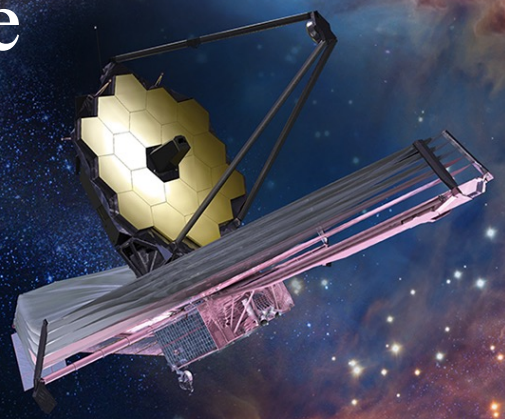
Unveiling the Cosmos: The James Webb Space Telescope

David H. Lehman
NASA / Jet Propulsion Laboratory,
Project Manager (Retired) and
Volunteer Solar System Ambassador

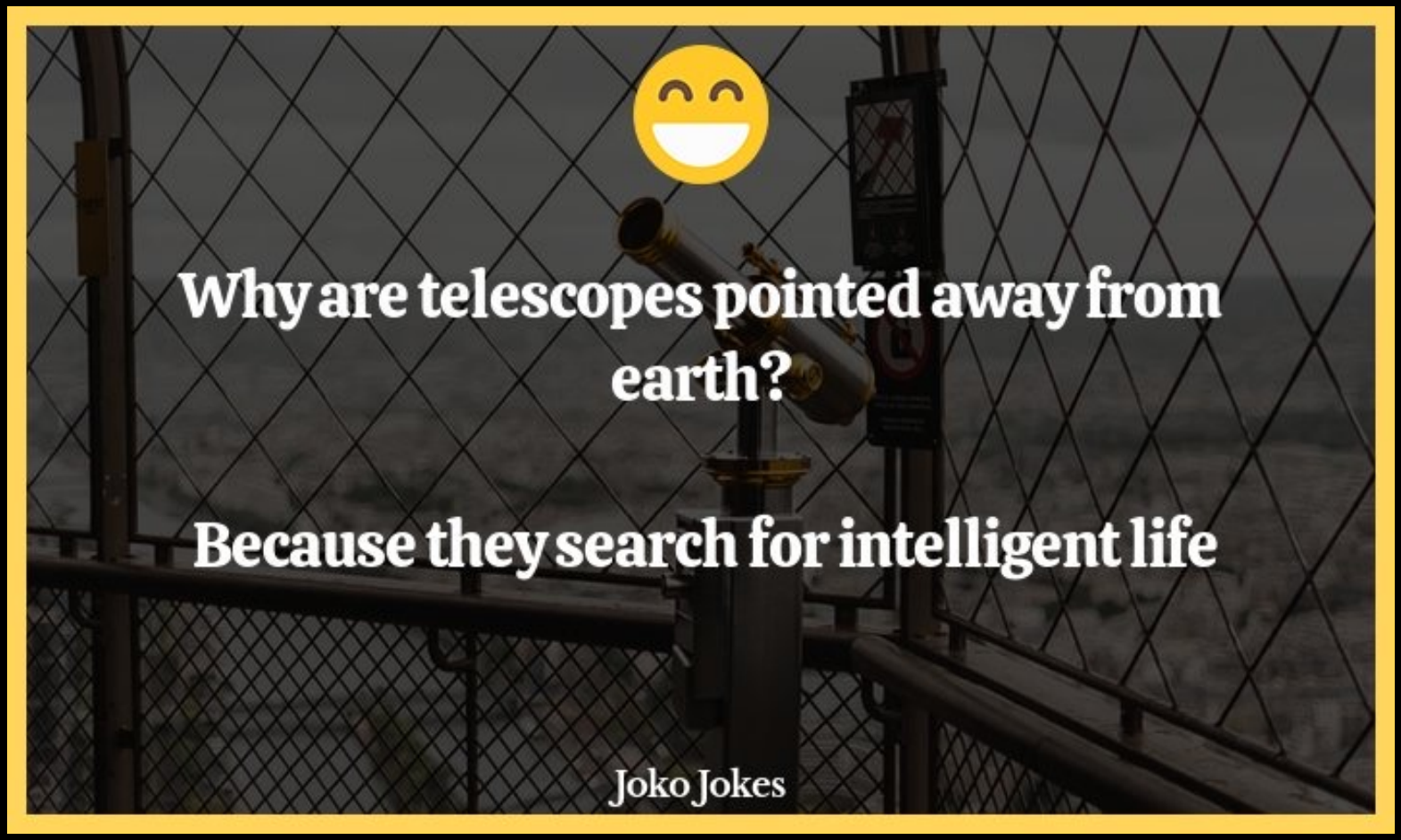


WEBB JAMES WEBB SPACE TELESCOPE

Topics

- Introduction to the James Webb Space Telescope
- Description of the Webb's Spacecraft, Telescope, and Technologies
- Launch and Orbit
- Some Top Science Results
- Summary


Why are telescopes pointed away from earth?
Joko Jokes


Why are telescopes pointed away from earth?
Because they search for intelligent life
Joko Jokes

Introduction

- Purpose of Webb
  - First Light and Reionization
  - Assembly of Galaxies
  - Birth of Stars and Protoplanetary Systems
  - Planetary Systems and Origins of Life
- History of Webb
  - Concept and planning started in the 1990s
  - Construction began in 2004
  - Long delays due to the complexity of its design and required precision
  - Launch and deployment in December 2021

Questions we hope Webb will answer:

- Are we alone in the Universe?
- Where and when did the first stars form?
- What are the origins of Supermassive Black Holes?
- What is Dark Matter?
- How do massive stars go Supernova?
- Where do planets like Earth get their water?
- Does the Rate of Expansion of the Universe bust our best Cosmological Model?

"...The Webb is
designed to reveal
the evolution of the
Universe,
from its early phases
to the modern era..."

The Webb will not “see”
visible light,
such as we see in the
backyard.

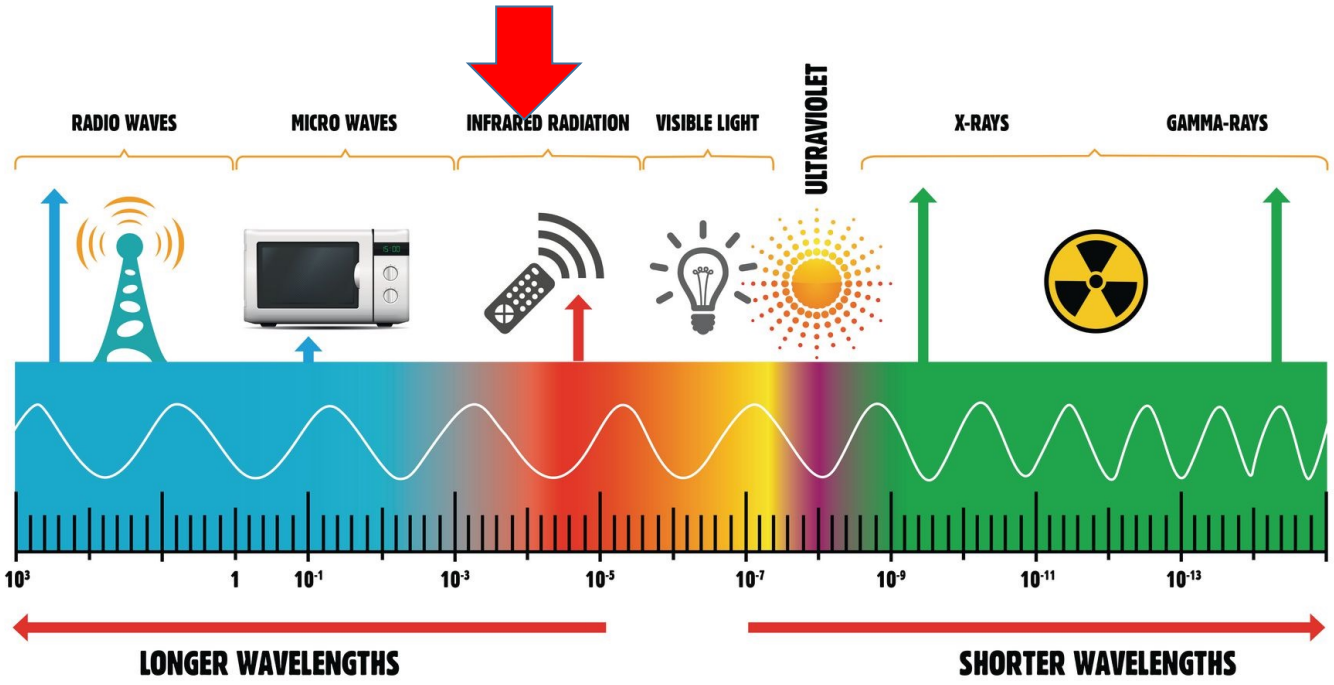
“…In the case of the first stars and galaxies, they are so far away that the Universe has expanded greatly since their light began its journey...”

“…This expansion (of the Universe) has caused the light to stretch, transforming what was once visible light into infrared light...”

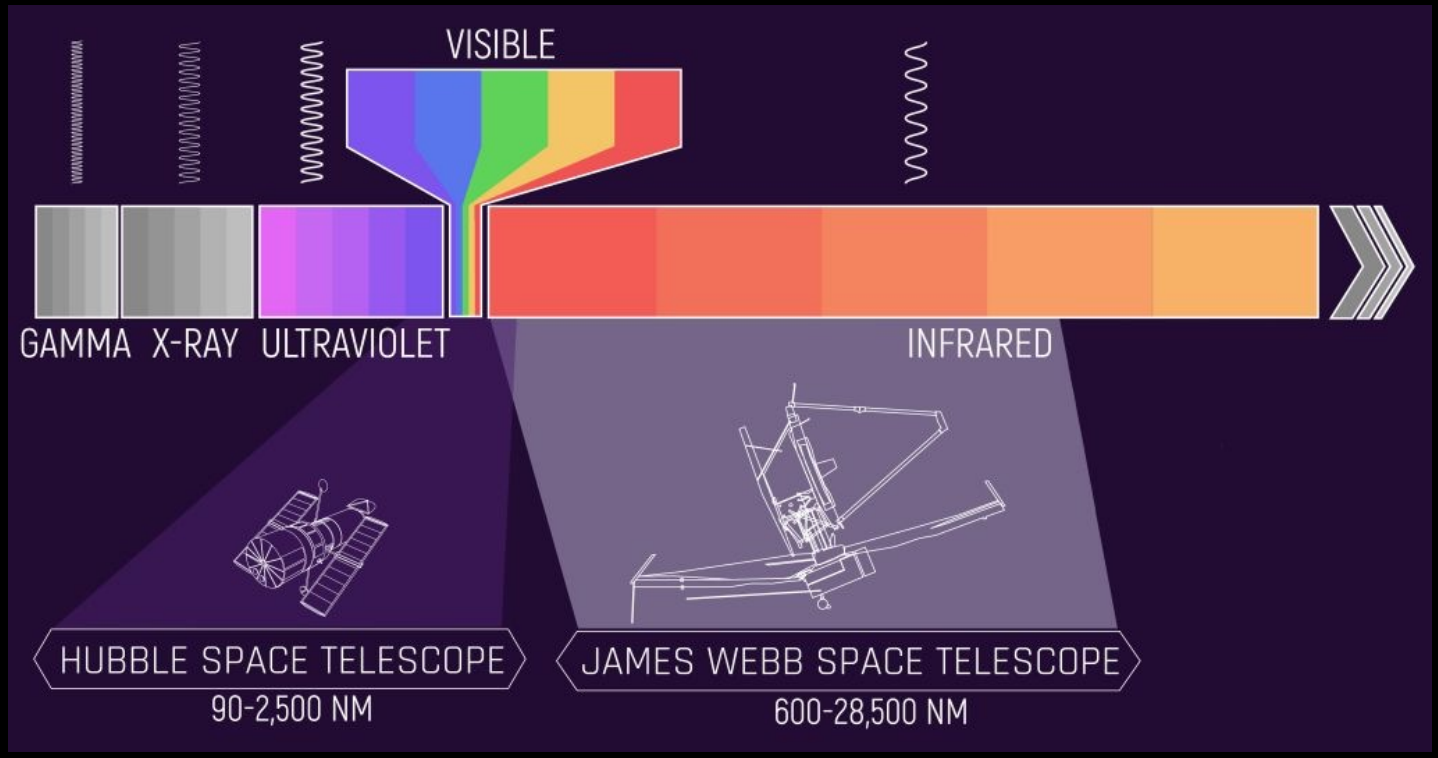
The Webb sees in the infrared ----
it “SEES” heat

THE ELECTROMAGNETIC SPECTRUM

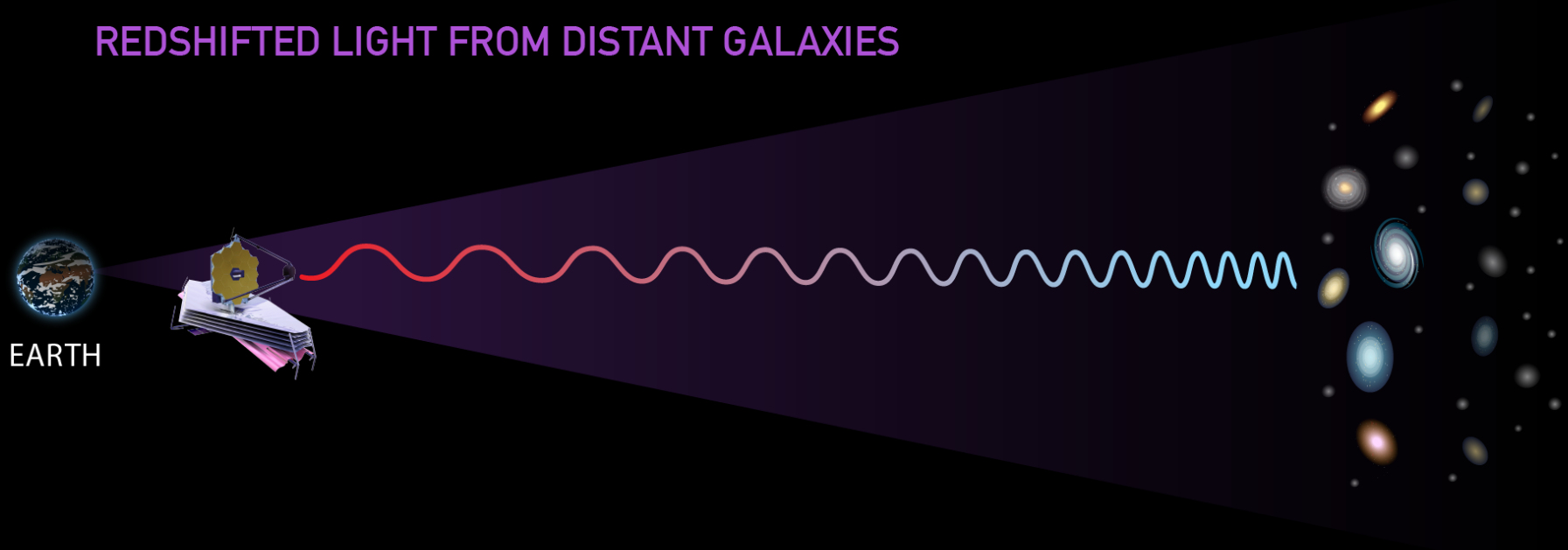
...is a band of colours, as seen in a rainbow, produced by separation of the components of light by their different degrees of refraction according to wavelength.

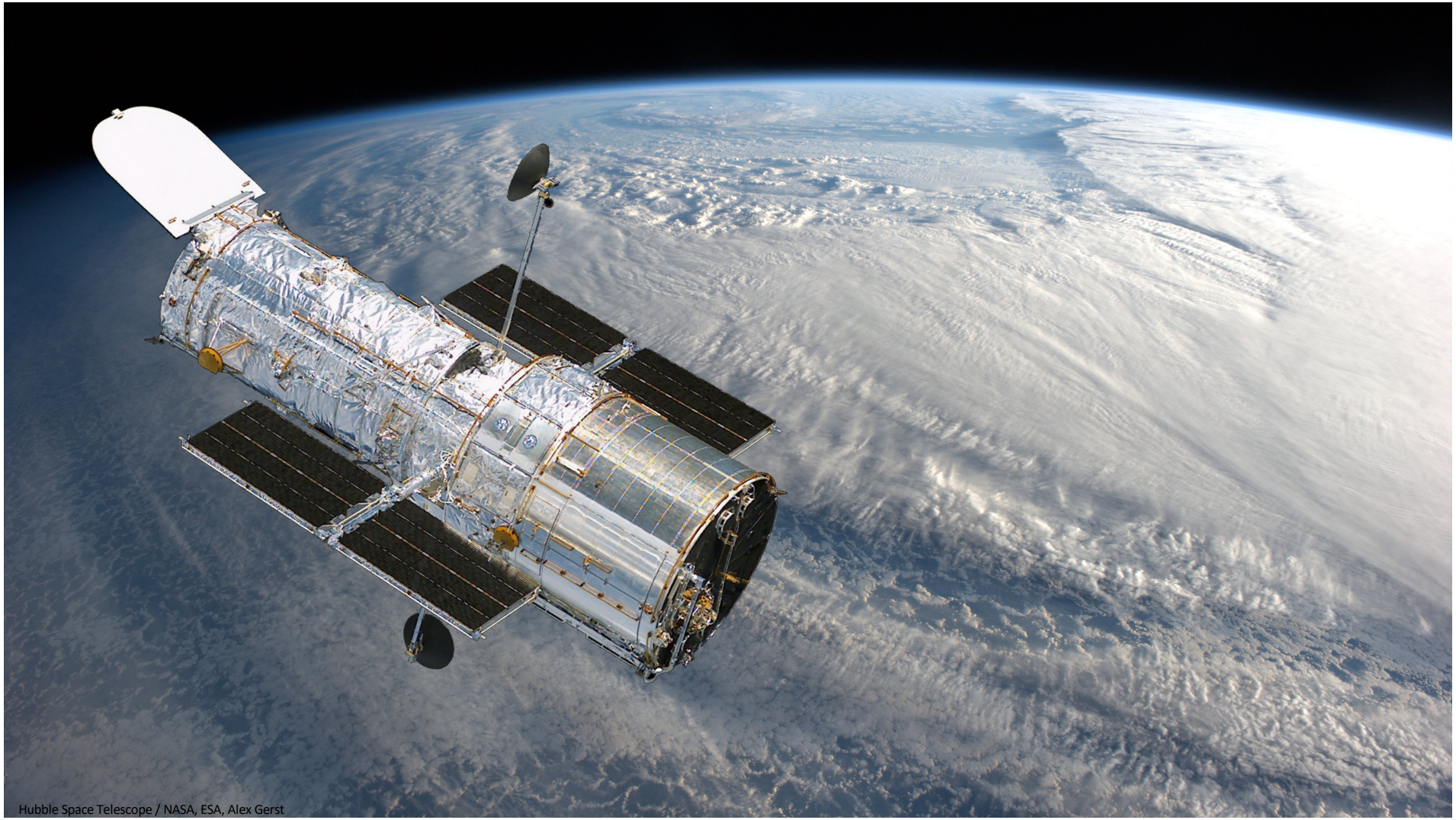


"…The JWST was designed to use a broad range of infrared light, and this is a key reason the JWST can see further back in time than Hubble..."



Observing the Ancient Universe



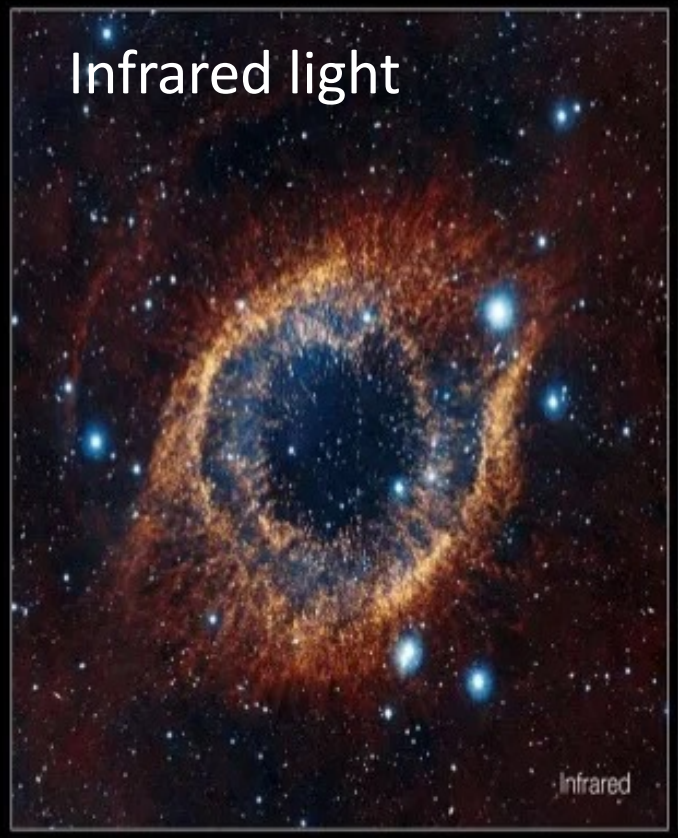


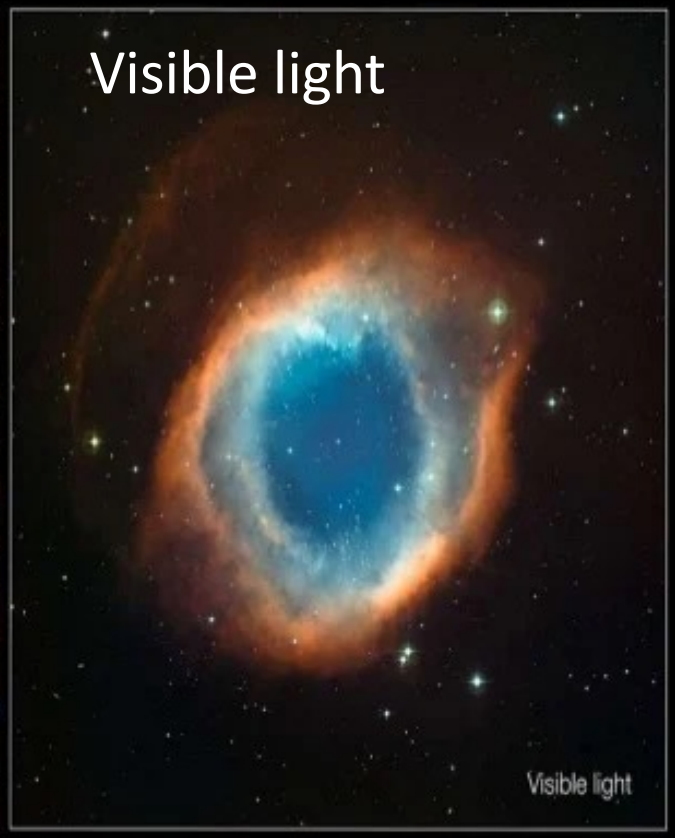
Hubble Space Telescope / NASA, ESA, Alex Gerst

Visible · WFC3 · 2015

Infrared · WFC3 · 2015

The “Pillars of Creation” in the Eagle Nebula





A supernova is a powerful and luminous explosion of a star. A supernova occurs during the last evolutionary stages of a massive star, or when a white dwarf is triggered into runaway nuclear fusion.

SUPERNOVA

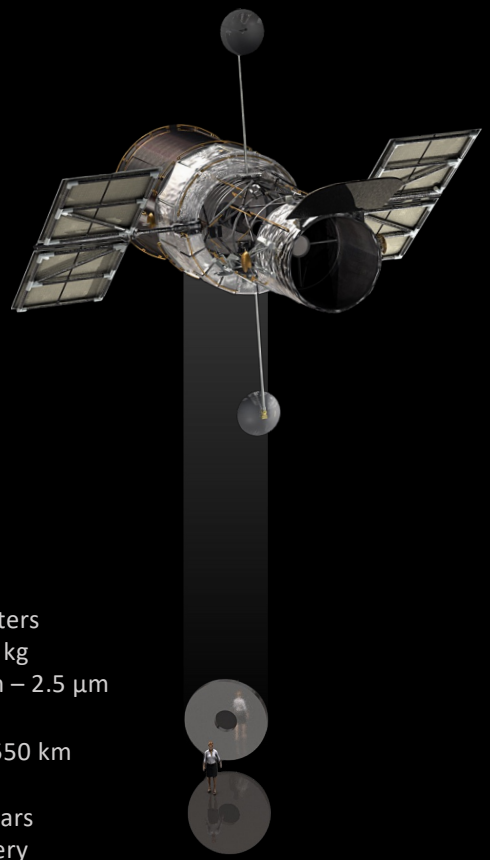
Who Was James Webb?

James Webb (1906 – 1992)

- Second Administrator of NASA (1961 – 1968)
- Oversaw first manned spaceflight program (Mercury)
- Oversaw second manned spaceflight program (Gemini)
- Oversaw Mariner and Pioneer planetary exploration programs
- Oversaw Apollo program
- Insisted that NASA have a strong science program

Hubble Space Telescope

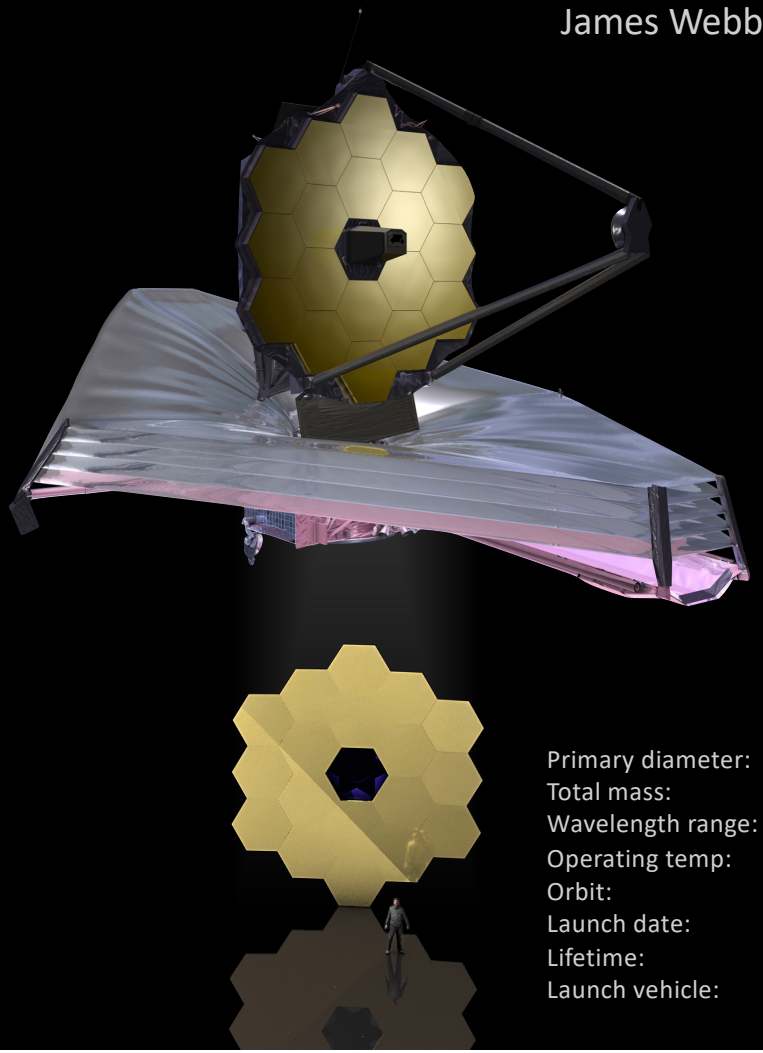
NASA, ESA



Primary diameter:	2.4 meters
Total mass:	12,437 kg
Wavelength range:	115 nm – 2.5 µm
Operating temp:	20°C
Orbit:	LEO, ~550 km
Launch date:	1990
Lifetime:	> 28 years
Launch vehicle:	Discovery

James Webb Space Telescope

NASA, ESA, CSA



Primary diameter:	6.5 meters
Total mass:	6,200 kg
Wavelength range:	0.6–28.5 µm
Operating temp:	< –223°C
Orbit:	L2, ~1.5 million km
Launch date:	2021
Lifetime:	5–10 years
Launch vehicle:	Ariane 5

Who's behind Webb?

An international, collaborative effort involving:

- Over 120 American, European, and Canadian universities, organizations, and companies across 14 different countries and over 29 U.S. states
- Within **NASA**:
  - Goddard Space Flight Center : manages project, microshutters
  - JPL: mid-infrared instrument
  - Ames Research Center: detector technology
  - Johnson Space Center: observatory test facilities
  - Marshall Space Flight Center: mirror tech development and environmental research
  - Glenn Research Center: cryogenic component development
- **ESA**: near infrared spectrograph, mid-infrared instrument optics assembly, Ariane launch vehicle
- **CSA**: fine guidance sensor/near infrared imager and slitless spectrograph
- **Northrop Grumman Aerospace Systems**: the main industrial contractor, responsible for building the optical telescope, spacecraft bus, and sunshield; responsible for preparing the observatory for launch
- **STScI**: manages operations once Webb is in orbit

Contributors to Webb standing next to Northrop's full-scale model at GSFC

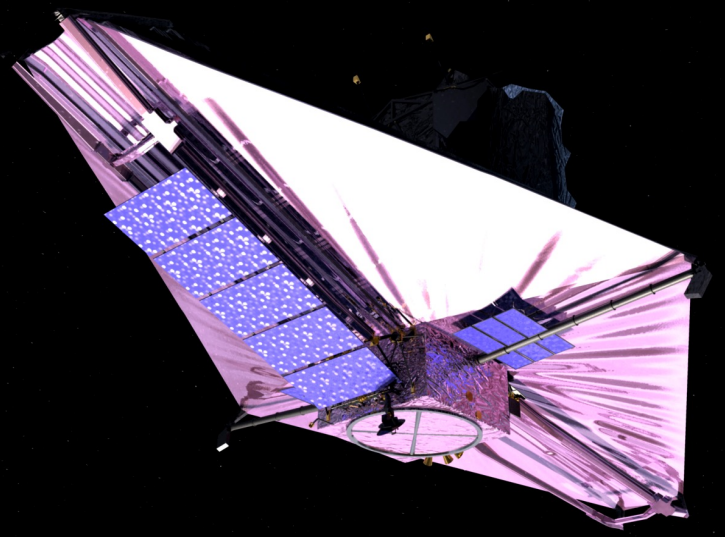
Spacecraft and Telescope

Optical Telescope Element (OTE)

Primary Mirror
Secondary Mirror
Backplane

Spacecraft Element

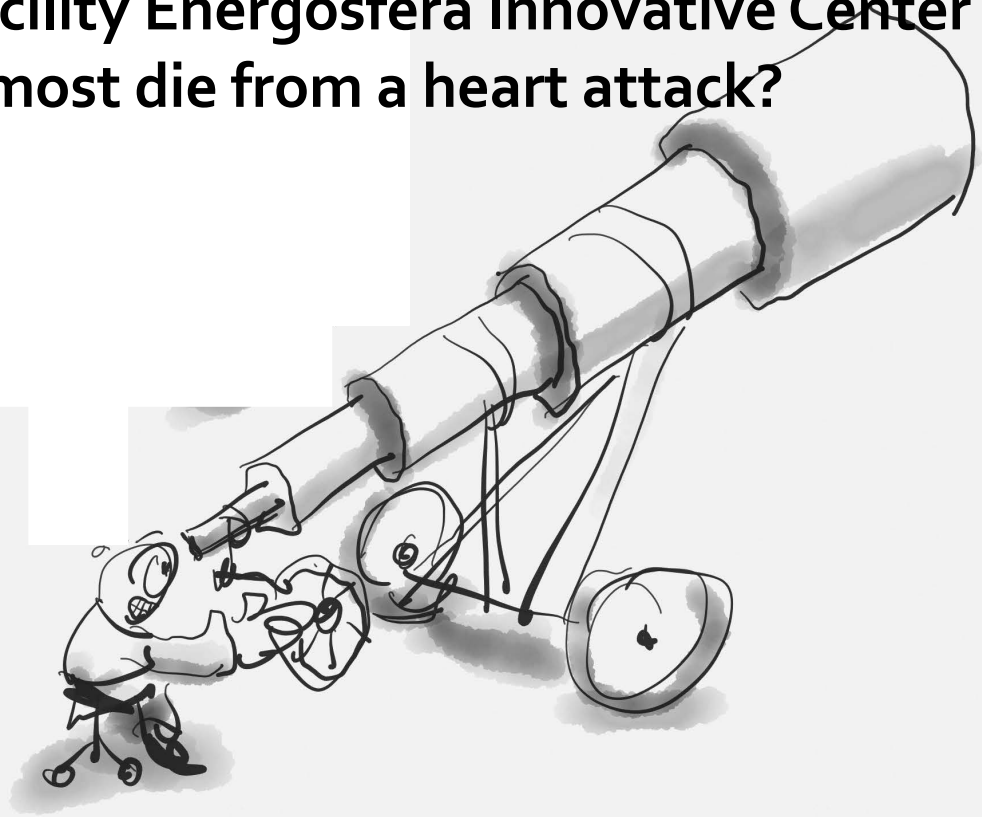
Sunshield
Bus (hosts structural, communications, and propulsion components)

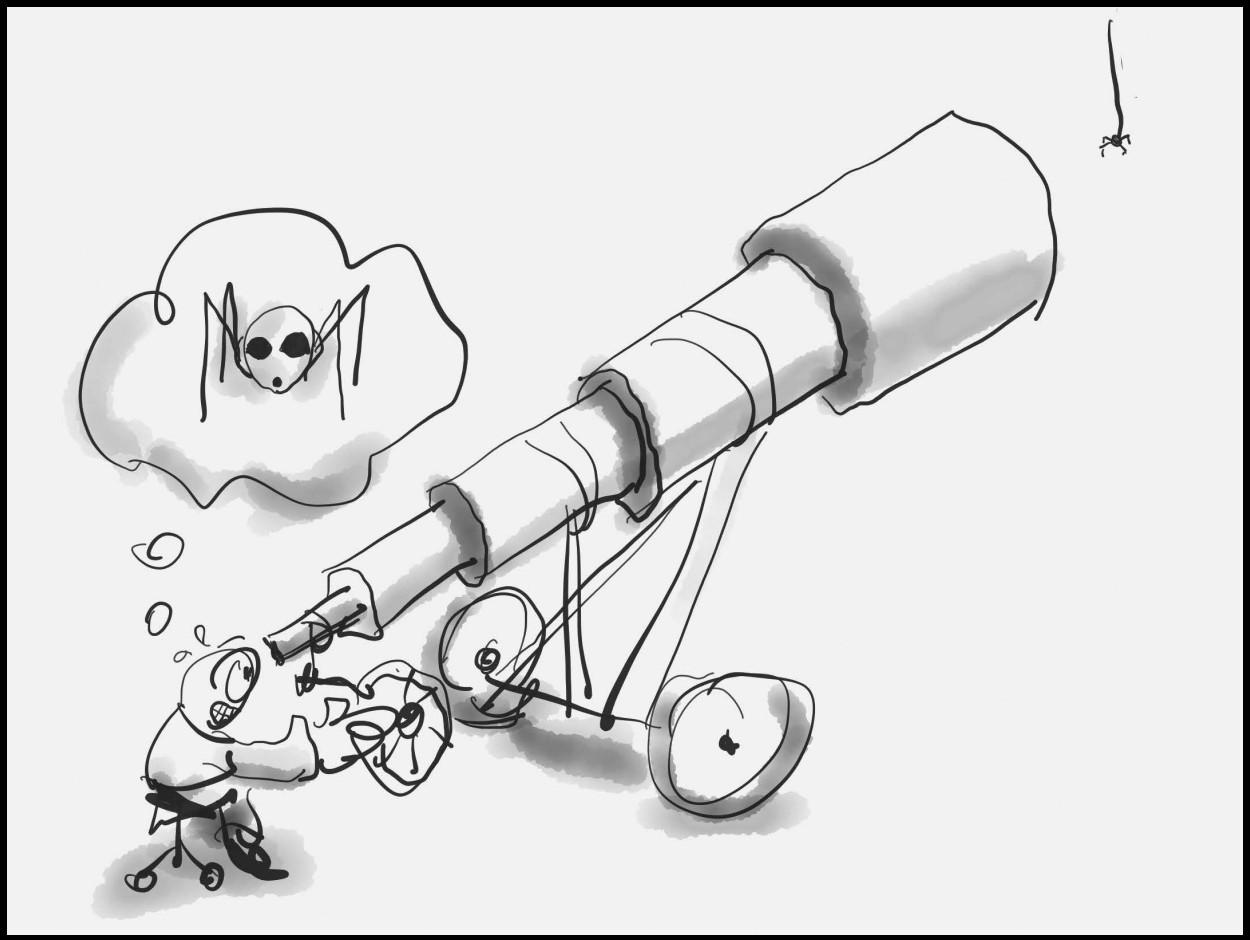


Integrated Science Instrument Module (ISIM)

Mid Infrared Instrument
Near Infrared Spectrograph
Near Infrared Camera
Fine Guidance Sensor/
Near Infrared Imager & Slitless Spectrograph

Why did the astronomer from the Cosmic Facility Energosfera Innovative Center almost die from a heart attack?

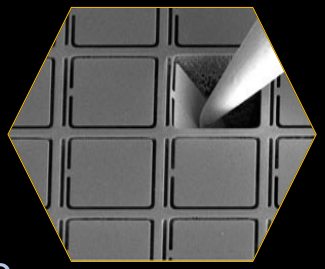




Webb's technological innovations

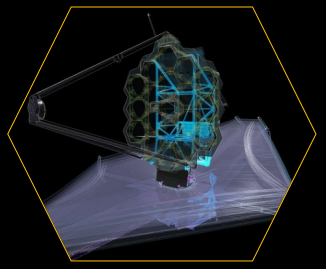
Webb's scientific objectives were so audacious that several new technologies had to be invented in order for it to achieve its scientific goals

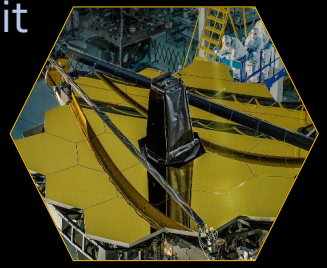
Microshutters



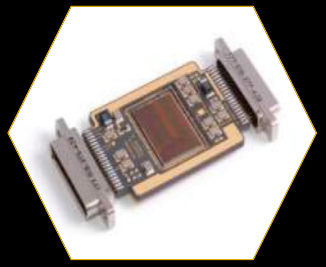
Cryocooler

Backplane





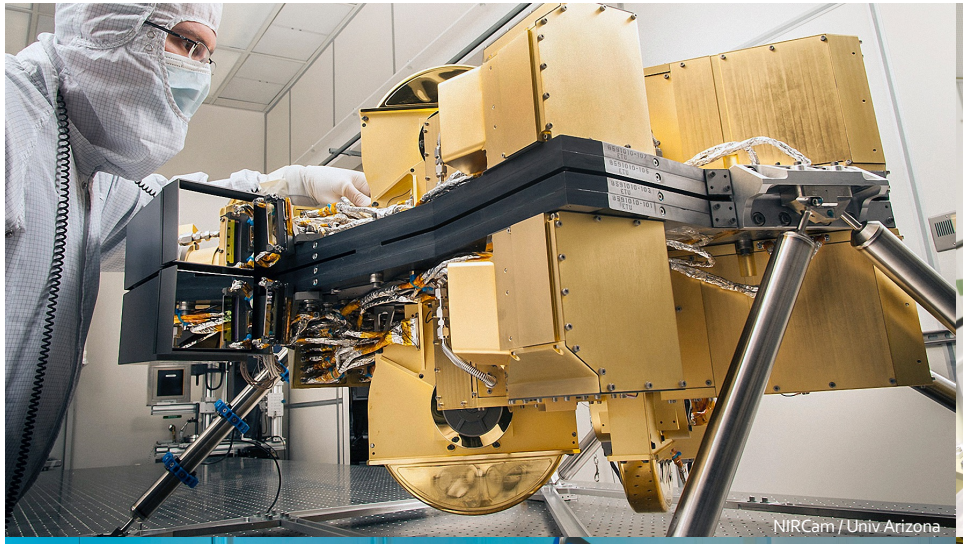
Lightweight Cryogenic Mirrors

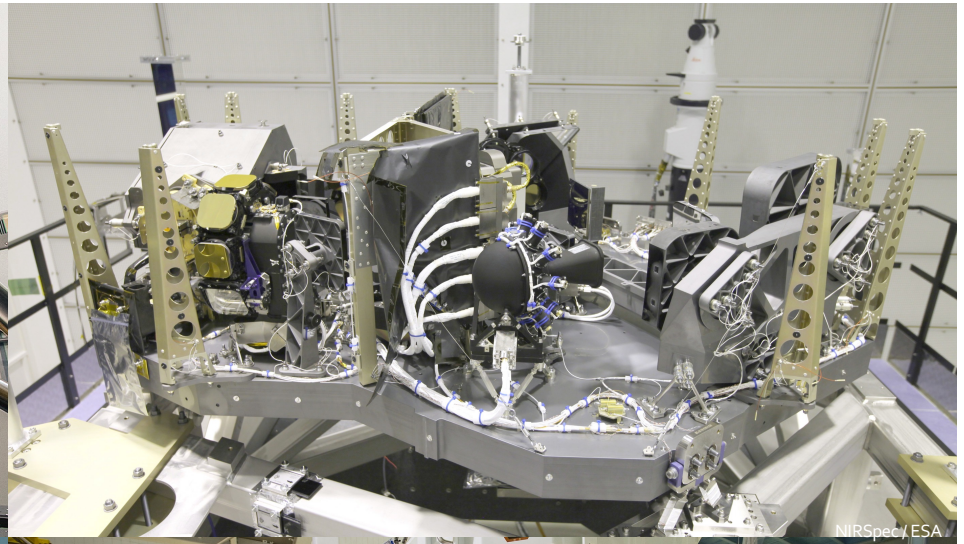


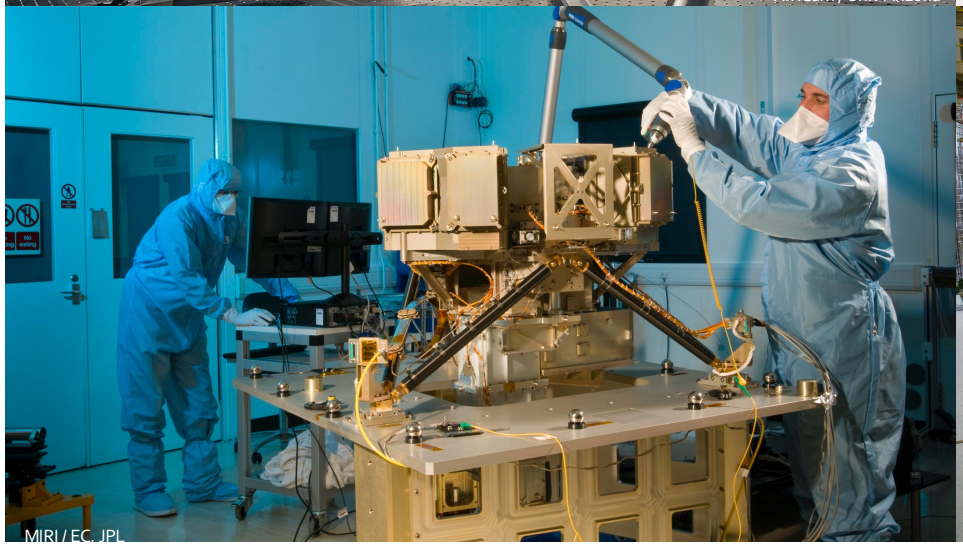
Cryogenic ASICs

Sunshield Coating

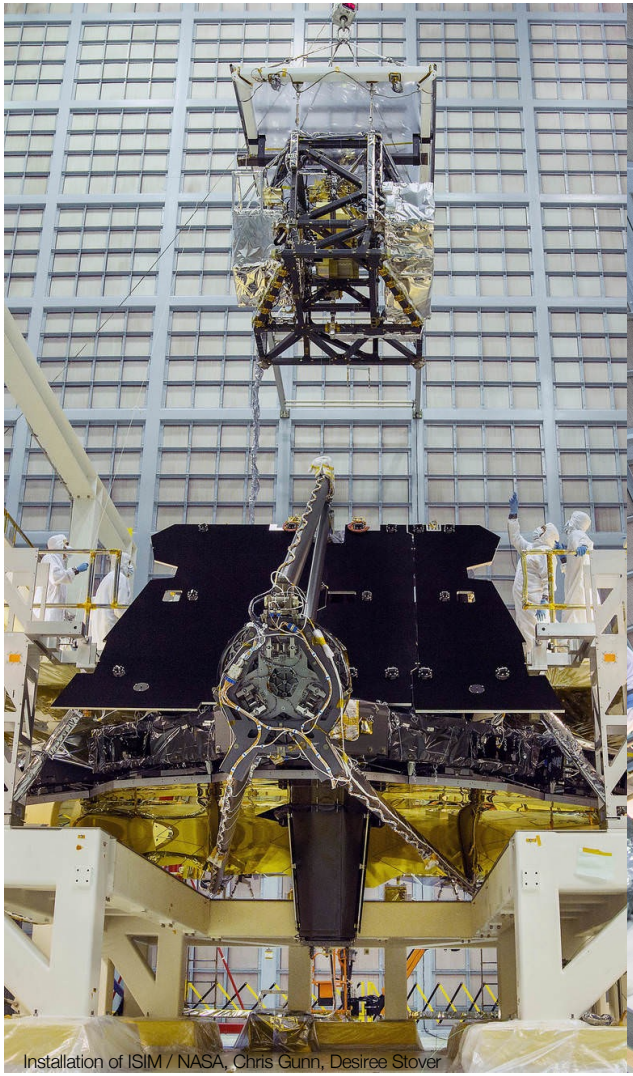
Plus, NIR and MIR Detectors and WFS&C Software


NIRCam / Univ Arizona


NIRSpec / ESA


MIRI / EC, JPL

NIRISS-FGS / CSA



Installation of ISIM / NASA, Chris Gunn, Desiree Stover

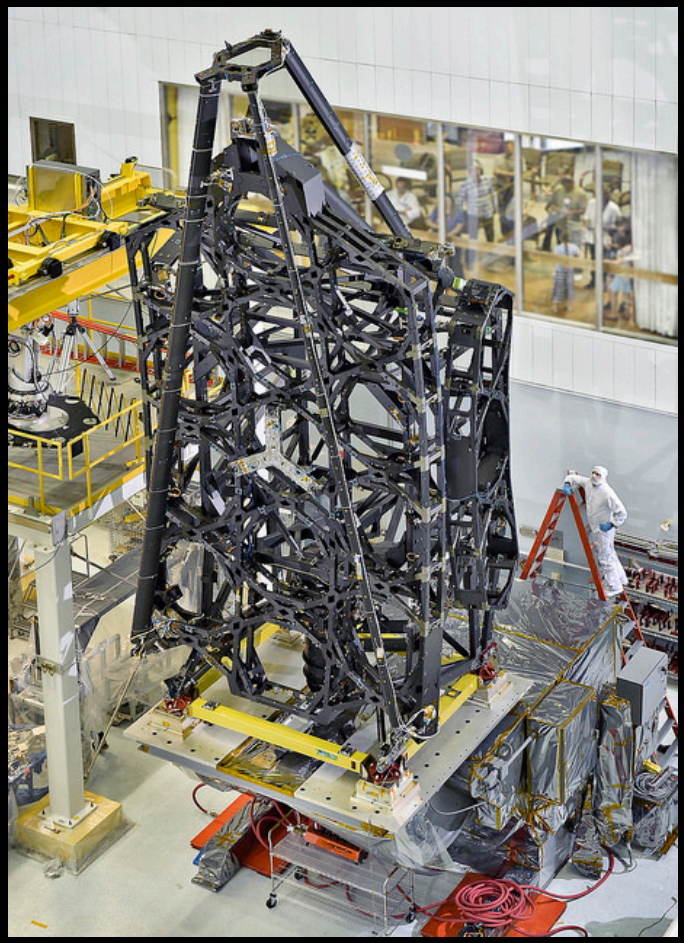
Mirror technology

6-8m class segmented, cryogenic mirror

- Needed Low Areal Density (3x less than Hubble)
- Stable at cryo-temperatures
  - Specific stiffness of Beryllium is 6 times that of steel but at 2/3rd the density of aluminum

Stable cryo-structures

- JWST Structures must hold mirrors and science instruments stable
- Their behavior must be known to ~38 nanometers (~1/10,000th of a human hair!)
- It must maintain this stability while being cooled by 400 degrees

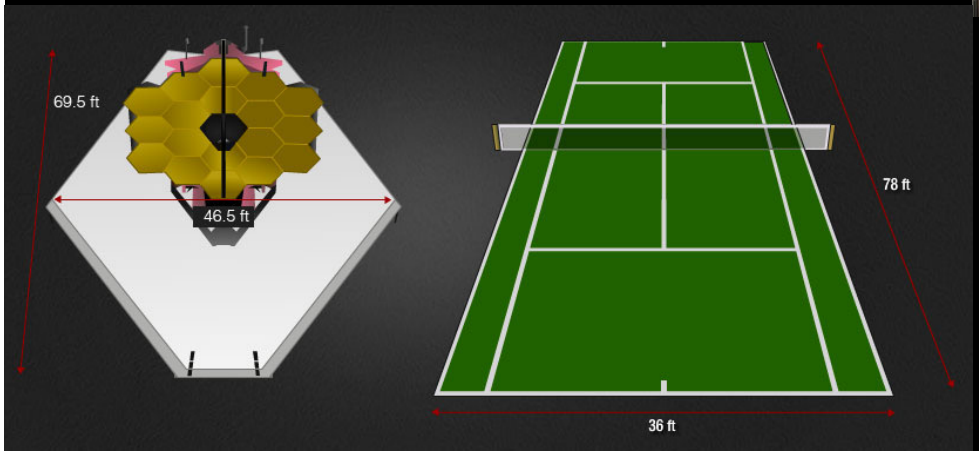


Sunshield technology

Five (0.02mm thick) layers of alloyed silicon coated Kapton.

Continuous roll production at high cleanliness

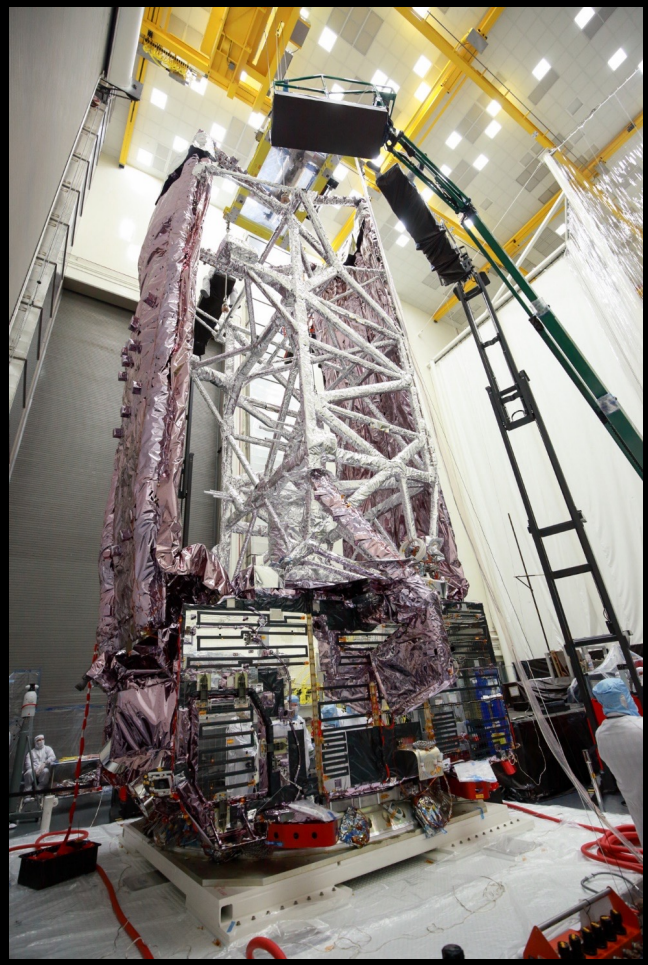
Coatings to provide required cooling



Reducing the temperature from ~380K on the hot side to ~40 K on the cool side, effectively giving Webb "**SPF 1 million**"!

Spacecraft Element

- Spacecraft bus combined with Sunshield make up the Spacecraft Element (SCE)
- Image at right also has a telescope mass simulator (silver lattice structure)
- Image of the SCE before testing at Northrop Grumman

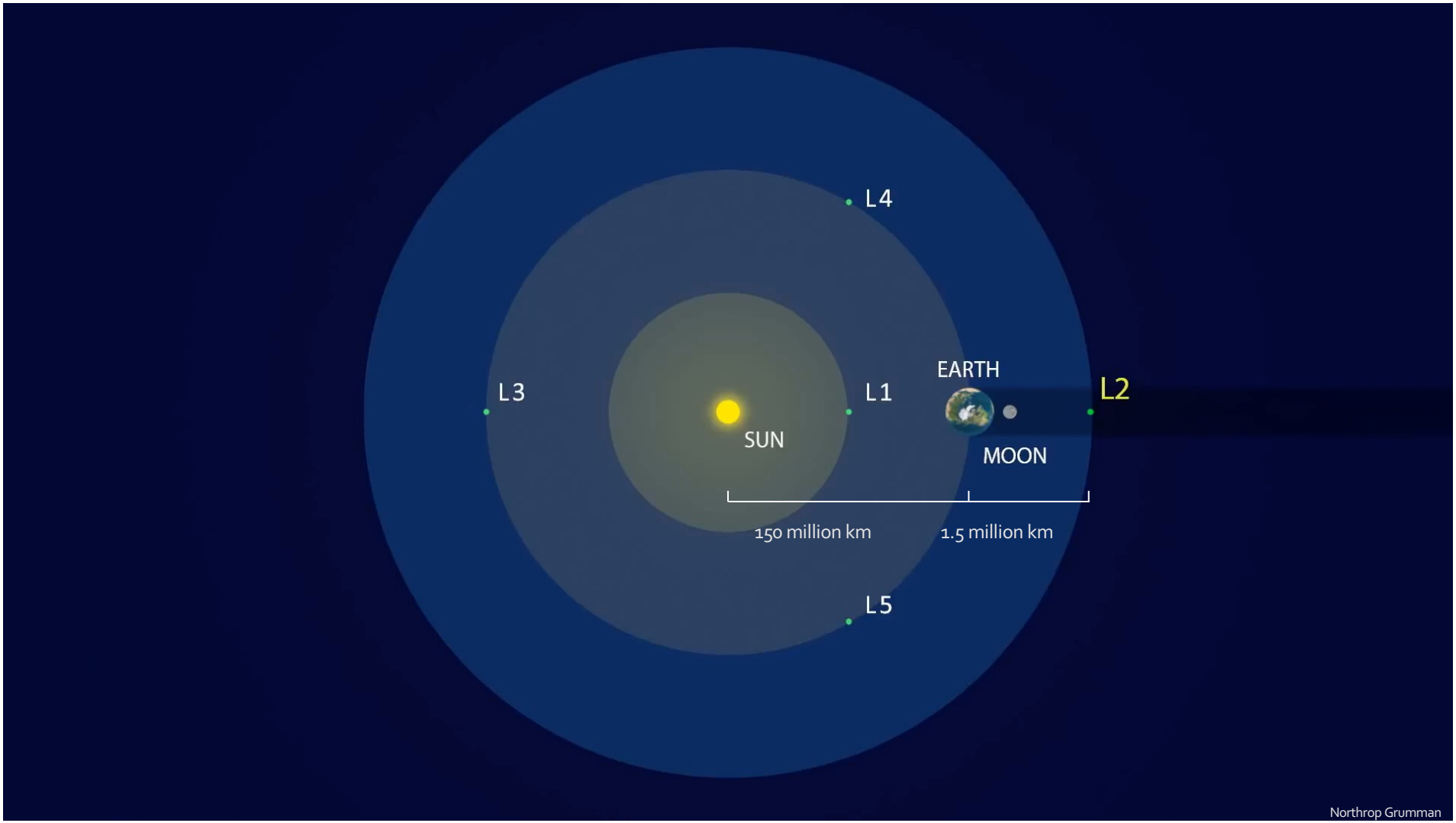


Launch and orbit

Webb was launched on top of ESA's Ariane 5 in December 25, 2021 from French Guiana

It completed a month long 1.5 million km journey to its destination at the 2nd Lagrange point

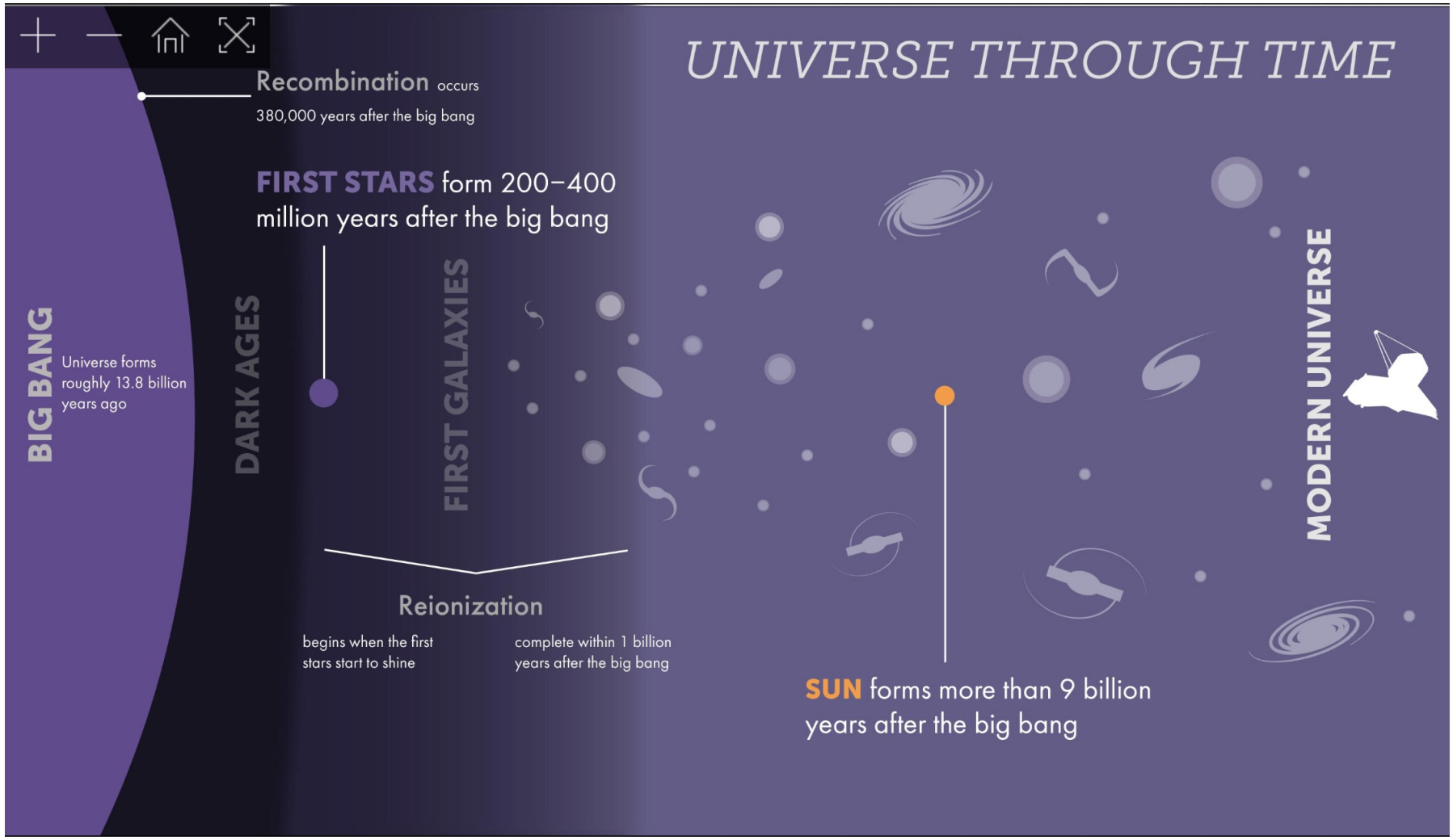
Photo credit: ESA


L4
L3
L1
EARTH
L2
SUN
MOON
150 million km
1.5 million km
L5
Northrop Grumman

"...Lagrange Points are places around the moon where the gravitational pull is almost zero, making it a great place to put a telescope, because it doesn't expend fuel staying in place..."

Some Important Webb Science Results

- First Images of Early Galaxies
- Detailed Observations of Exoplanet Atmospheres
- Technosignatures


UNIVERSE THROUGH TIME
Recombination occurs
380,000 years after the big bang
FIRST STARS form 200–400
million years after the big bang
BIG BANG
Universe forms
roughly 13.8 billion
years ago
DARK AGES
FIRST GALAXIES
MODERN UNIVERSE
Reionization
begins when the first
stars start to shine
complete within 1 billion
years after the big bang
SUN forms more than 9 billion
years after the big bang

"…The James Webb Telescope will reveal the dawn of the Cosmos…"

"...the theory is ...(the first stars) could be **gigantic Megastars**, burning more brightly and hotter than anything in the Universe today..."

"...We will not see
the Big Bang,
but we will see the
earliest stars
forming..."

Webb sees stars forming

First, The Big Bang creating "Dark Matter or neutral hydrogen and helium gas."

Next after "…a few hundred million years, the gas started to coalesce, forming stars, **and then the lights switched on.** The radiation from these first stars ionized the neutral gas around them…"

"…the Universe had gone from a **homogeneous primordial soup** to a **highly structured arrangement, with galaxies, stars probably even planets…a Cosmic Dawn…"**

THIS is the neighborhood that Webb is exploring.

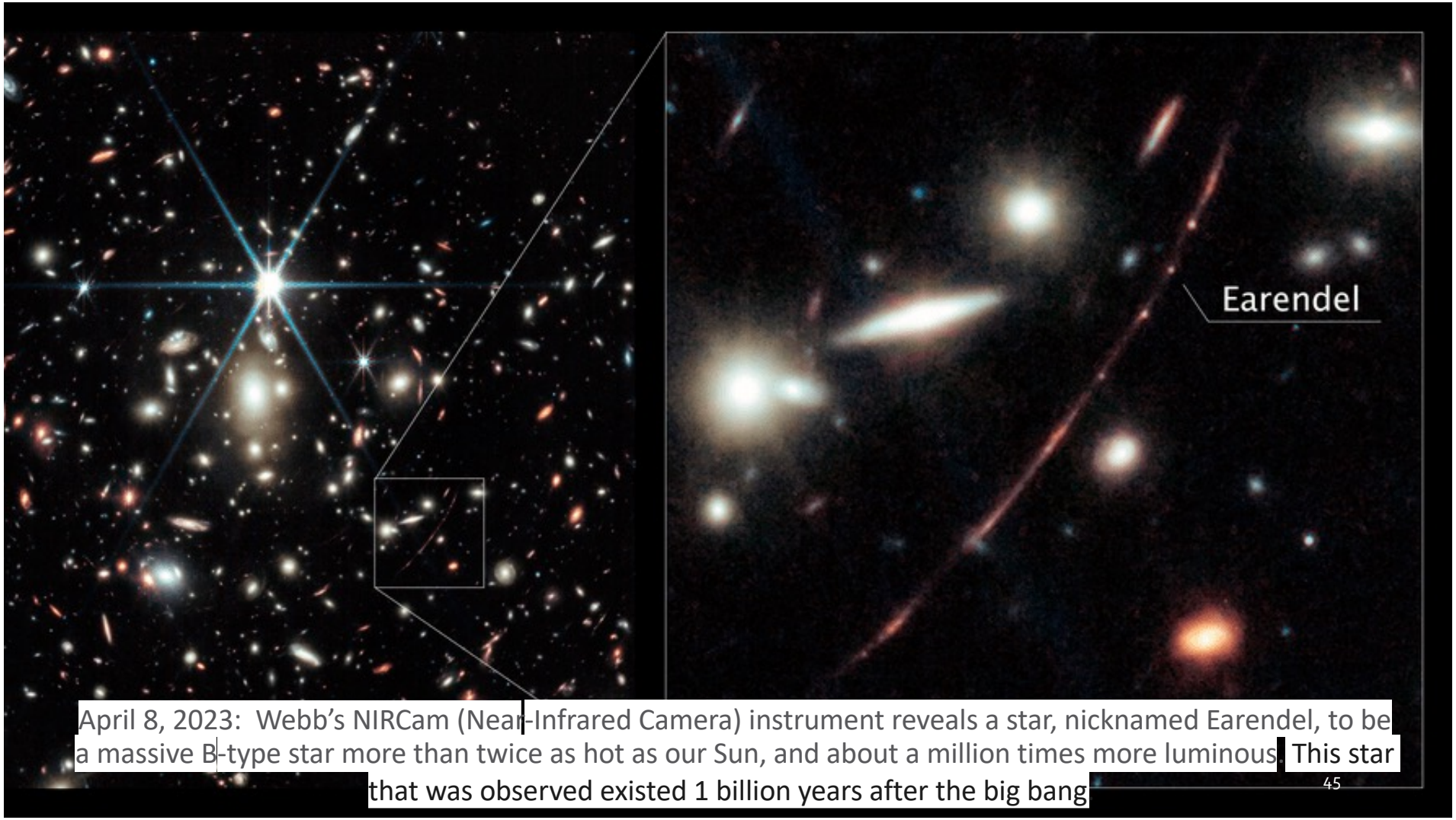
"...Light age does not equal distance. Using the JWST, we will be able to capture extremely distant galaxies as they were only 100 million years after the Big Bang — which happened around 13.8 billion years ago...

...So we will be able to see light from 13.7 billion years ago. What's about to hurt your brain, however, is that those galaxies are not 13.7 billion light-years away. The actual distance to those galaxies today would be ~46 billion light-years..."

The Webb will see the earliest stars not long after they first formed.

"…We'll be able to see more than just the brightest and rarest representatives of the first generation of galaxies. With the Webb, we'll be watching the very first collections of stars coming together all across the cosmos…"

JWST can voyage back to the "…the edge of time not by actually going anywhere, but by sending us direct images of some of the earliest moments of the Universe --- showing us **what it would have looked like if we had actually been there**, more than **13 billion years ago, watching the first galaxies form…"**

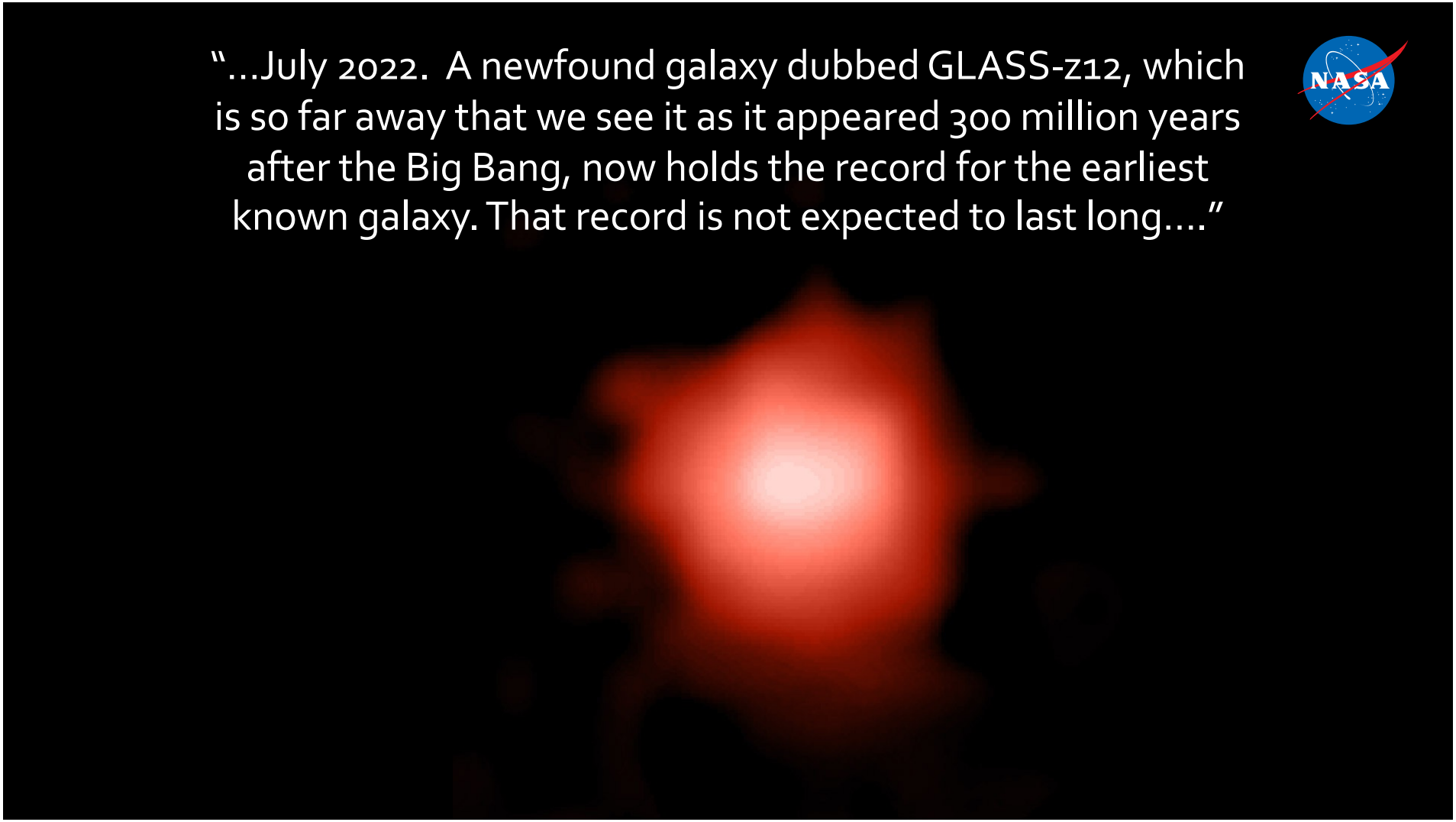


April 8, 2023: Webb's NIRCam (Near-Infrared Camera) instrument reveals a star, nicknamed Earendel, to be a massive B-type star more than twice as hot as our Sun, and about a million times more luminous. This star that was observed existed 1 billion years after the big bang

"Astronomers have discovered signs of supermassive stars at the center of globular clusters born not long after the Big Bang…

…Cosmic monsters dwell in dense star clusters born just a few hundred million years after the universe's birth, new observations by the James Webb Space Telescope (JWST) suggest…
…these monsters are supermassive stars, which JWST spotted signs of in globular clusters born about 13.4 billion years ago…."

"…July 2022. A newfound galaxy dubbed GLASS-z12, which is so far away that we see it as it appeared 300 million years after the Big Bang, now holds the record for the earliest known galaxy. That record is not expected to last long…."

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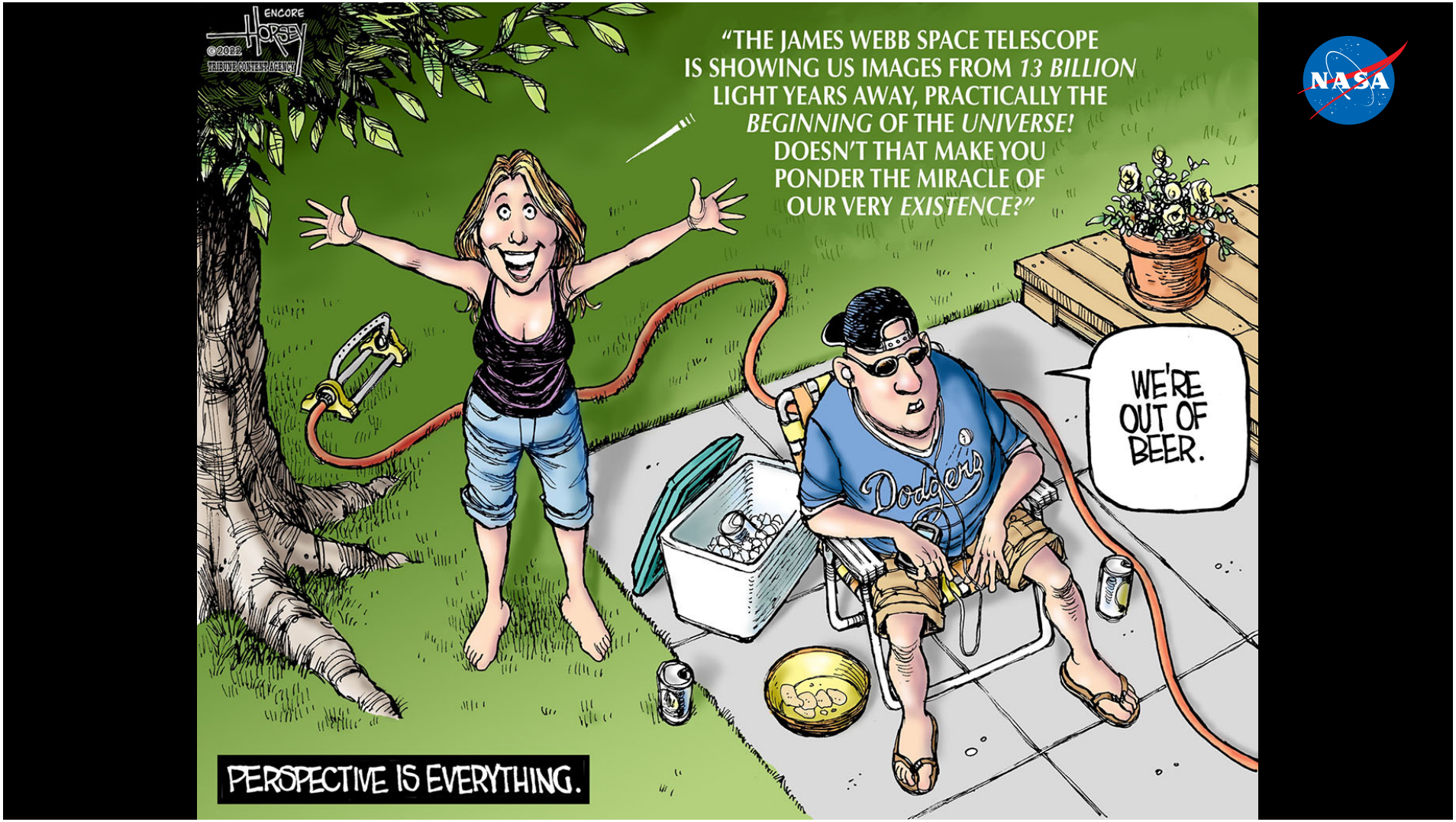
"THE JAMES WEBB SPACE TELESCOPE IS SHOWING US IMAGES FROM *13 BILLION* LIGHT YEARS AWAY, PRACTICALLY THE *BEGINNING* OF THE *UNIVERSE!* DOESN'T THAT MAKE YOU PONDER THE MIRACLE OF OUR VERY *EXISTENCE?*"
NASA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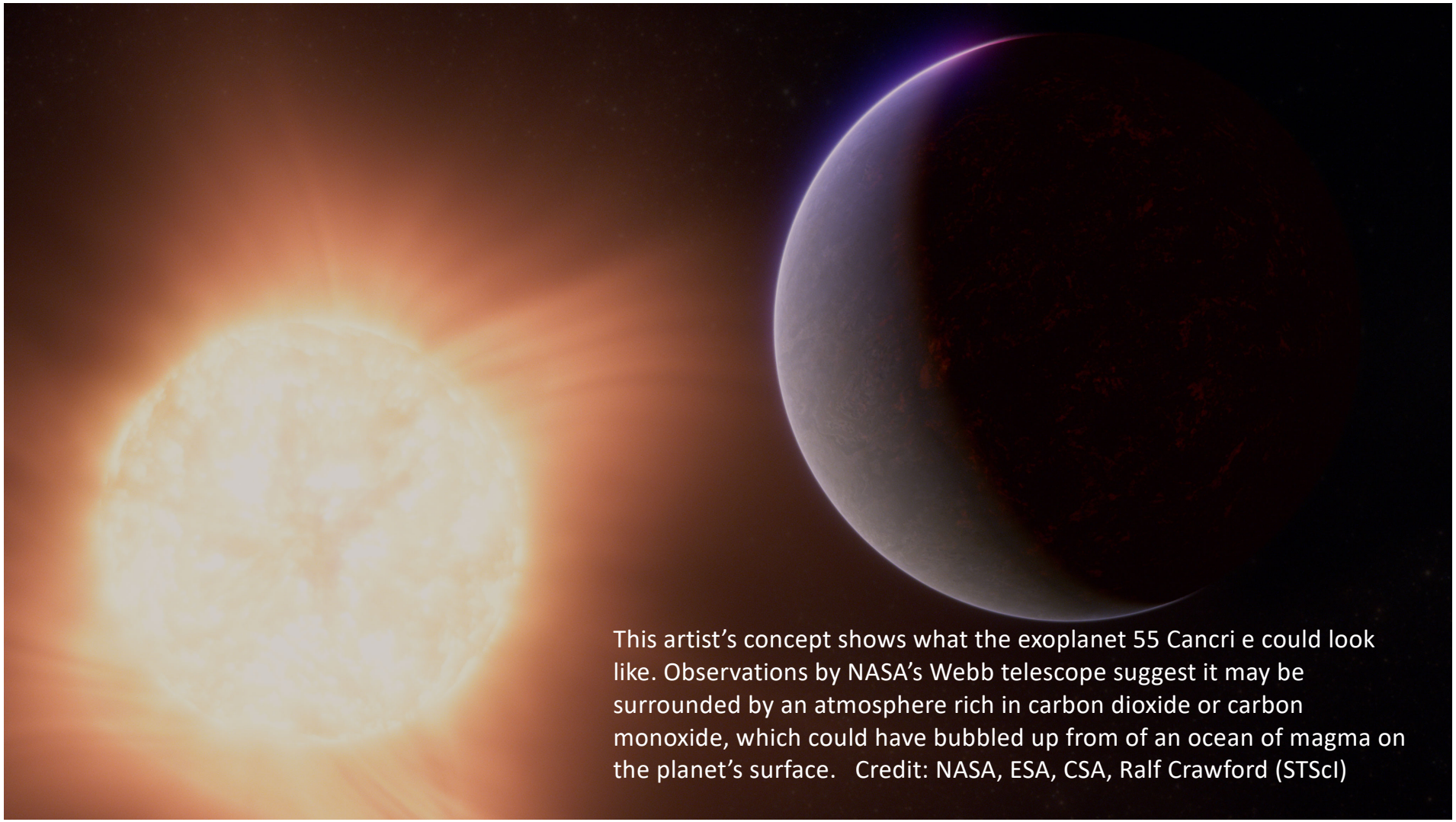
NASA
WE'RE OUT OF BEER.
Dodgers
PERSPECTIVE IS EVERYTHING.

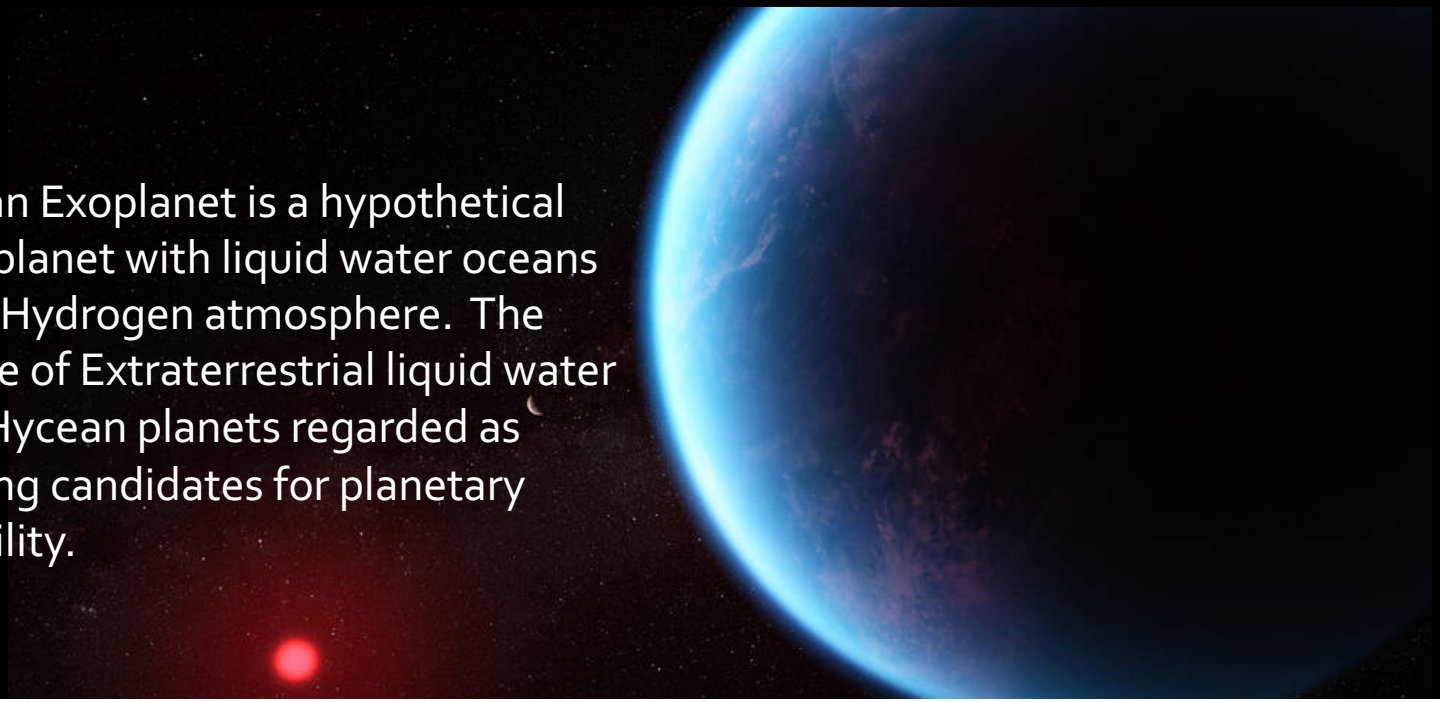
Detailed Observations of Exoplanet Atmospheres



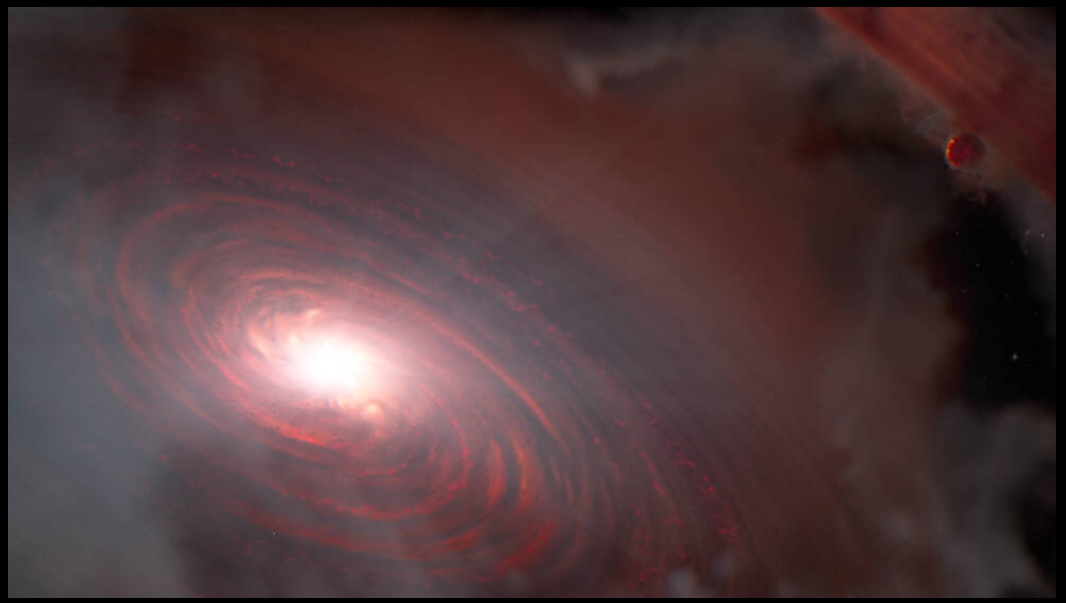
This artist's concept shows what the exoplanet 55 Cancri e could look like. Observations by NASA's Webb telescope suggest it may be surrounded by an atmosphere rich in carbon dioxide or carbon monoxide, which could have bubbled up from of an ocean of magma on the planet's surface. Credit: NASA, ESA, CSA, Ralf Crawford (STScI)

"Webb Discovers Methane, Carbon Dioxide in Atmosphere of K2-18 b"
A new investigation with NASA's James Webb Space Telescope into K2-18 b, an exoplanet 8.6 times as massive as Earth, has revealed the presence of carbon-bearing molecules including methane and carbon dioxide. Webb's discovery adds to recent studies suggesting that K2-18b could be a Hycean exoplanet, one which has the potential to possess a hydrogen-rich atmosphere and a water ocean-covered surface."

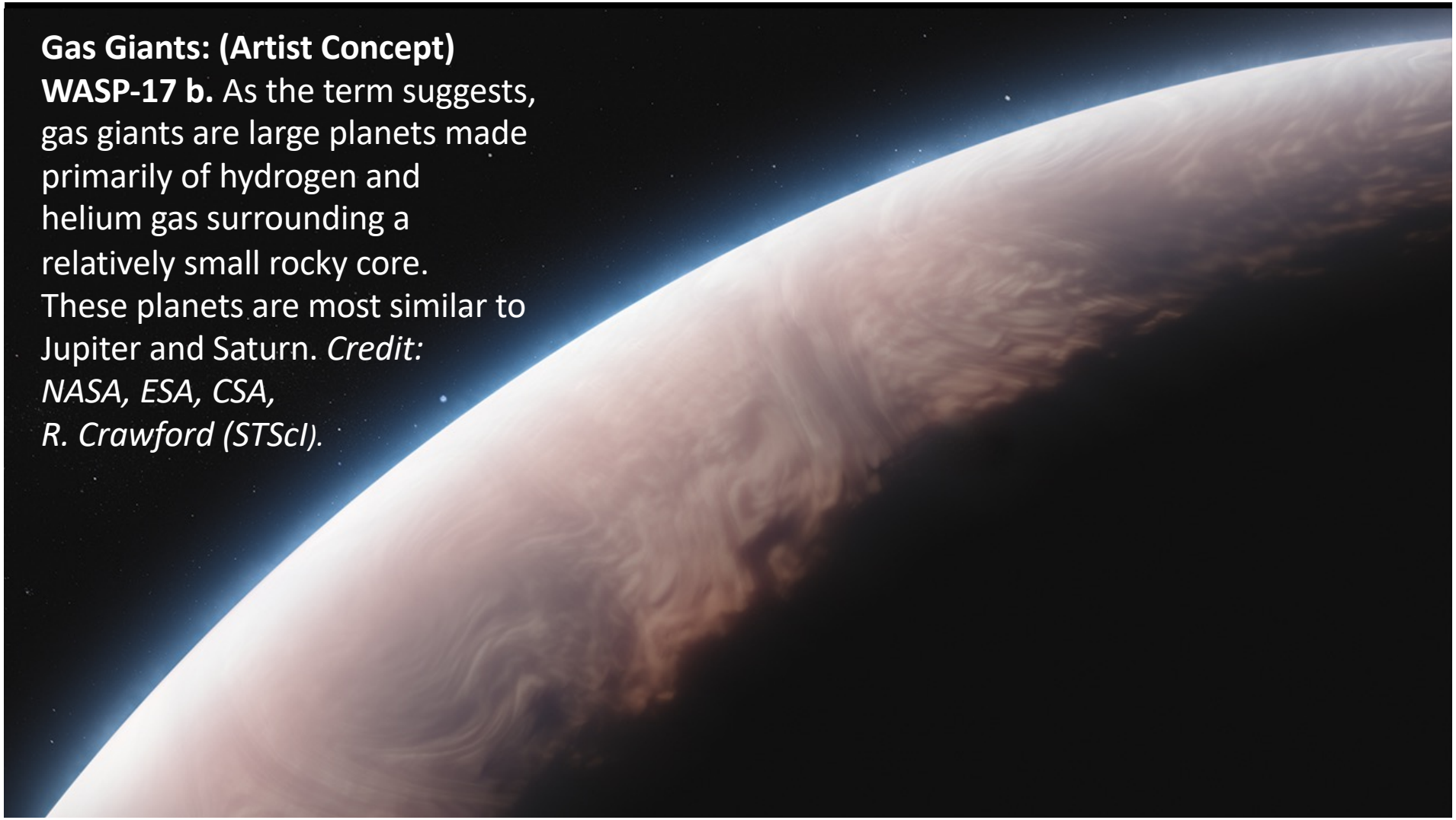
A Hycean Exoplanet is a hypothetical type of planet with liquid water oceans under a Hydrogen atmosphere. The presence of Extraterrestrial liquid water makes Hycean planets regarded as promising candidates for planetary habitability.



"...Webb Detects Water Vapor in Rocky Planet-Forming Zone..."



"…One possibility is that water molecules are forming in place, where we detect them, as hydrogen and oxygen atoms combine. A second possibility is that ice-coated dust particles are being transported from the cool outer disk to the hot inner disk, where the water ice sublimates and turns into vapor…"



Gas Giants: (Artist Concept) WASP-17 b. As the term suggests, gas giants are large planets made primarily of hydrogen and helium gas surrounding a relatively small rocky core. These planets are most similar to Jupiter and Saturn. *Credit: NASA, ESA, CSA, R. Crawford (STScI).*

Webb is also looking

for Technosignatures

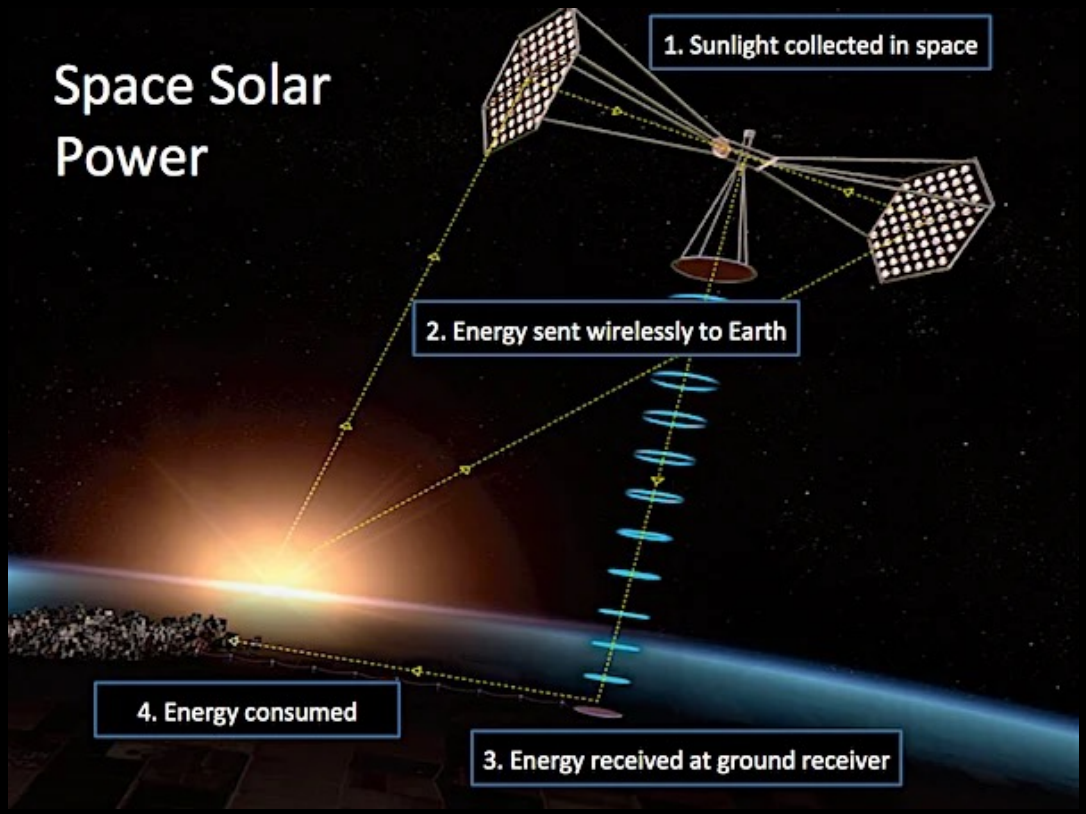
WHY CAN'T THE JWST SEE ALIENS FROM OUTER SPACE?

BECAUSE SOMETIMES IT IS HARD TO SEE THINGS THAT ARE RIGHT IN FRONT OF YOUR FACE.

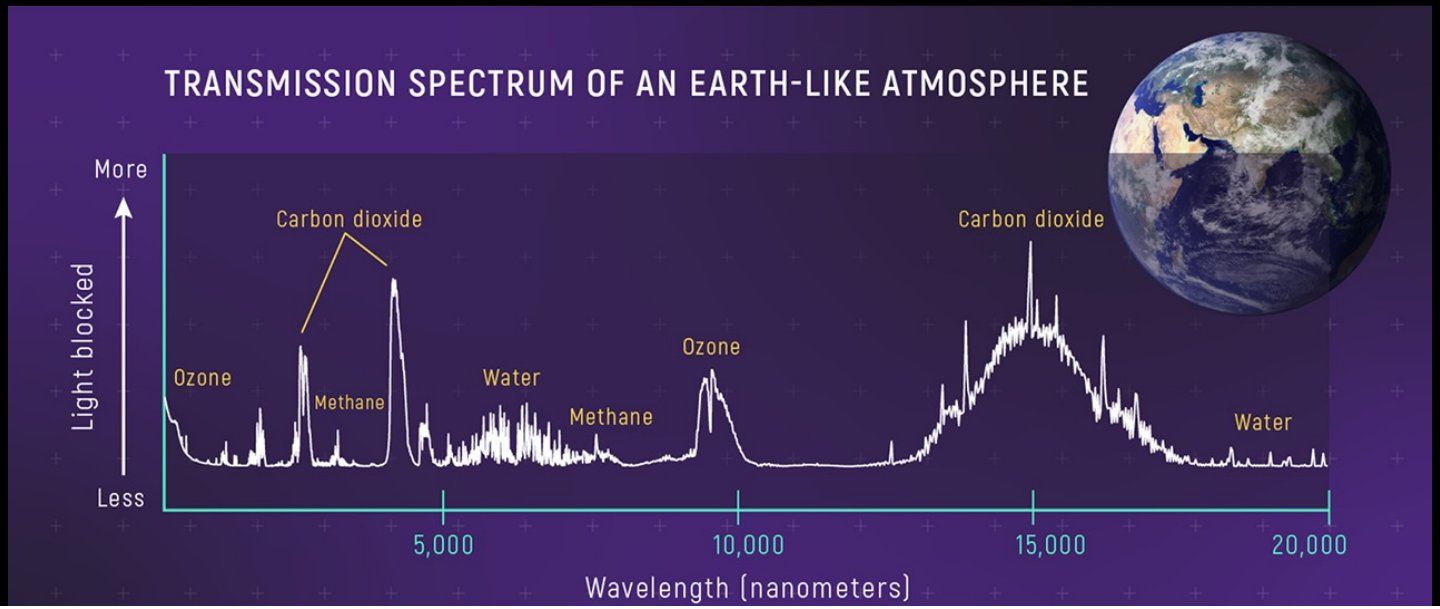
“...Researchers have shown that if the James Webb Space Telescope was pointed at Earth from a distant star, it could detect the signatures of intelligent life in our planet's atmosphere. The finding raises hopes that the Webb could detect alien civilizations as it stares out toward distant worlds in our galaxy...”

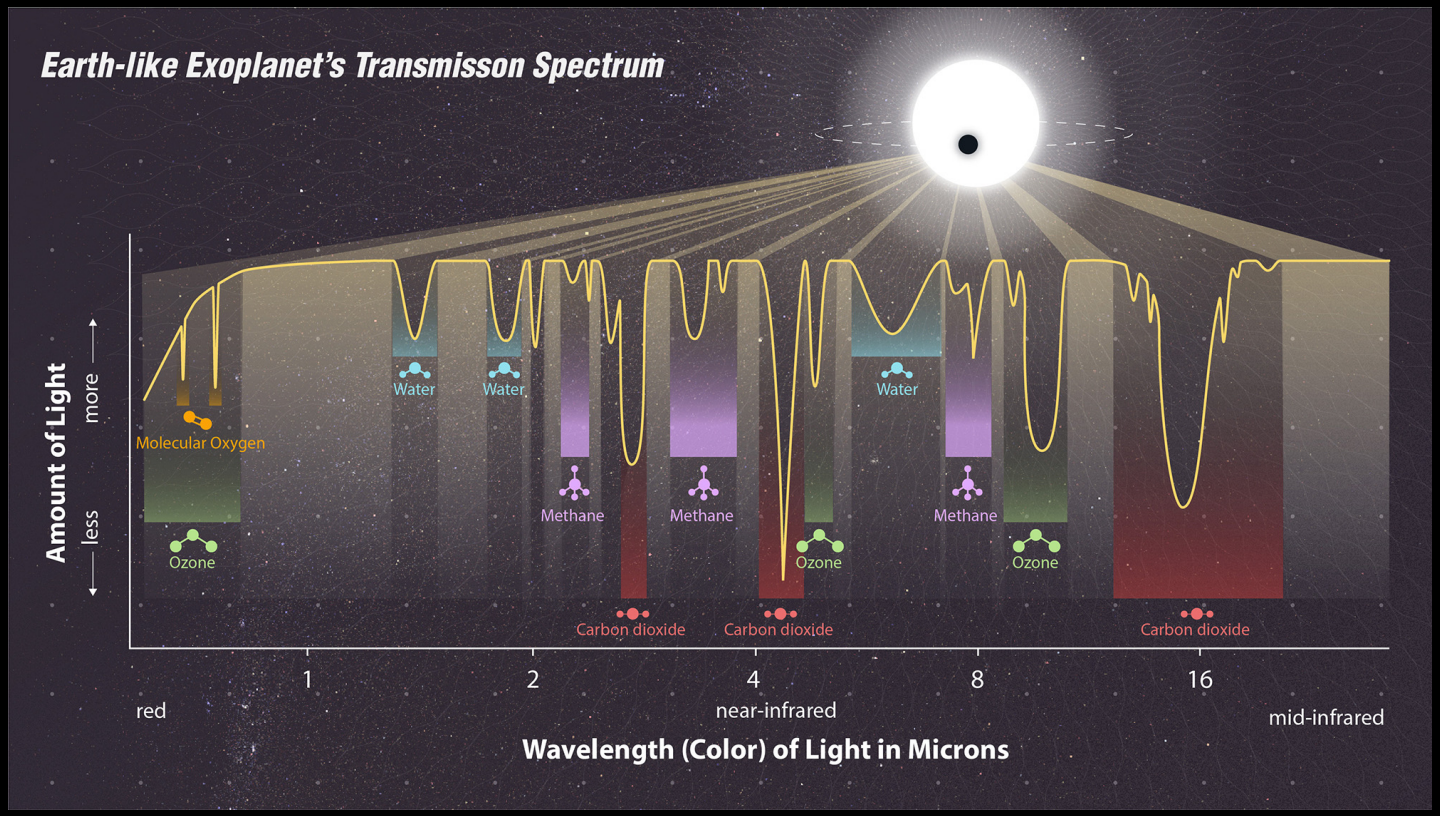
“...one of the telescope's secondary objectives is to analyze the atmospheres of nearby exoplanets, or planets beyond the solar system, to look for gases produced by biological life, known as biosignatures, and chemicals produced by advanced alien civilizations, known as technosignatures...”

Webb will be looking for atmospheric signs of civilization such as
Structures for Space Solar Power



“The team developed a computer model, which replicated JWST's sensor capabilities, to see if the spacecraft could detect **the key biosignatures and technosignatures from the dataset, such as methane and oxygen, produced by biological life, and nitrogen dioxide and chlorofluorocarbons (CFCs), which are produced by humans.** The results show that JWST could detect all the key markers of non-intelligent and intelligent life in our planet's atmosphere.”




Earth-like Exoplanet's Transmisson Spectrum
Amount of Light
more
less
Molecular Oxygen
Ozone
Water
Water
Methane
Methane
Carbon dioxide
Carbon dioxide
Ozone
Water
Methane
Ozone
Carbon dioxide
1
2
4
8
16
red
near-infrared
mid-infrared
Wavelength (Color) of Light in Microns

Light pollution

Atmospheric pollution from factories, combustion engines, etc. "…This air pollution is composed of solid and liquid particles made up of ash, metals, soot, diesel exhaust, and chemicals…"

"…maybe there are Aliens
from Outer Space everywhere!…"

"...So why do human kidnappings by Aliens from Outer Space only occur at night?..."

"…It is 8 o'clock at night and you are only now just asking me for a human that you need for school tomorrow…"

Other scientific findings of JWST

- Uncertainties about the Hubble Constant
- Water around a mysterious comet
- Earth's closest star-forming region
- Galaxies in the early universe seem to be far more massive than expected

“James Webb Space Telescope deepens major debate over universe’s expansion rate”. The universe is expanding, and its rate is in question. “Hubble tension”- the measurements of the Hubble and the Webb do not agree.

“According to most models, the Hubble constant should equal something around **68 kilometers per second** per megaparsec (km/s/Mpc).
One megaparsec is 1,000,000 parsecs, or about 3,262,000 light-years, for context.

But after scanning stars and galaxies across our universe, some experts calculate the constant to be **69.8 km/s/Mpc**, while others find it to be as high as **74 km/s/Mpc**, depending on the method of measurement.
Still others have suggested solutions that fall between the two. ”

James Webb Space Telescope discovers water around a mysterious comet

"The James Webb Space Telescope has spotted water around a rare comet located in the main asteroid belt between Jupiter and Mars.

The observation represents another scientific breakthrough for the James Webb Space Telescope (JWST), representing the first time that gas, in this case, water vapor, has been detected around a comet in the main asteroid belt. This is important as it shows that water in the early solar system could have been preserved as ice in the main asteroid belt."

"The Rho Ophiuchi cloud complex…
Earth's closest star-forming region…
400 light years away from us."

"…Many galaxies in the early universe seem to be far more massive than expected. Researchers using the James Webb Space Telescope (JWST) spotted galaxies with masses up to 100 billion times that of the sun that must have formed faster than current models can explain…"

Thank you for being here.

Questions?

- Back up Charts

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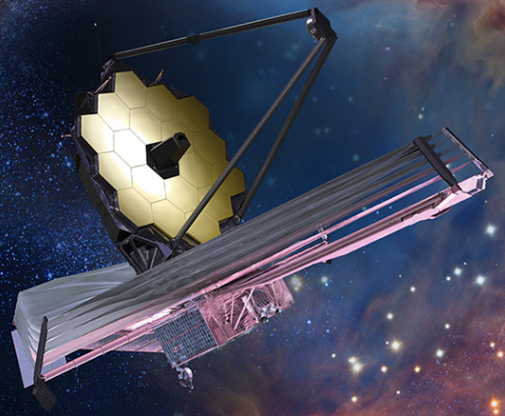
Eric P. Smith
JWST Program Scientist, NASA Headquarters

Solar System Ambassadors 8-May-2019



WEBB JAMES WEBB SPACE TELESCOPE

Online resources

@NASAWebb

@webbtelescope

nasa.gov/webb

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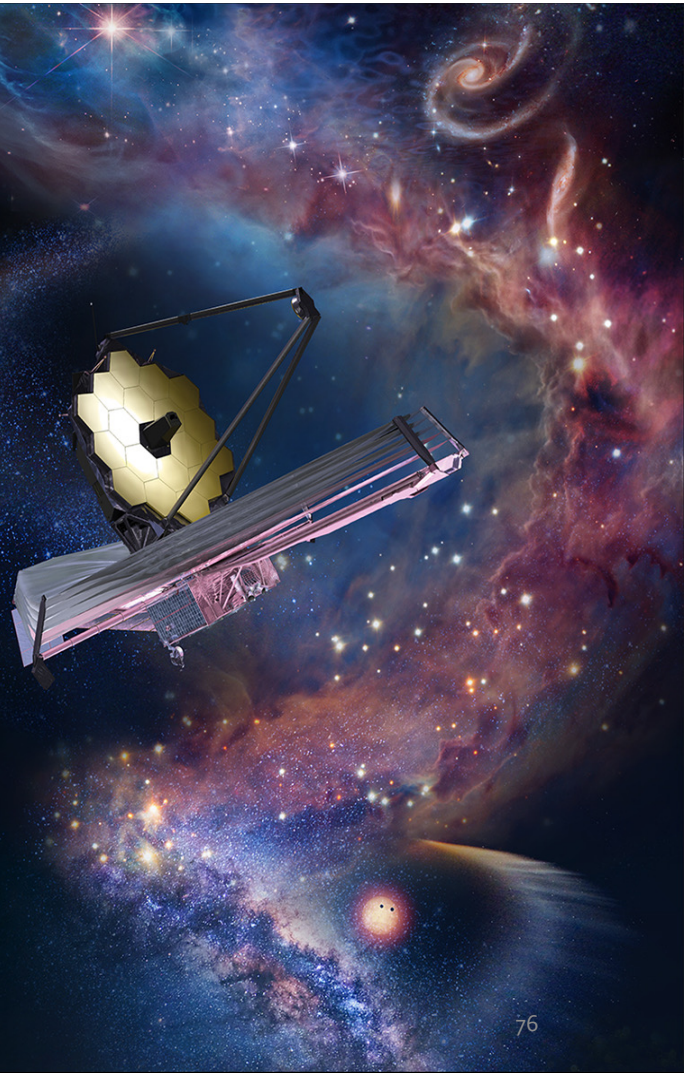
svs.gsfc.nasa.gov



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