LaGrange points and JWST's Orbit

A LaGrange point is a spot in space where the gravitational forces of our planet and the sun are roughly equal, creating a stable orbital location. There are five such points which were postulated in the 18th century by mathematician Joseph-Louis LaGrange. At these points a small object can orbit steadily around the sun along with Earth.

The Webb telescope does not locate itself on L2 but revolves around it in an orbit almost as large as the moon's orbit.

There are other space vehicles, Gaia, Planck, and Herschel, orbiting around L2 but because the orbit is so large they don't interfere with Webb.

L2 was chosen because by being not quite perfect it does not attract and keep small asteroids as some other LaGrange points do.

Webb needs to use some fuel periodically to adjust its orbit. There is some speculation that after its projected life span of 10 years we may by that time have the capability of sending a rocket out to refuel. [4]

Comparison of the Hubble and James Webb Space Telescopes [15]

	Hubble	JWST
Scientific Focus	Primarily observes in visible and ultraviolet light, allowing it to study the structure and composition of galaxies, nebulae, and other celestial objects.	Fundamentally designed for wider infrared astronomy. enabling it to peer through dust clouds and see the formation of stars and galaxies in the early universe. It can observe objects which are 100 times fainter than the threshold of the Hubble telescope.
Mirror Size and Light-Gathering Power	Has a primary mirror 2.4 meters (7.9 feet) in diameter.	Features a segmented, 6.5-meter (21.3 feet) mirror, giving it six times the light-gathering power of Hubble.
Location and Cooling	Operates in low Earth orbit, which allows for easier maintenance and servicing, but is subject to atmospheric effects and the Earth's heat.	Located much farther from Earth which allows for extremely cold operating temperatures necessary for infrared observations. Also, it can operate continuously as it is never in Earth's shadow as Hubble is at times.
Capabilities:	Groundbreaking observations of the universe, Pillars of Creation and the Hubble Ultra Deep Field.	Can see deeper into the universe than Hubble, revealing previously unseen details of star and galaxy formation and the early universe. (BYJU.com)

Webb and Hubble comparison.

On the left, the Hubble Space Telescope’s view of the galaxy M74, aka the Phantom Galaxy, ranges from the older, redder stars toward the center, to younger and bluer stars in its spiral arms, to sites of active star formation in the red bubbles of H II regions. On the right, the James Webb Space Telescope sees at different wavelengths (Webb primarily looks at the universe in the infrared, while Hubble studies it primarily at optical and ultraviolet wavelengths). So the image is strikingly different. Webb’s image highlights the masses of gas and dust within the galaxy’s arms and the dense cluster of stars at its core. In the center, the 2 images are combined. Images via Hubble/ Webb/ ESA. [16]

Figure 25 : Hubble – Webb comparison https://earthsky.org/upl/2022/08/phantom-galaxy-m74-comparision-views-hubble-webb-aug2022-e1661795047720.jpg

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Image Sources

Figure 1: Primary Mirror. science.nasa.gov/mission/webb/webbs-sunshield/.

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Figure 16 : https://webbtelescope.org/contents/articles/how-are-webbs-full-color-images-made#:~:text=They%20can%20either%20layer%20the,the%20colors%20are%20knitted%20together.

Figure 17 : Editing for Composition https://webbtelescope.org/contents/articles/how-are-webbs-full-color-images-made#:~:text=They%20can%20either%20layer%20the,the%20colors%20are%20knitted%20together.

Figure 18 : Pillars of Creation (NIRCam and MIRI Composite Image)
https://webbtelescope.org/contents/media/images/01GK2KKTR81SGYF24YBGYG7TAP?Topic=04-nebulas&keyword=pillar&itemsPerPage=15&page=1

Image Sources

Figure 19 : Stephan's Quintet (NIRSpec IFU) https://webbtelescope.org/contents/media/images/2022/034/01G7FJFCNKGARKRFM13FWQ881E?Collection=First%20Images&itemsPerPage=15&page=1

Figure 20 : Astronomical Spectroscopy https://www.eso.org/public/teles-instr/technology/spectroscopy/

Figure 21 : 4 different IR instruments https://webbtelescope.org/contents/articles/whats-in-webbs-toolkit

Figure 22: Canada's Contribution retrieved from https://www.asc-csa.gc.ca/eng/satellites/jwst/canada-role.asp

Figure 23 : JWST Instruments retrieved from https://dug.com/james-webb-space-telescope-preps-for-launch/

Figure 24: Ariane 5 Rocket retrieved from https://science.nasa.gov/mission/webb/launch/

Figure 25 : Hubble – Webb comparison https://earthsky.org/upl/2022/08/phantom-galaxy-m74-comparision-views-hubble-webb-aug2022-e1661795047720.jpg