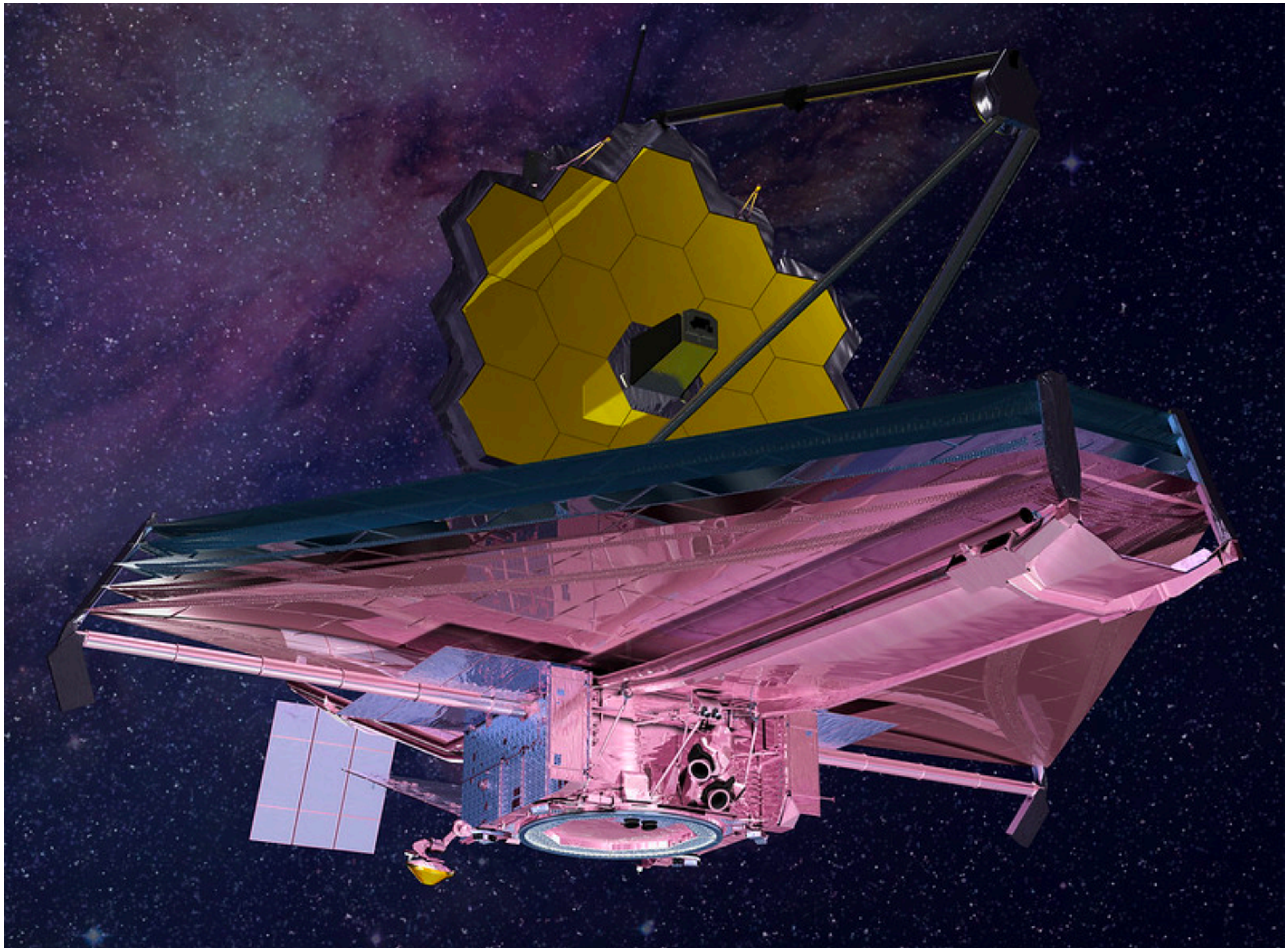
A Million Miles Toward Midnight

The James Webb Space Telescope

Richard Edgar, for the Learners Science Sampler course, March 3, 2022

- NASA / ESA / Canadian
- Newest Space Telescope
- Launched Christmas 2021



Outline

- Who am I? An introduction to today's speaker.
- Why go to space? (With some background on physics and astronomy)
- Major research areas: Cosmology and Exoplanets
- What drove the design? Engineering marvels to create good science
- History of space telescopes
- Comparison to Hubble
- The Lagrange point #2: the orbit of JWST
- What can we do with it?

Who am I, anyway?

- BA, Math/Physics, CU-Boulder
- MS, PhD, Physics, University of Wisconsin—Madison
- 8 years working on the Diffuse X-ray Spectrometer, which flew on the Space Shuttle in January 1993
- 24 years working on the Chandra X-ray Observatory, a Hubble-class satellite launched in 1999 that a does x-rays instead of visible light (like the Hubble).
- I worked for the Smithsonian Astrophysical Observatory, in Cambridge MA, under contract with NASA
- Retired 2019, moved to Wind Crest
- Other interests include choral music, writing speculative fiction

The Advertisement

Necessary Lies

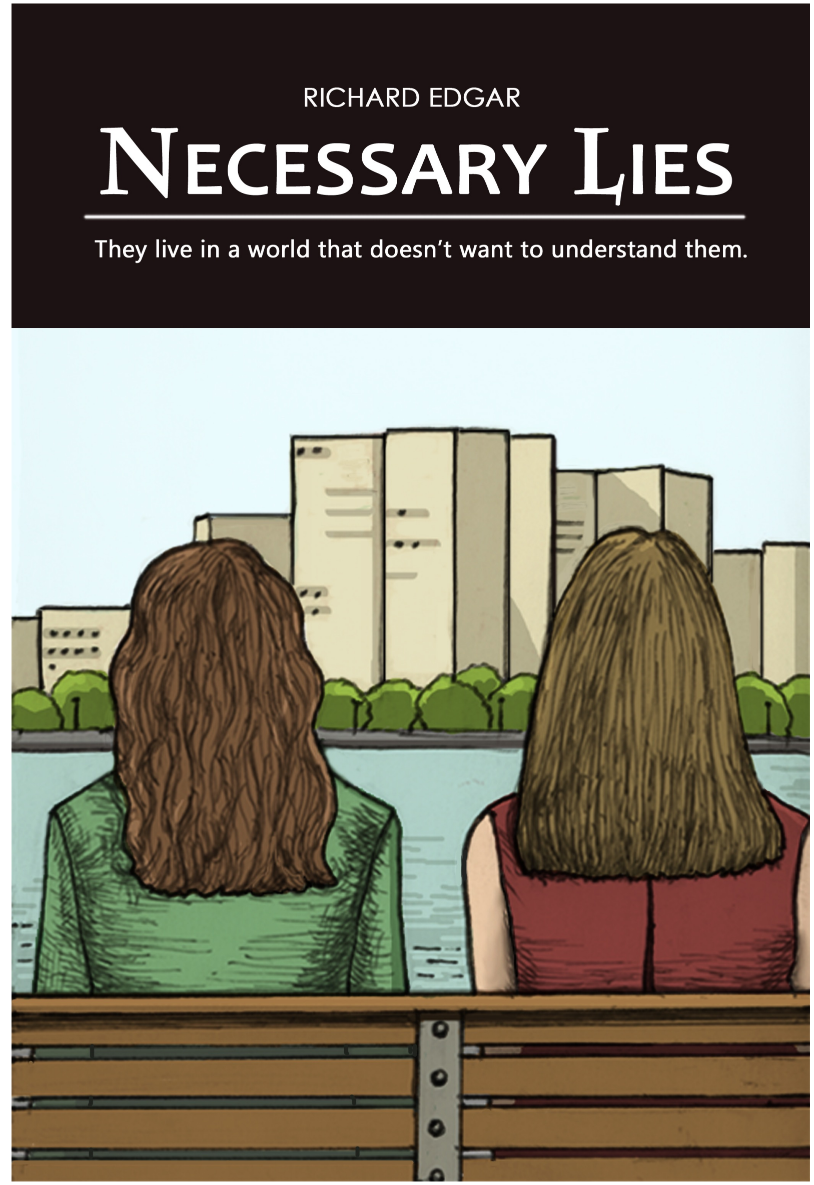
Richard Edgar

What if they told you you could never have children?
But maybe there's a way…

What if your marriage is only valid on one side of the river, and the kid is in an accident on the other side?

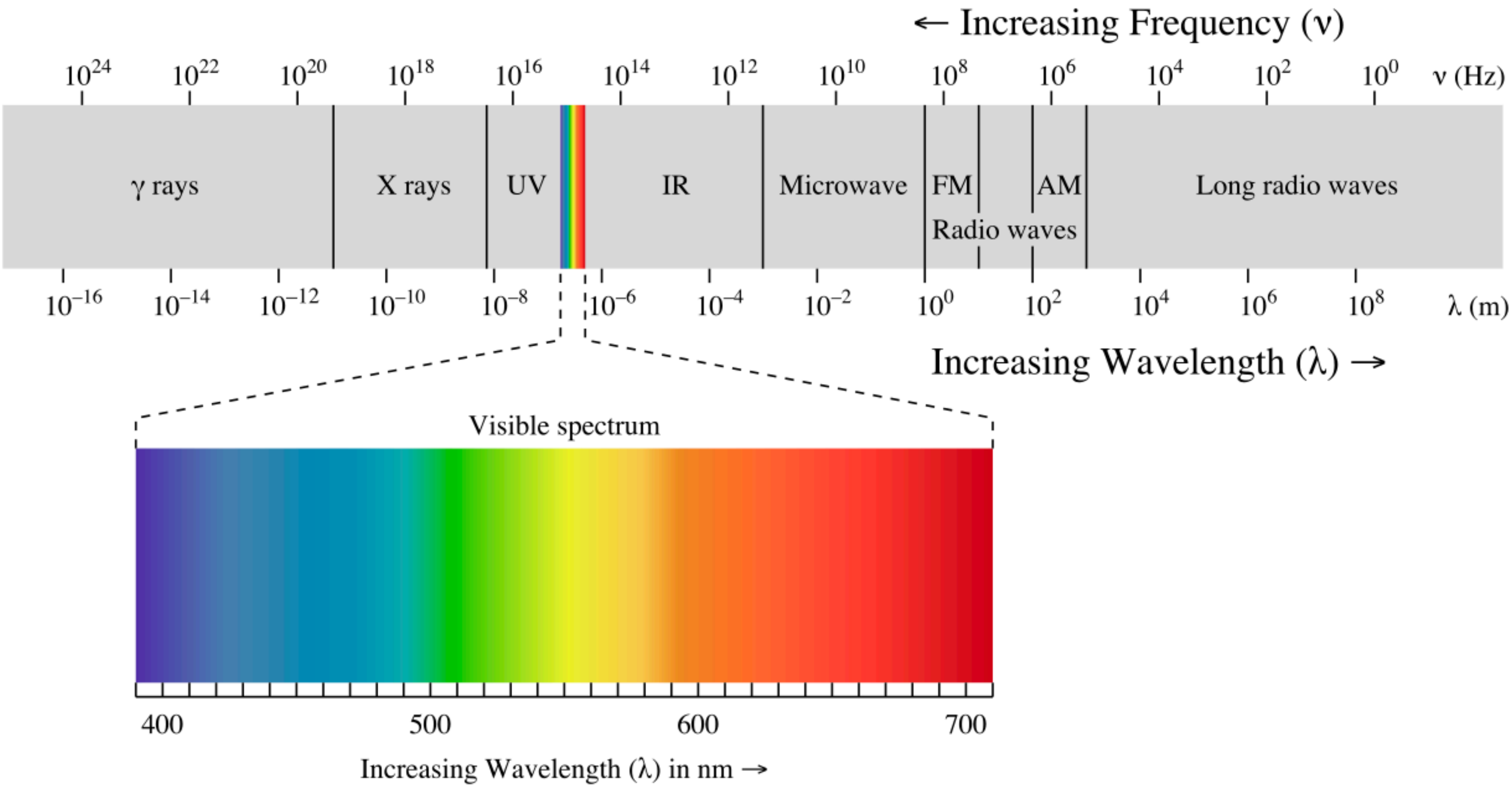
Work hard, do your homework, cheat a little when you have to.

Available now on Amazon



Let there be Light

- We do astronomy (almost exclusively) by detecting light or other electromagnetic radiation sent to us by distant objects.
- Light is a wave in the electric and magnetic fields. The waves travel (in vacuum) at 3×10^8 meters/second (186,000 miles/second, or about a billion feet per second).
- Visible light has wavelengths between 400 and 700 nanometers, or 4 and 7×10^{-7} meters.
- That's just one octave (factor of two) in a very very long piano keyboard.
- Wavelength (meters per wave) times frequency (waves per second) gives the speed of light (meters per second)
- Light sometimes acts like a stream of particles called *photons*, each with an energy given by Planck's constant times the frequency of the wave.


← Increasing Frequency (ν)
10^{24} 10^{22} 10^{20} 10^{18} 10^{16} 10^{14} 10^{12} 10^{10} 10^{8} 10^{6} 10^{4} 10^{2} 10^{0} ν (Hz)
γ rays
X rays
UV
IR
Microwave
FM
AM
Radio waves
Long radio waves
10^{-16} 10^{-14} 10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2} 10^{4} 10^{6} 10^{8} λ (m)
Increasing Wavelength (λ) →
Visible spectrum
400
500
600
700
Increasing Wavelength (λ) in nm →

Light, continued

- Every kind of atom, ion, molecule, etc. has favorite wavelengths of light it likes to emit and absorb. We can exploit this to find out what astronomical objects are made of.
- Objects also emit because they’re warm (mostly in the infrared part of the spectrum unless they’re hot, like stars, flames, etc.)
- The wave nature of light means it spreads out if you force it through a hole such as a telescope aperture. The finest objects you can see depend on the ratio of aperture size to wavelength.

- We can learn a lot by sorting incoming light into bins according to the wavelength, to form a *Spectrum*. We do this with instruments called *Spectrographs*.

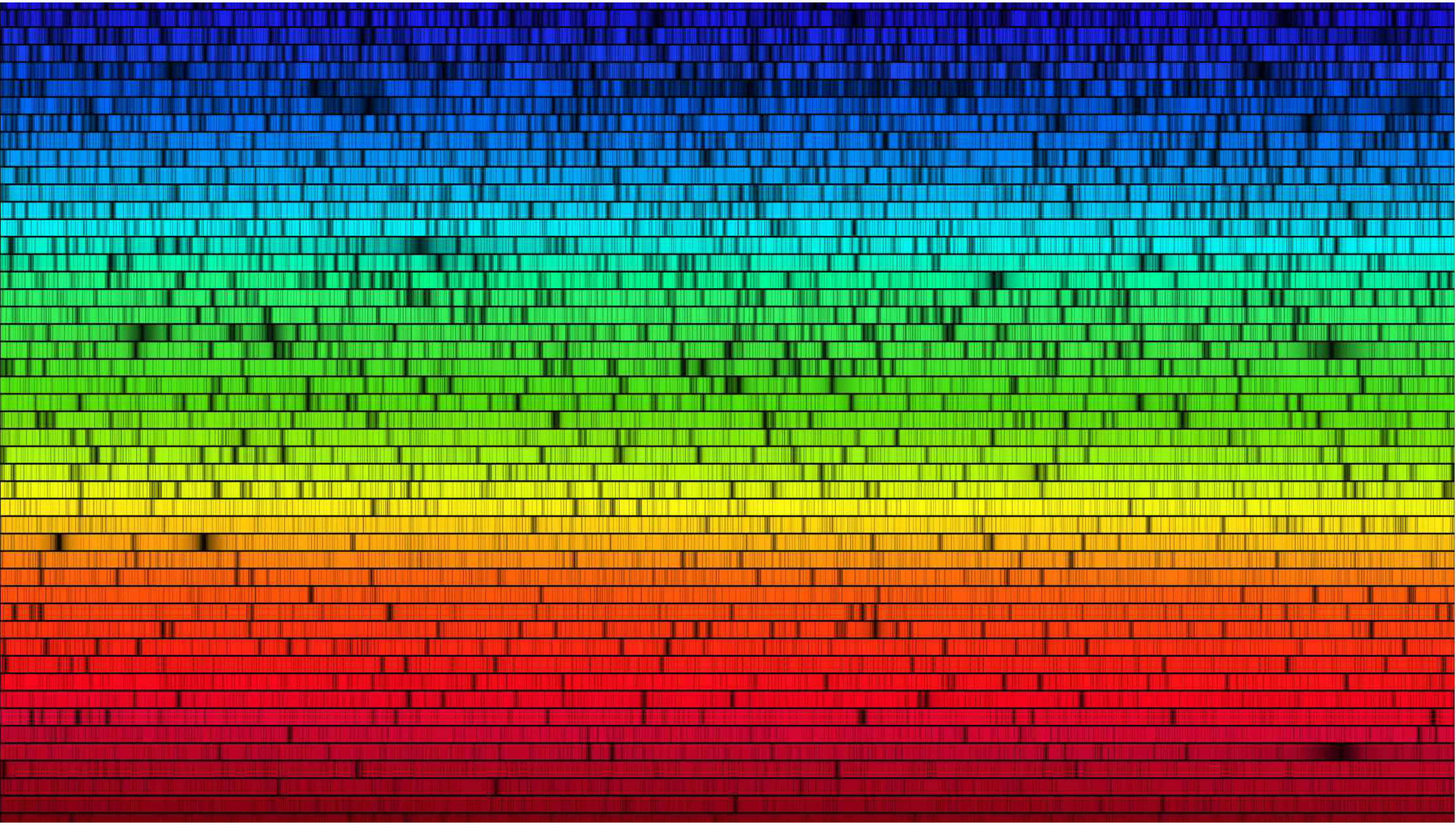
- Composition: what elements, ions, molecules make up the source

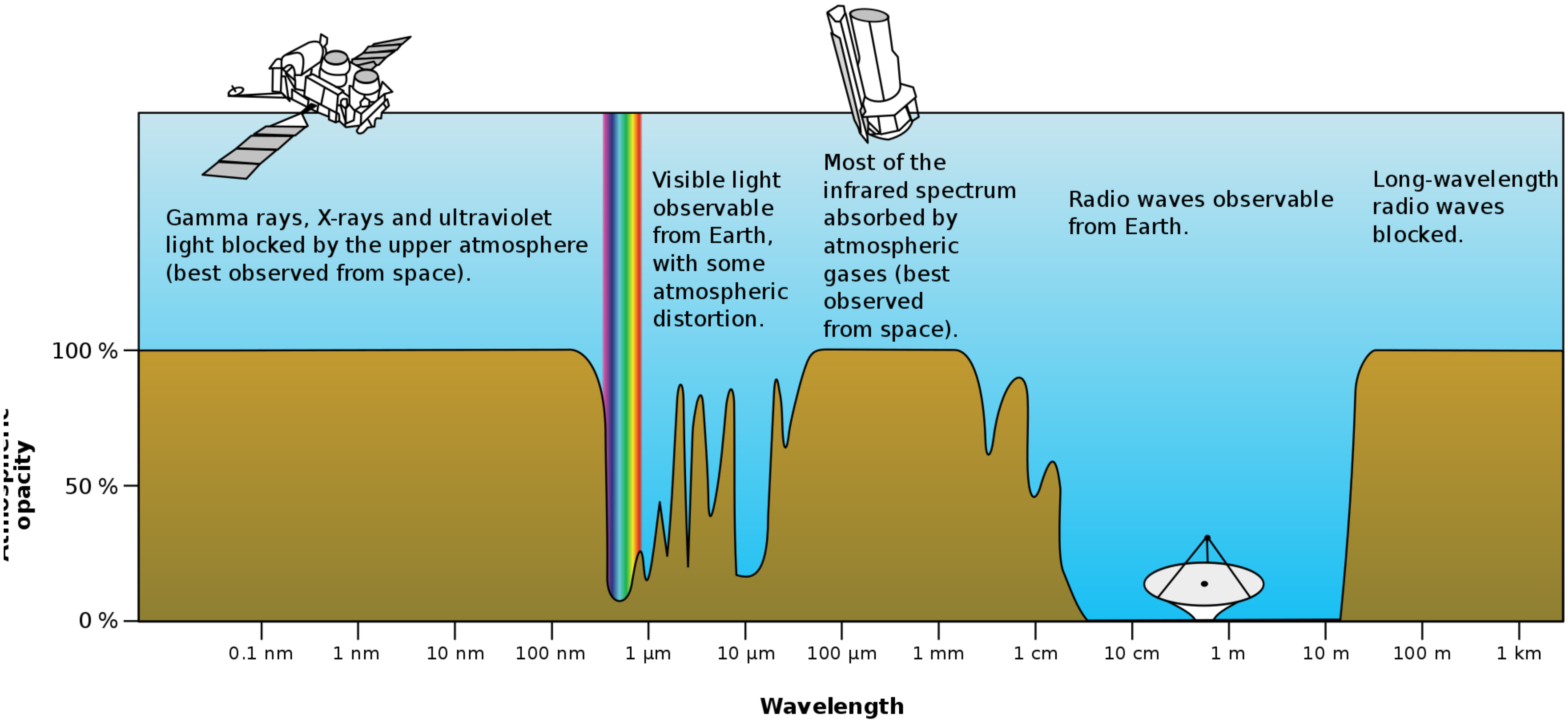
- Physical conditions such as temperature, density, etc.

- Velocity of the object toward or away from the observer. Light shifts toward the long wavelength end of the spectrum when the source is moving away from the observer. This is called *Redshift*. (If it's approaching us, we see a *Blueshift*.)

- We can see absorption from stuff along the line of sight.

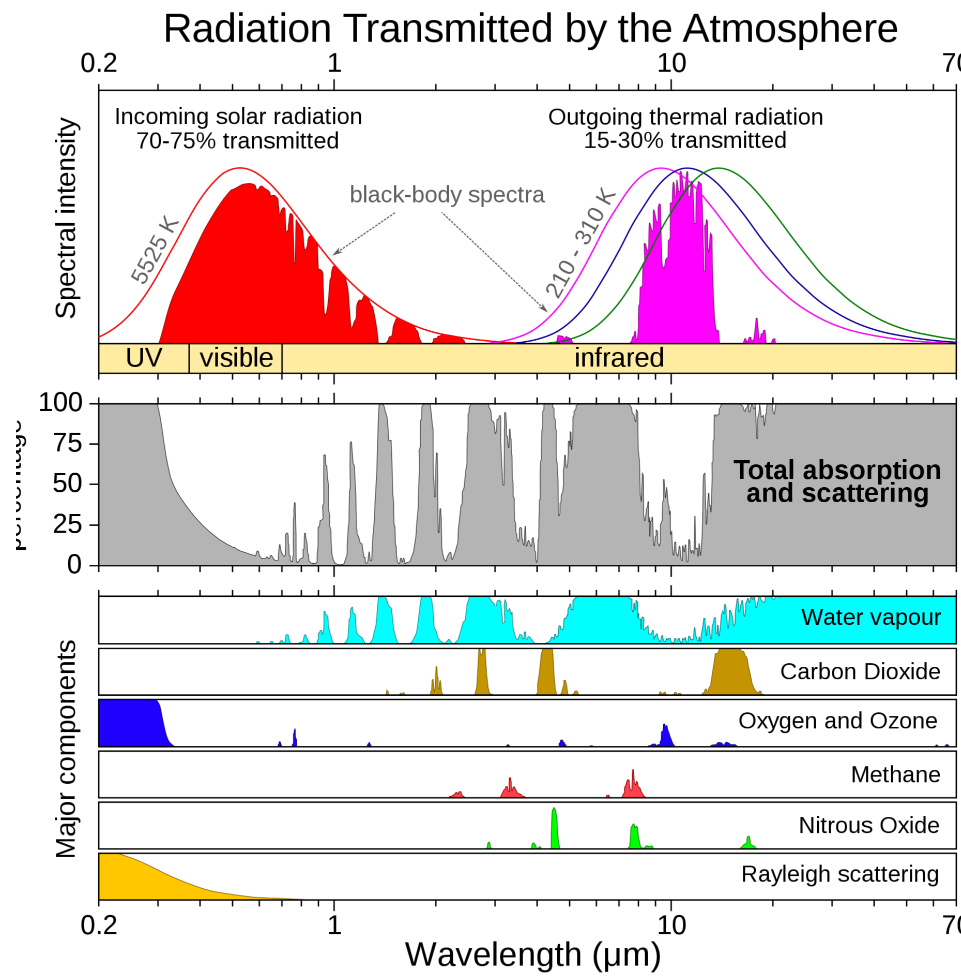
- Next slide: the spectrum of the sun (Thanks to Bob Kurucz, SAO).





- Why space? The atmosphere is opaque at many wavelengths
- The atmosphere also smears images (“seeing”).

- Another version of the atmosphere's effects on astronomy.
- Smooth curves are the spectrum of the sun (above the atmosphere) and outgoing thermal radiation from earth.
- Note water vapor & CO2 block parts of the IR band.
- JWST is cooled to get its thermal emission out of the near/mid IR (shoved to the right).

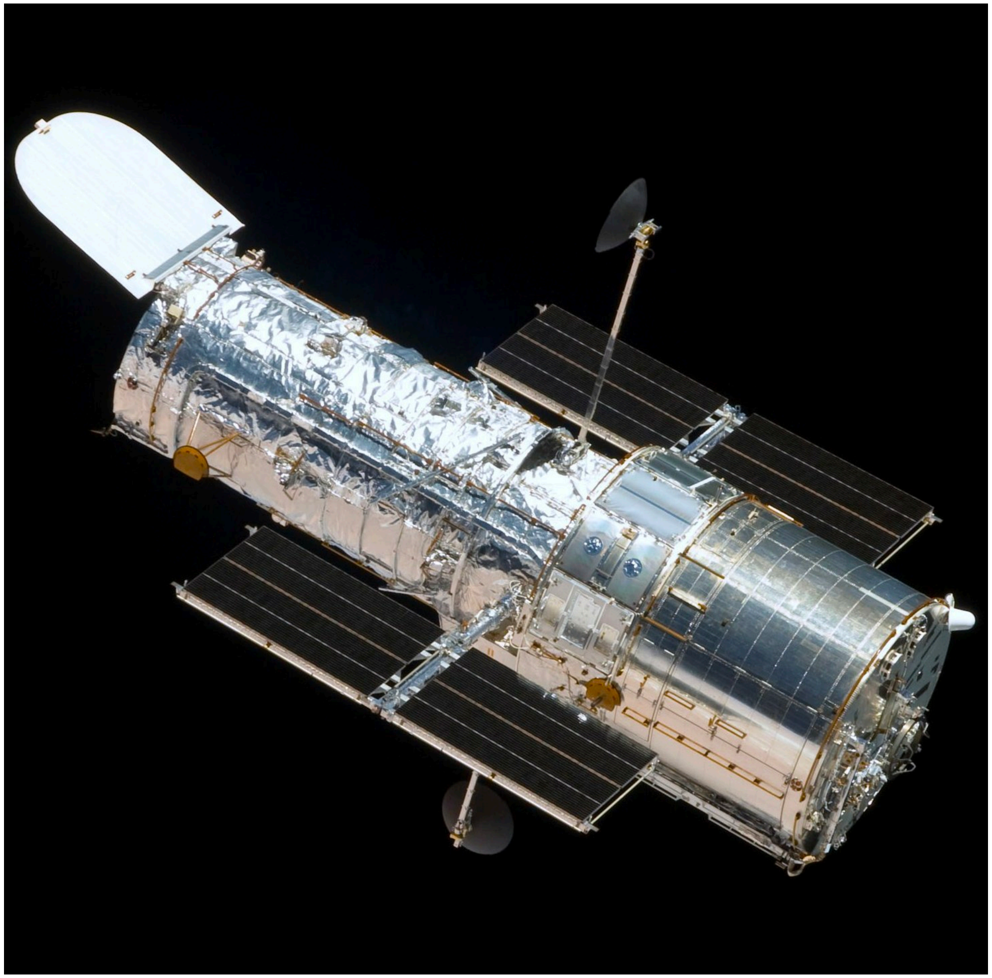


Why the infrared?

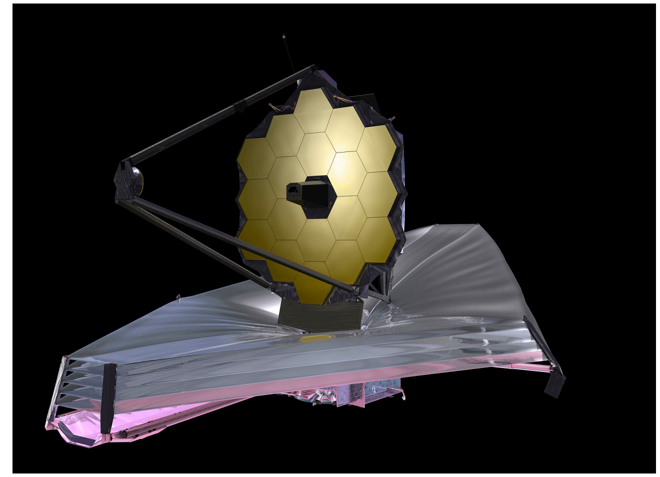
- JWST is optimized for infrared astronomy, for a few main reasons.
- Galaxies and quasars in the early universe emitted light often in the ultraviolet, but it's been redshifted in transit as the universe expands, so many interesting spectral features are now in the infrared. Wavelengths are often stretched by factors of five to ten.
- Planets around nearby stars are very faint compared to their stars. The contrast is much less in the infrared.
- Molecules have their spectral features in the infrared.
- Infrared light can pass through dust along the line of sight.

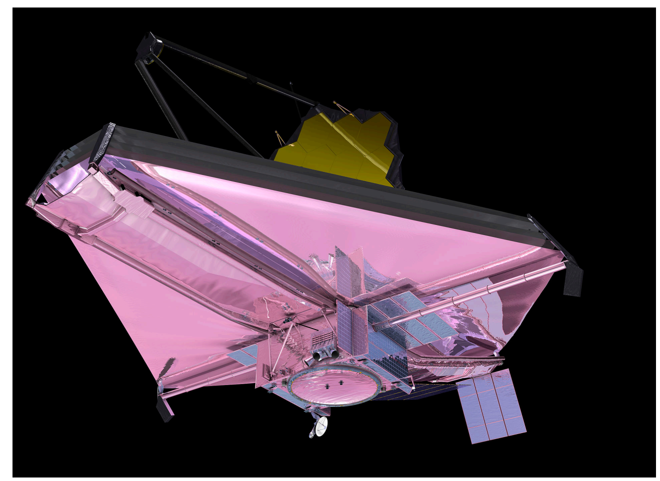
Hubble Space Telescope

- Launched 1990 from Space Shuttle into low earth orbit.
- Covers UV, Visible, near IR
- Designed to be serviced by shuttle astronauts
- Low orbit means the earth is in the field of view ~40% of time



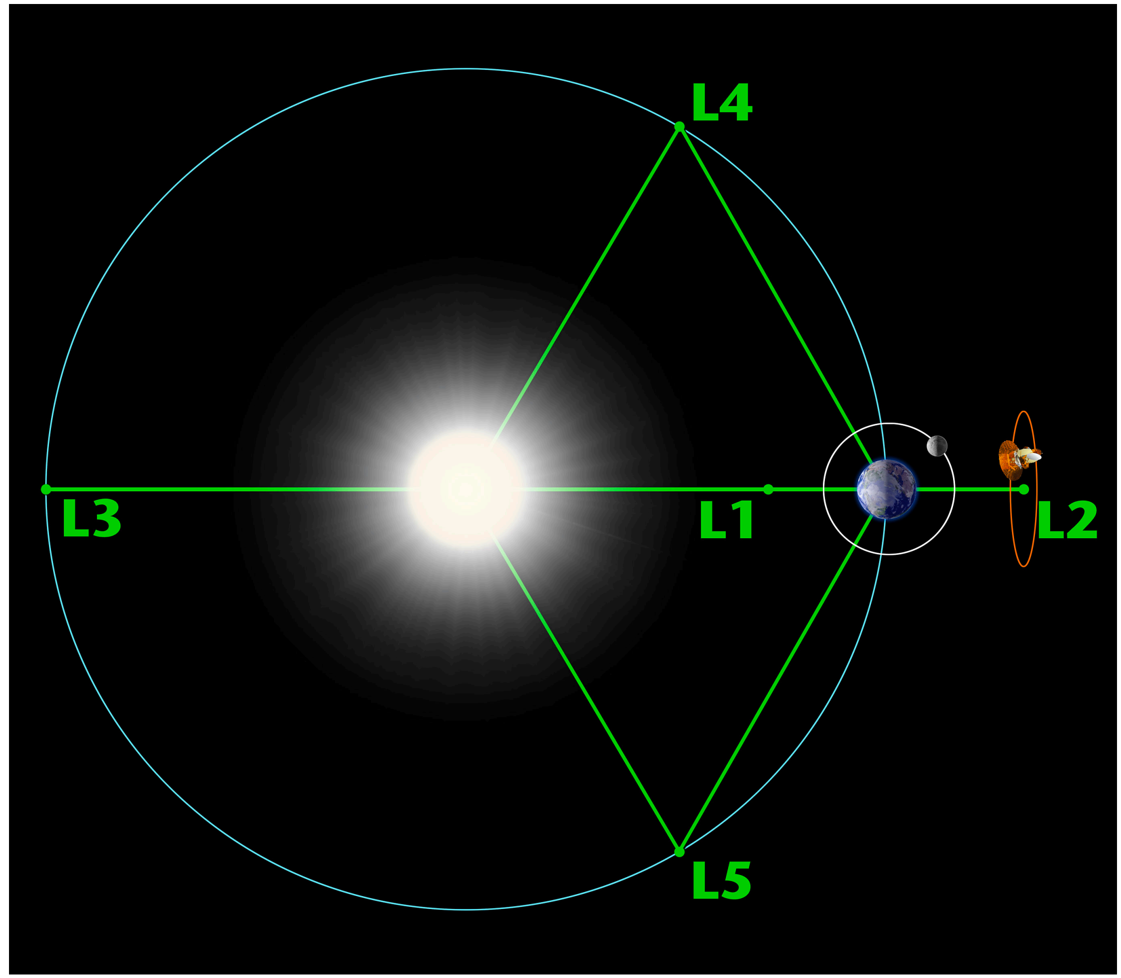
- In the early 1990s after HST was launched, astronomers started thinking about the design of a Next Generation Space Telescope (then called NGST).
- Some engineers & scientists have been working at least part-time on this project all their careers.
- To cover near- to mid-IR (0.6 to 27 μm wavelengths)
- Many new technologies were needed
- Telescope & instruments need to be very cold, because warm objects glow brightly in the infrared.
- Heat loads from being near the warm earth are a problem for some other spacecraft, so put it far from the earth
- But not too far because data link bandwidth would suffer.



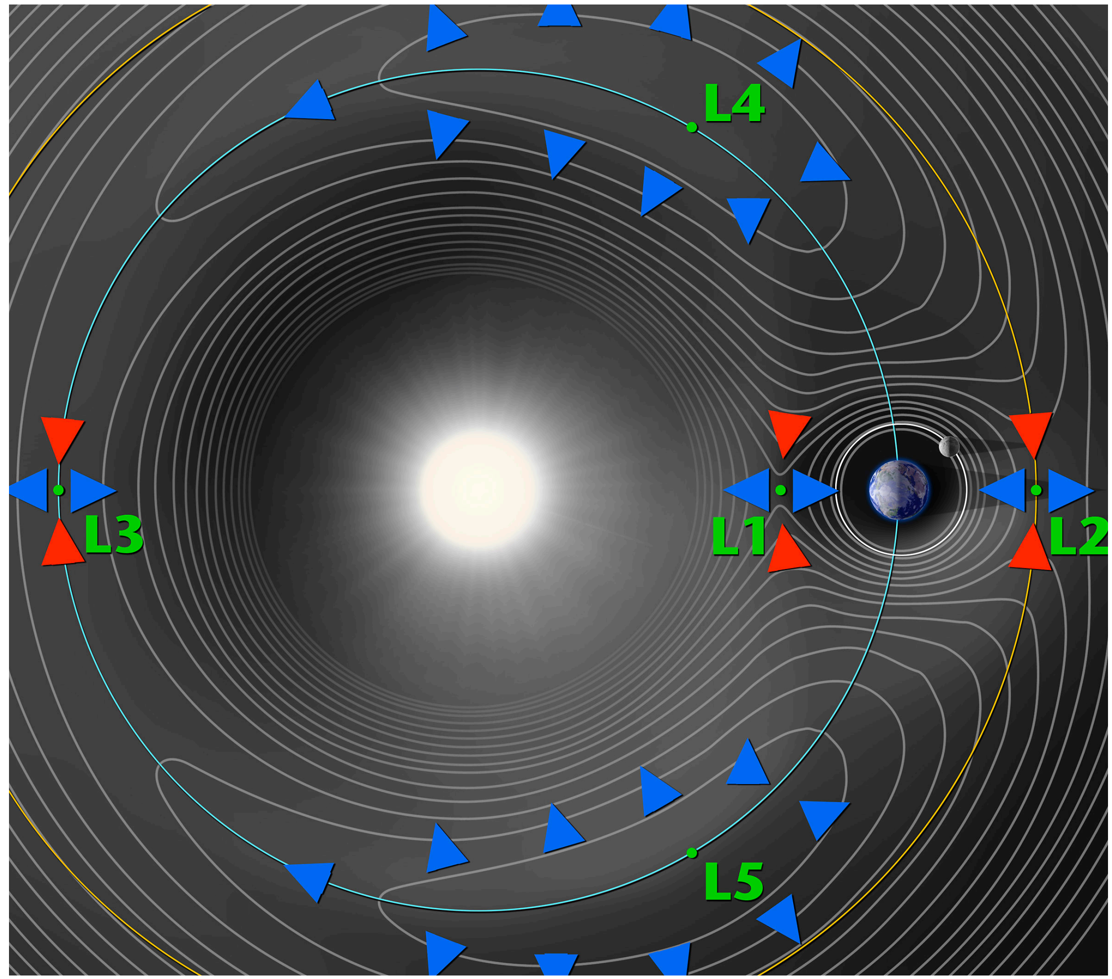


Lagrange Points

- Josephy-Louis Lagrange figured them out in 1772.
- Gravity of the sun & earth balance the centrifugal force at 5 locations.
- JWST is in a halo orbit around L2
- Sun-observing craft are near L1
- Diagram not to scale.
- earth-L2 is about a million miles, or 1% of the sun-earth distance.



- Contours show the effective potential energy (sun + earth + centrifugal).
- The centrifugal force results from the fact that the coordinate system is rotating.
- This lets us think of the sun and earth being at rest.

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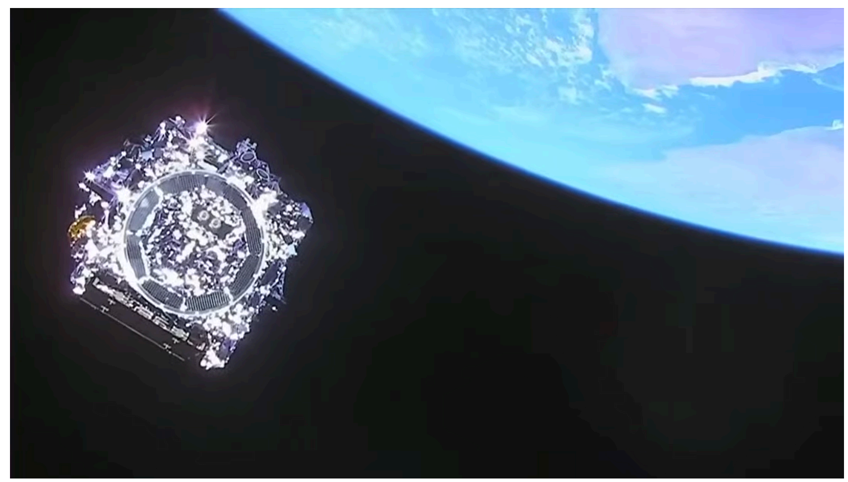
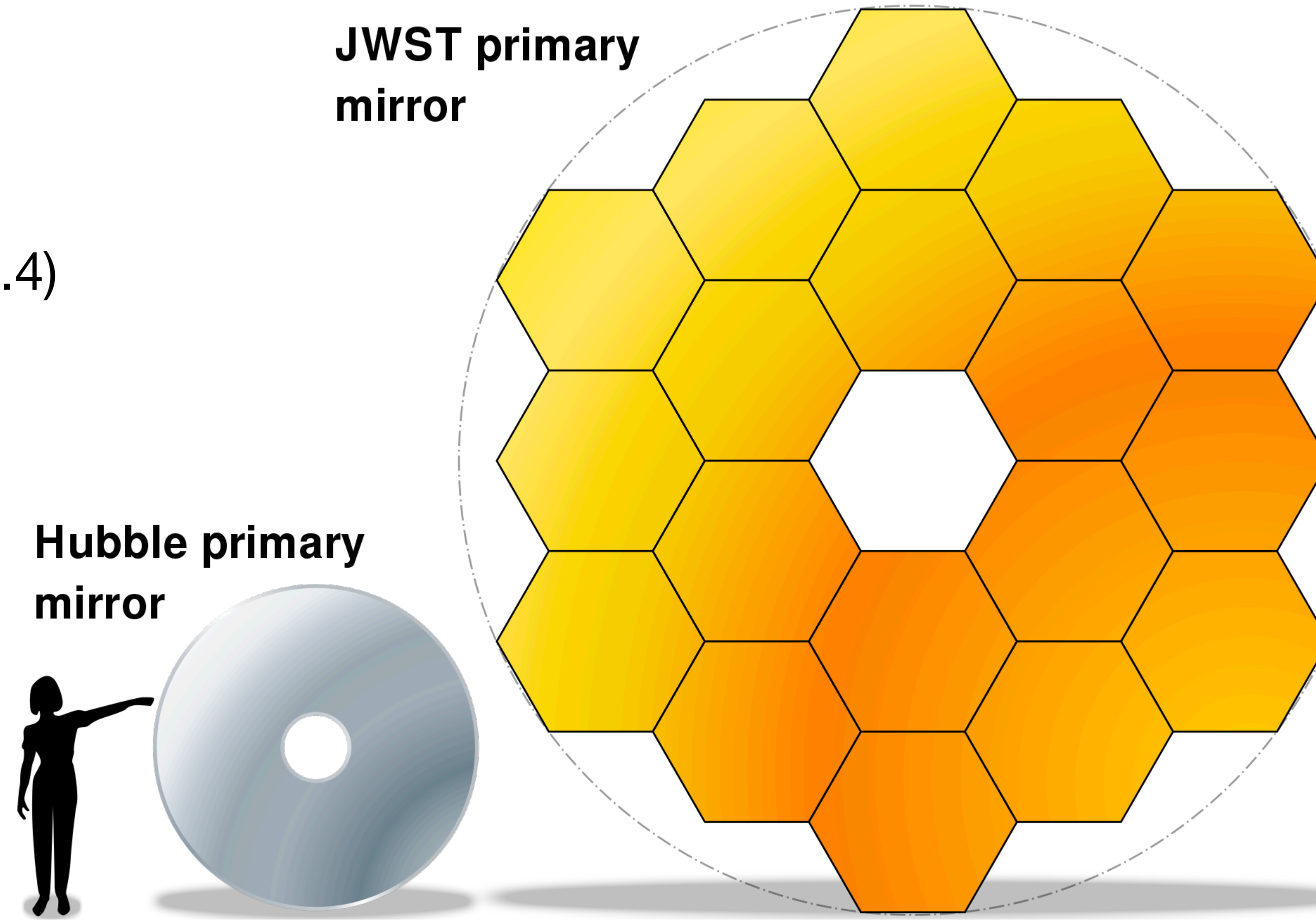


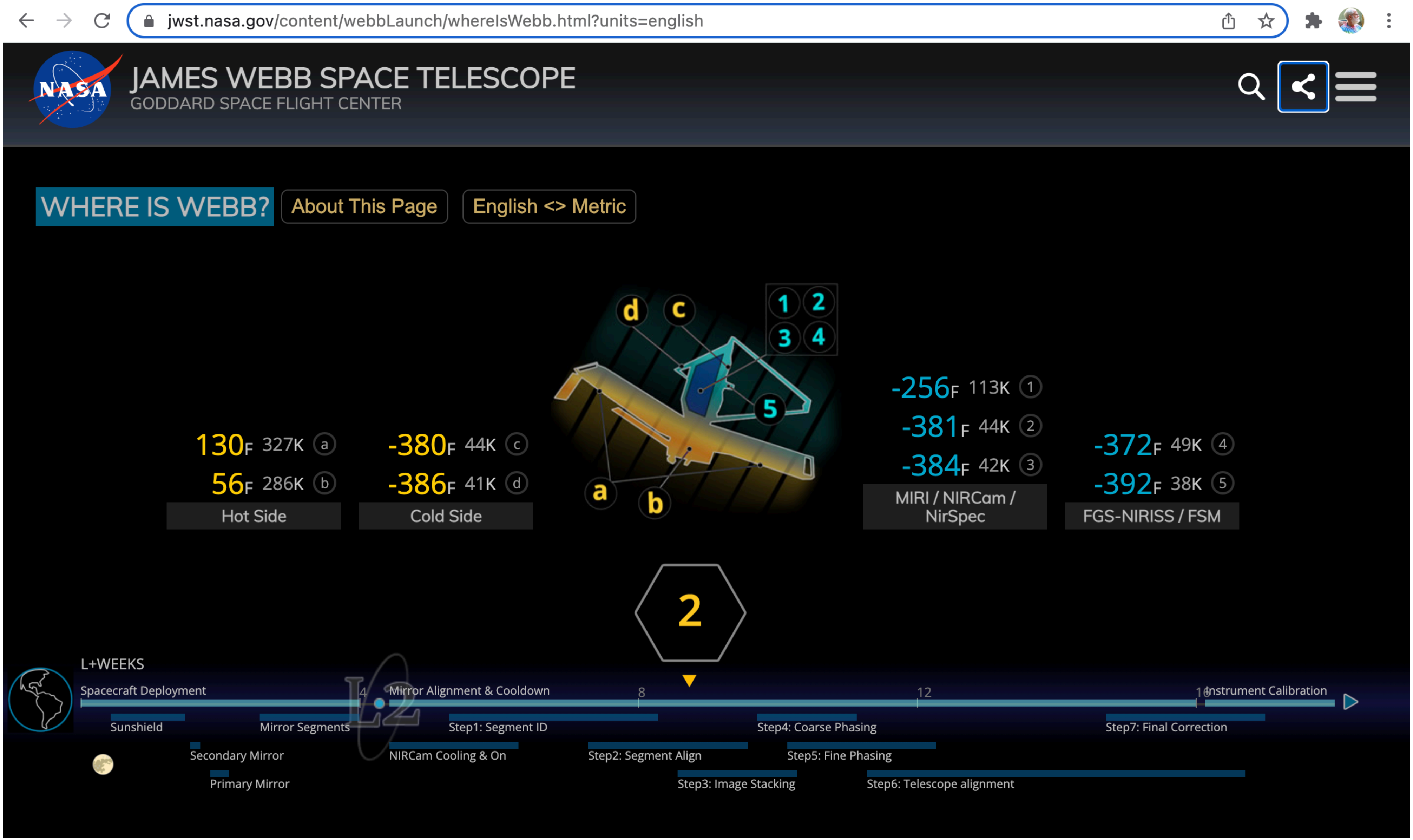
Folded for launch

- JWST had to be folded up to fit in the rocket payload fairing.
- Many single-point risks were retired in the first few weeks after launch, as everything unfolded successfully.
- Spacecraft bus at bottom, sunshades folded L & R, one wing (3 segments) of mirror.

Optical system

- 6.5 meters wide (vs. HST 2.4)
- 18 hexagonal segments
- Beryllium coated in gold
- Be has excellent thermal properties at low temps & lightweight



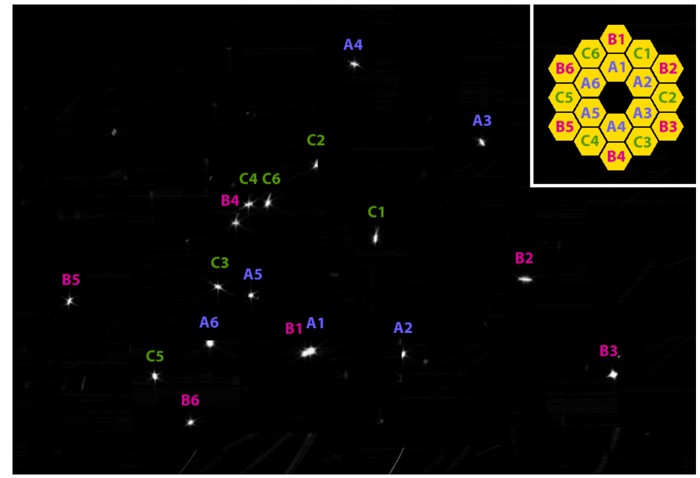


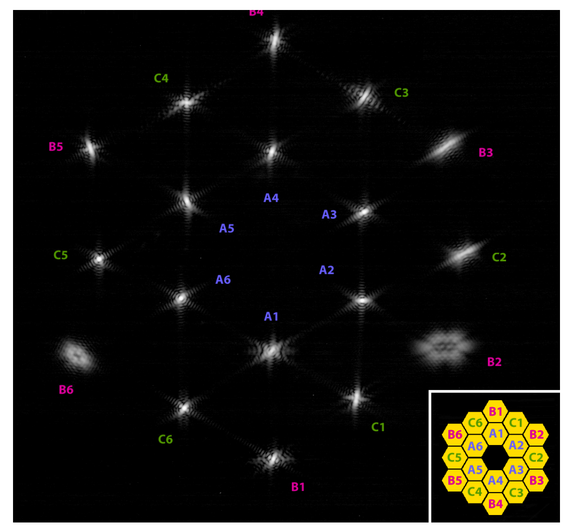
jwst.nasa.gov/content/webbLaunch/whereIsWebb.html?units=english
NASA
JAMES WEBB SPACE TELESCOPE
GODDARD SPACE FLIGHT CENTER
WHERE IS WEBB?
About This Page
English <> Metric
130F 327K a
56F 286K b
Hot Side
-380F 44K c
-386F 41K d
Cold Side
d c 1 2 3 4 5 a b
-256F 113K 1
-381F 44K 2
-384F 42K 3
MIRI / NIRCam / NirSpec
-372F 49K 4
-392F 38K 5
FGS-NIRISS / FSM
2
L+WEEKS
Spacecraft Deployment
4
Mirror Alignment & Cooldown
8
12
16
Instrument Calibration
L2
Sunshield
Mirror Segments
Step1: Segment ID
Step4: Coarse Phasing
Step7: Final Correction
Secondary Mirror
NIRCam Cooling & On
Step2: Segment Align
Step5: Fine Phasing
Primary Mirror
Step3: Image Stacking
Step6: Telescope alignment

Now playing… Optical alignment and focusing

- Watch progress at jwst.nasa.gov/content/webbLaunch/whereIsWebb
- When the NIRCam instrument got cold enough, JWST was pointed at an isolated sun-like star in Ursa Major. First image showed 18 different images, one from each of the mirror segments, as expected.
- Mirror segments were tilted & tipped to arrange them and figure out which image came from which mirror.
- A mirror “selfie” was taken with a special lens in the NIRcam instrument.
- Further focus & making the images into one will occupy the next month or two.
- The Canadian star tracker is now active.


PRIMARY MIRROR SELFIE


A4
A3
C2
C4 C6
B4
C1
B2
B5
C3
A5
A6
B1 A1
A2
B3
C5
B6
B1
C6 C1
B6 A1 B2
A6 A2
C5 C2
A5 A3
B5 A4 B3
C4 C3
B4


B4
C4
C3
B5
B3
A4
A3
A5
C5
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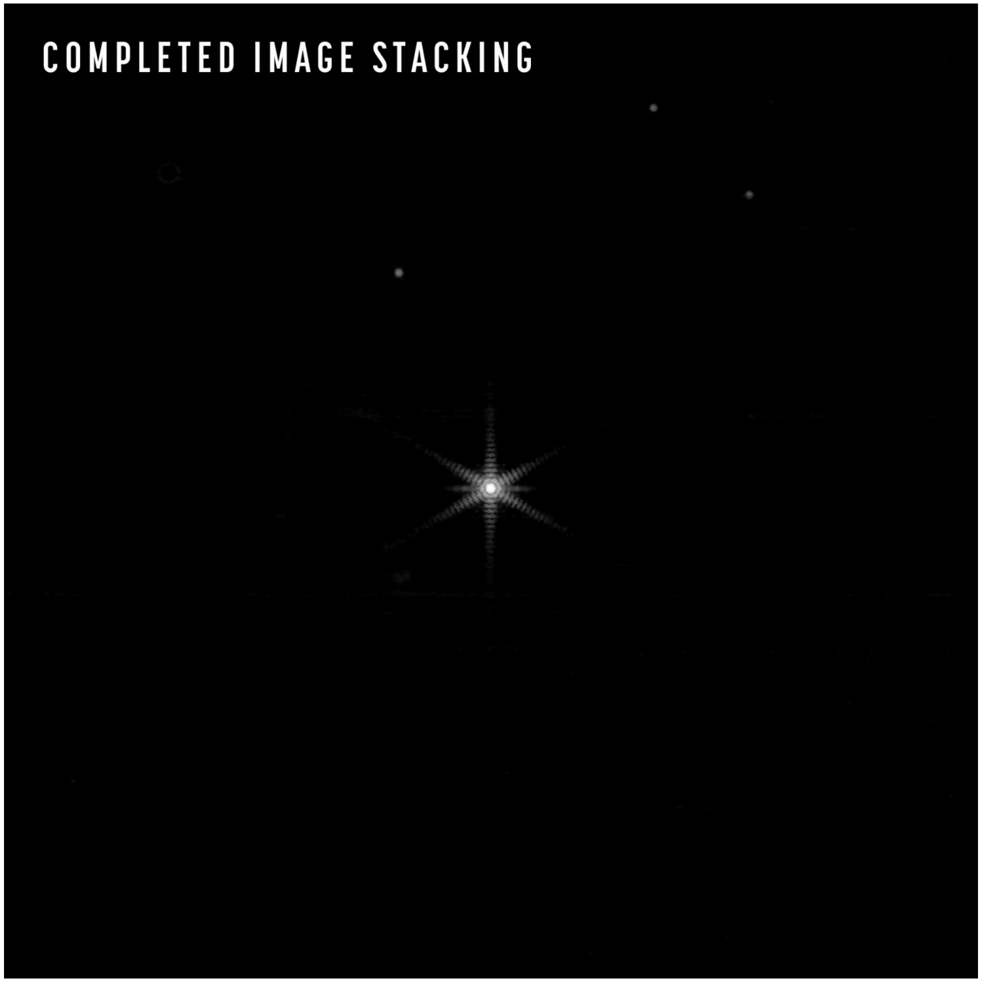
A6 A2
C5 C2
A5 A3
B5 A4 B3
C4 C3
B4


COMPLETED IMAGE STACKING

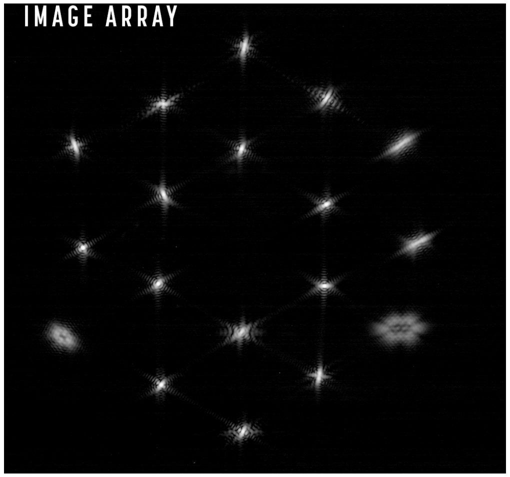
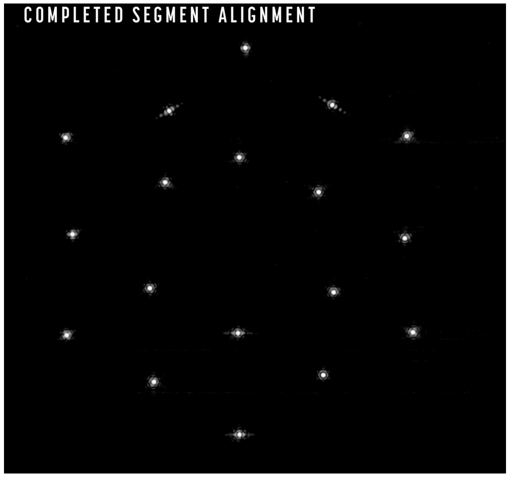
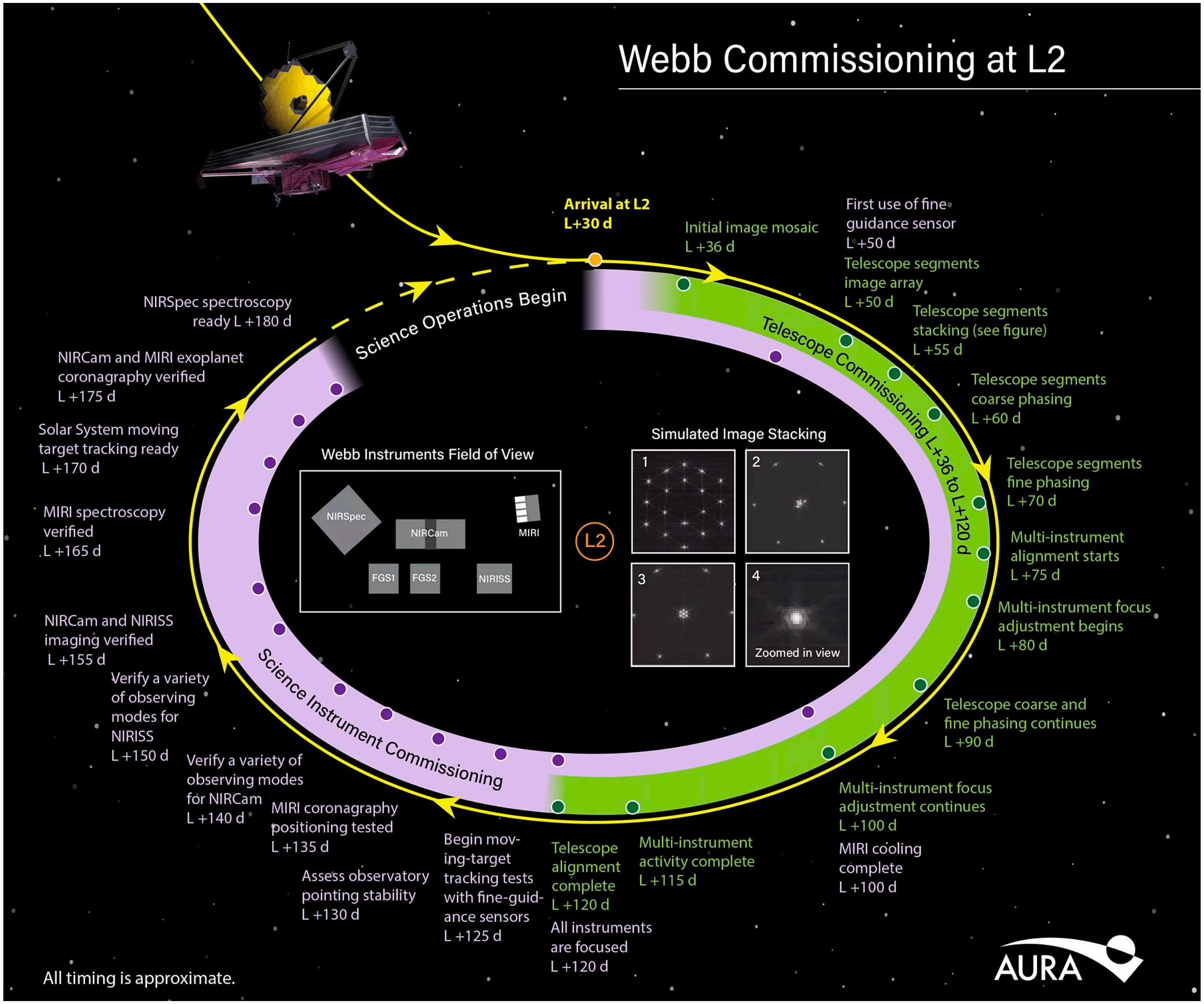


IMAGE ARRAY


COMPLETED SEGMENT ALIGNMENT



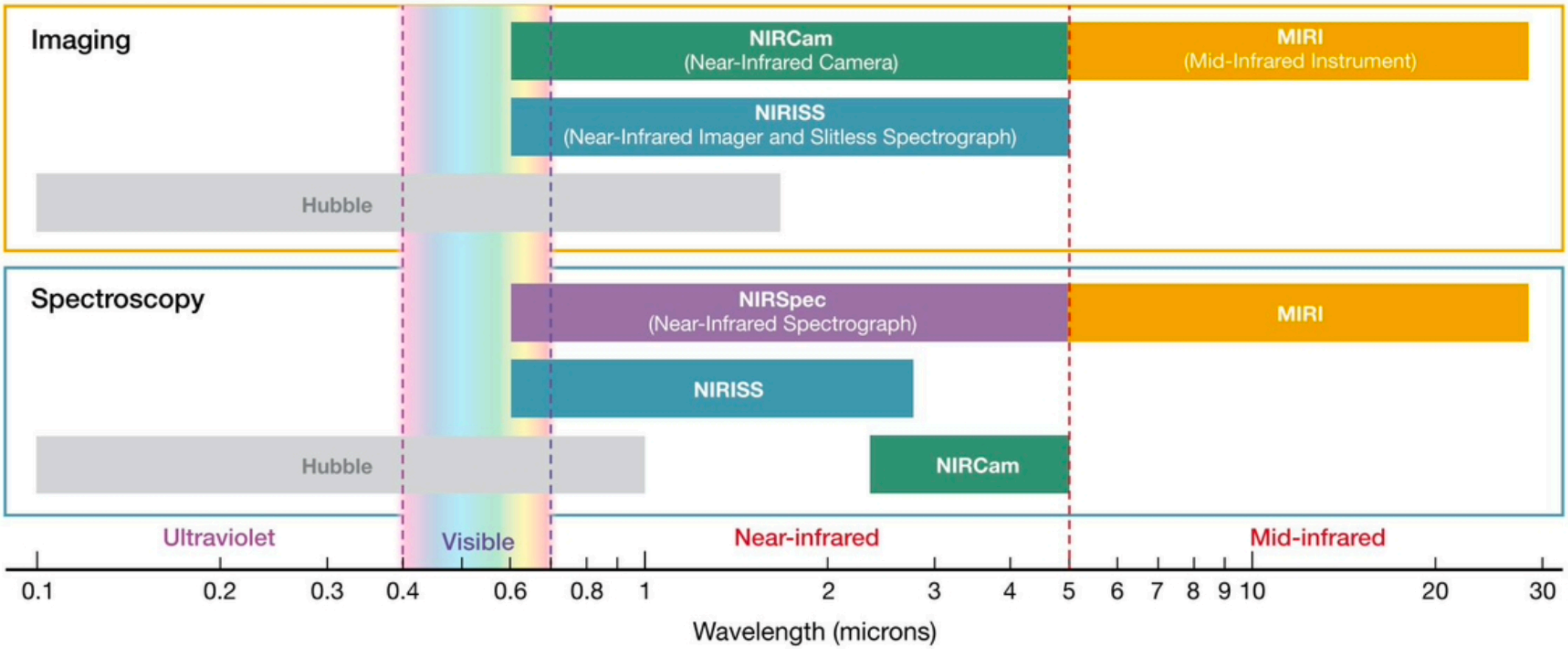
Webb Commissioning at L2
Arrival at L2
L+30 d
Initial image mosaic
L +36 d
First use of fine guidance sensor
L +50 d
Telescope segments image array
L +50 d
Telescope segments stacking (see figure)
L +55 d
Telescope segments coarse phasing
L +60 d
Telescope segments fine phasing
L +70 d
Multi-instrument alignment starts
L +75 d
Multi-instrument focus adjustment begins
L +80 d
Telescope coarse and fine phasing continues
L +90 d
Multi-instrument focus adjustment continues
L +100 d
MIRI cooling complete
L +100 d
Multi-instrument activity complete
L +115 d
Telescope alignment complete
L +120 d
All instruments are focused
L +120 d
Begin moving-target tracking tests with fine-guidance sensors
L +125 d
Assess observatory pointing stability
L +130 d
MIRI coronagraphy positioning tested
L +135 d
Verify a variety of observing modes for NIRCam
L +140 d
Verify a variety of observing modes for NIRISS
L +150 d
NIRCam and NIRISS imaging verified
L +155 d
MIRI spectroscopy verified
L +165 d
Solar System moving target tracking ready
L +170 d
NIRCam and MIRI exoplanet coronagraphy verified
L +175 d
NIRSpec spectroscopy ready L +180 d
Science Operations Begin
Telescope Commissioning L+36 to L+120 d
Science Instrument Commissioning
L2
Webb Instruments Field of View
NIRSpec
NIRCam
MIRI
FGS1
FGS2
NIRISS
Simulated Image Stacking
1
2
3
4
Zoomed in view
All timing is approximate.
AURA

Vital statistics

- Mass: 6165 kg = 13,580 lb
- Sunshield: 20 x 14 m = 66 x 46 feet
  5 layers of aluminized Kapton plastic, separated by about a foot.
  Each one lowers the temp by about 100 degrees F.
- Prime contractor: Northrup Grumman Space Technologies (NGST), formerly TRW, with help from Harris and Ball Aerospace.
- Power: 2 kW
- Launched: 25 December 2021. Arrived L2: late Jan 2022.
  Commissioning finished: June 2022.
- Budget: $11bn
- James Webb was NASA Administrator in the Apollo years.

Instruments

- NIRCam: Near Infrared Camera: imaging 0.6—5 μm
- NIRSpec: Near Infrared Spectrograph: high-res spectra
- FGS/NIRISS: Fine Guidance Sensor and Near Infrared Imager and Slitless Spectrograph
- MIRI: Mid Infrared Instrument: Imaging and spectroscopy 5—27 μm. Includes a cryo-cooler to make it very cold.

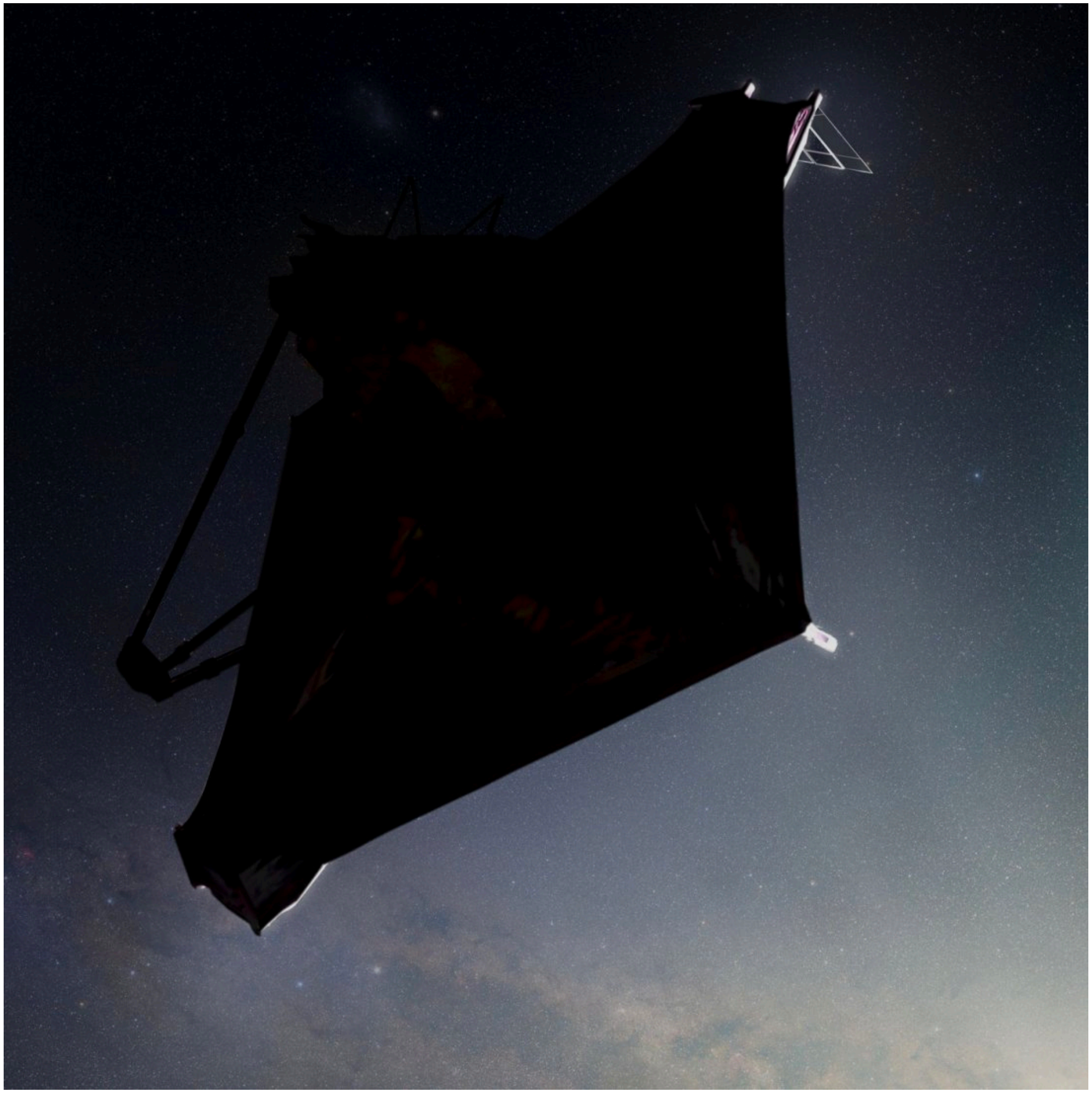


MIRRORS: CHRIS GUNN / NASA; INFRARED: LEAH TISCIONE / S&T, SOURCE: STSCI

Observing with JWST

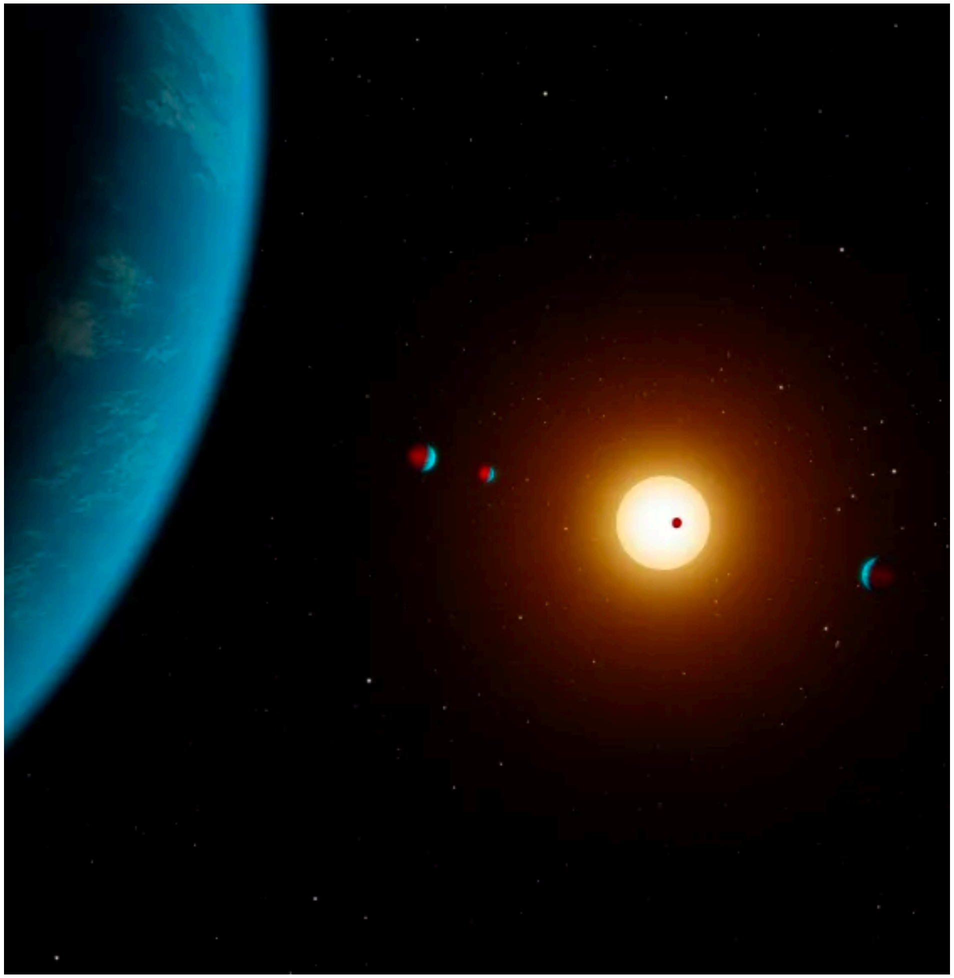
- Cycle 1 covers the first year of guest observer programs, starting summer 2022. Over 1000 proposals were submitted by scientists, 286 were selected.
- Submitted proposals were reviewed by panels of astronomers, ranked, and a cutoff applied when the available time was all allocated.
- Some time was reserved for instrument teams, and director’s discretionary time (for example, a transient source).
- The Space Telescope Science Institute (STScI) in Baltimore, MD implements the observing program, checks technical setups, etc.
- The operations center is also at STScI

Example Observations



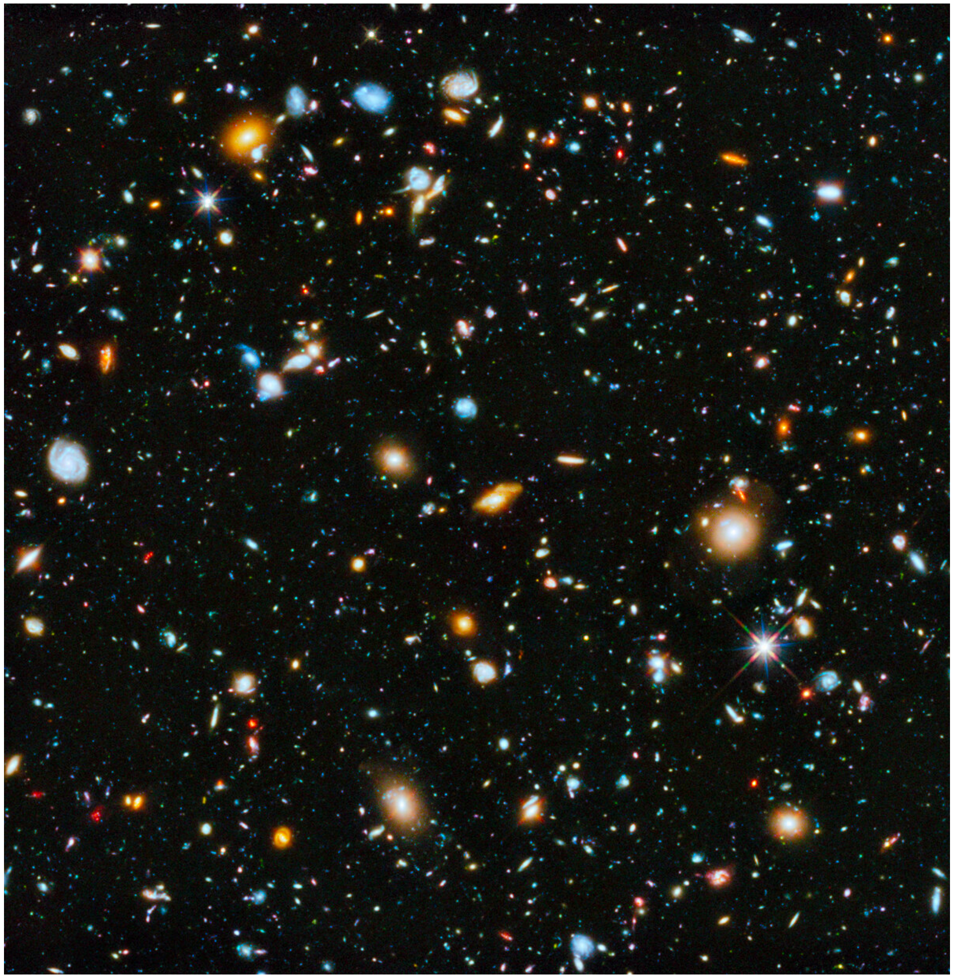
Exoplanets

- Nearly 5,000 planets are known orbiting around other stars.
- By observing at multiple points in a planet's orbit, JWST can see through the atmosphere against the star, or see the glow of the dayside of the planet.
- Compositions of atmosphere, including bio-signature molecules.
- Earth's O_2 is biogenic.



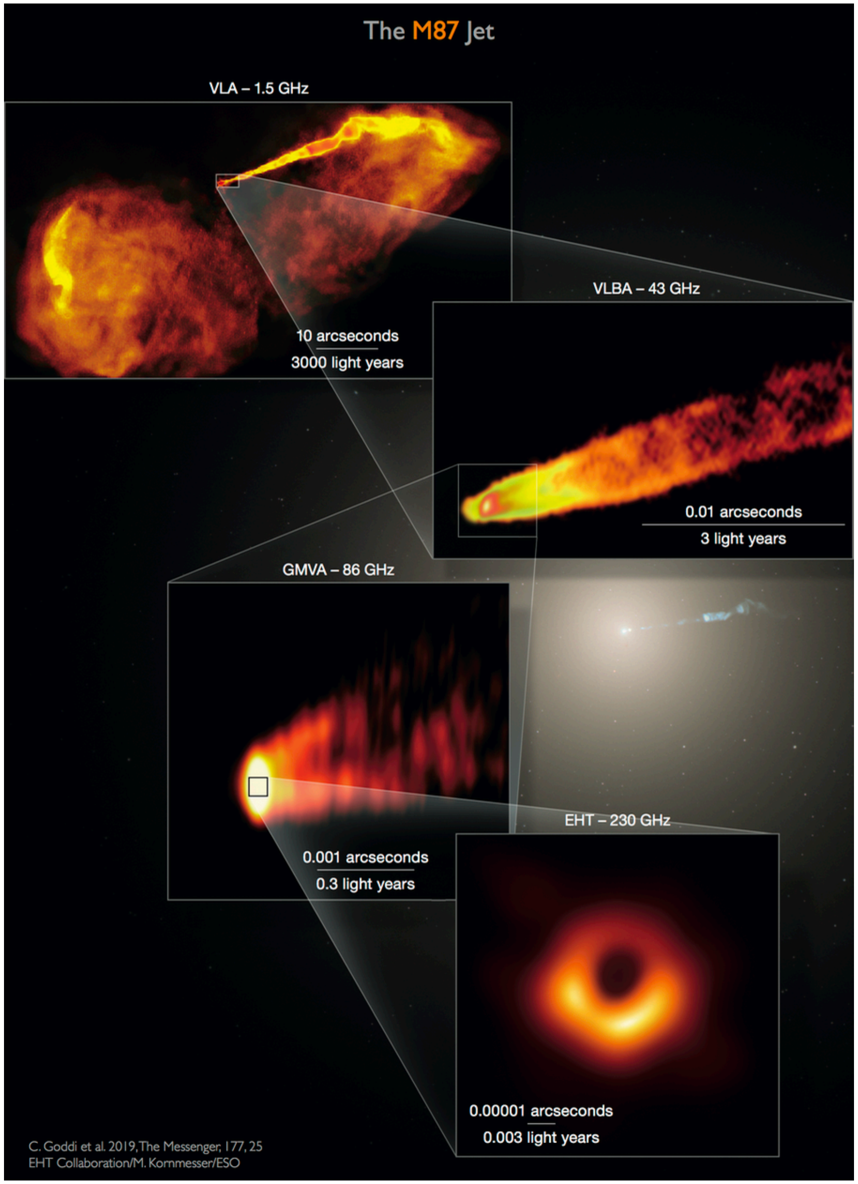
Galaxies

- The universe is 13.6 billion years old. Light from the first galaxies and stars takes nearly that long to get here.
- In the process, its wavelengths get stretched (redshifted) into the infrared.
- What were the first stars like? Galaxies apparently form by merging smaller galaxies.
- Big black holes were already there… how far back do they go?



Black Holes

- Large black holes are common in centers of galaxies.
- Black holes are black, but they're messy eaters and we can look at their dinner plates.
- JWST can see through dust in the environment or sightline (e.g. Milky Way center Sgr A*)
- Here is M-87 in Virgo:



That’s all, folks!

- Questions?
- The slides will be on my website:

  RichardJEdgar.github.io
- There’s lots of info on the NASA blog site:

  https://blogs.nasa.gov/webb/
  https://jwst.nasa.gov/content/webbLaunch/whereIsWebb.html
- I’m in the Wind Crest directory.