The James Webb Space Telescope

The Science Circle / 2022 Jan 22

Syzygy Asymptote / William F. Wall

LIVE! JWST Mirror Adjustment Tracker - James Webb Tracker! #NASA #WEBB

https://www.youtube.com/watch?v=SN74VErcd2M

William Frank Wall

Astronomer
at INAOE
researching
interstellar
medium on
galactic
scales
in mm-waves
and
far-IR.

Instituto Nacional de Astrofísica, Óptica, y Electrónica
(INAOE), Tonantzintla, Puebla, México, 2001

William Frank Wall

Astronomer at INAOE researching interstellar medium on galactic scales in mm-waves and far-IR.

Retired astronomer who kayaks with his family in West Vancouver, BC, Canada
Copper Cove, May, 2021

Member of
Royal Astronomical Society of Canada (RASC), Vancouver
and
The Science Circle

Instituto Nacional de Astrofísica, Óptica, y Electrónica (INAOE), Tonantzintla, Puebla, México, 2001

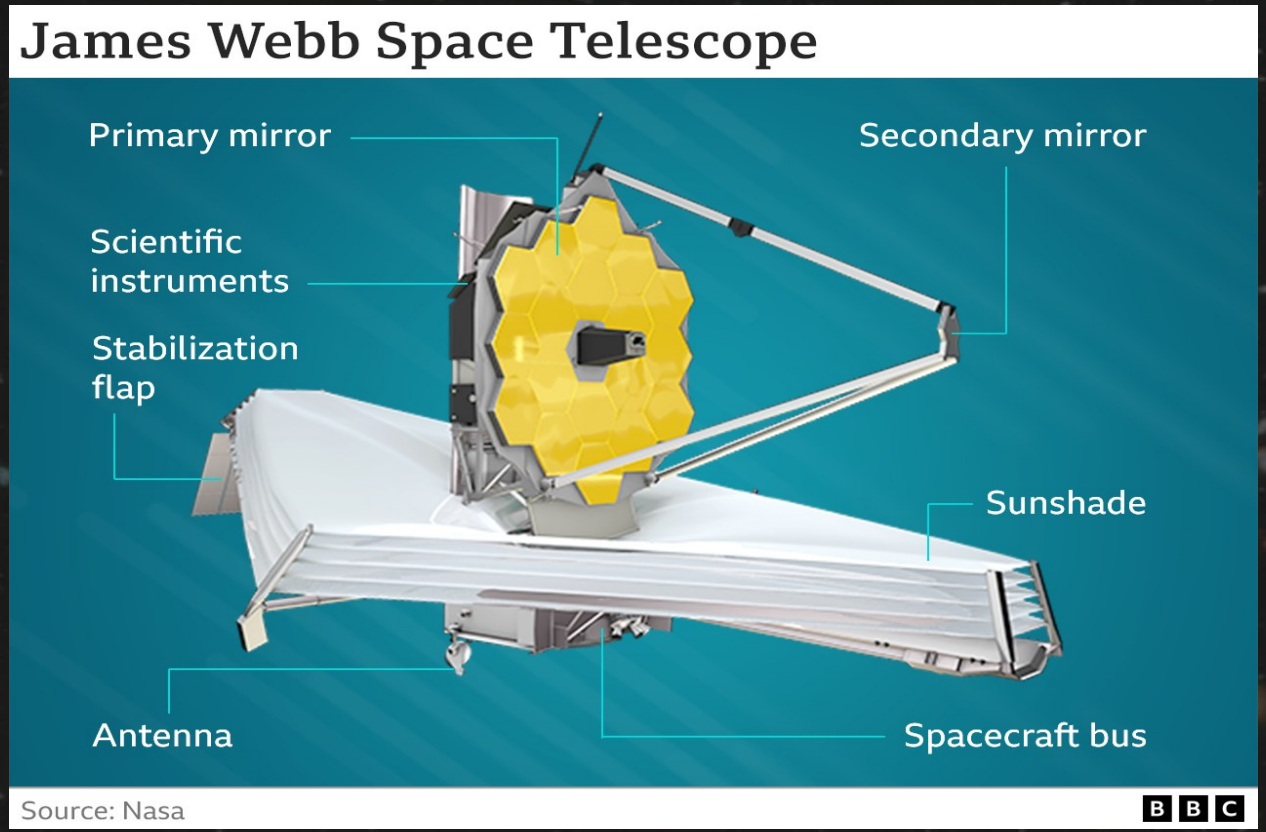
JWST

- Developed by *NASA* in collaboration with the *ESA* and the *CSA*.
- Named after James E. Webb administrator of *NASA* during the Apollo era.
- *Successfully launched on 25 December, 2021!*

https://www.nasaspaceflight.com/2021/12/ariane-5-webb-launch/

JWST

- Primary mirror composed of 18 hexagonal gold-plated beryllium mirrors, together with a total aperture of 6.5*m*.



James Webb telescope: Sun shield deployment is critical https://www.bbc.com/news/science-environment-59820059

JWST

- Search for the first stars/galaxies that formed after Big Bang.
- Formation and evolution of galaxies.

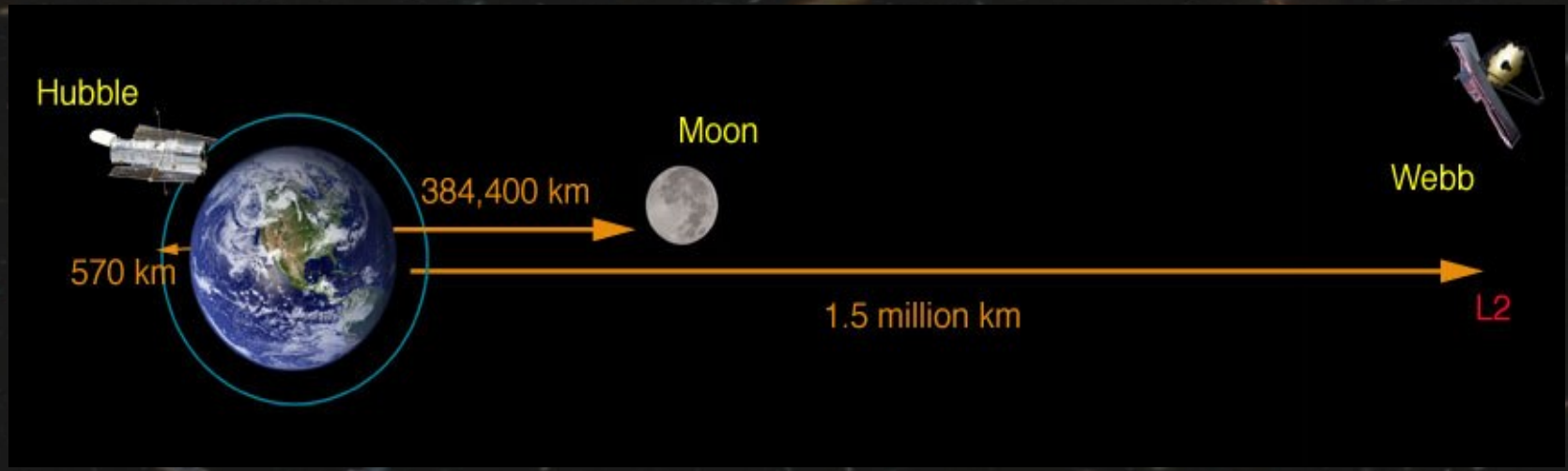
- Formation of stars and planetary systems.
- Planetary systems and the origins of life!

- ***NEED INFRARED OBSERVATIONS!***

https://www.stsci.edu/jwst/about-jwst/science-themes

JWST

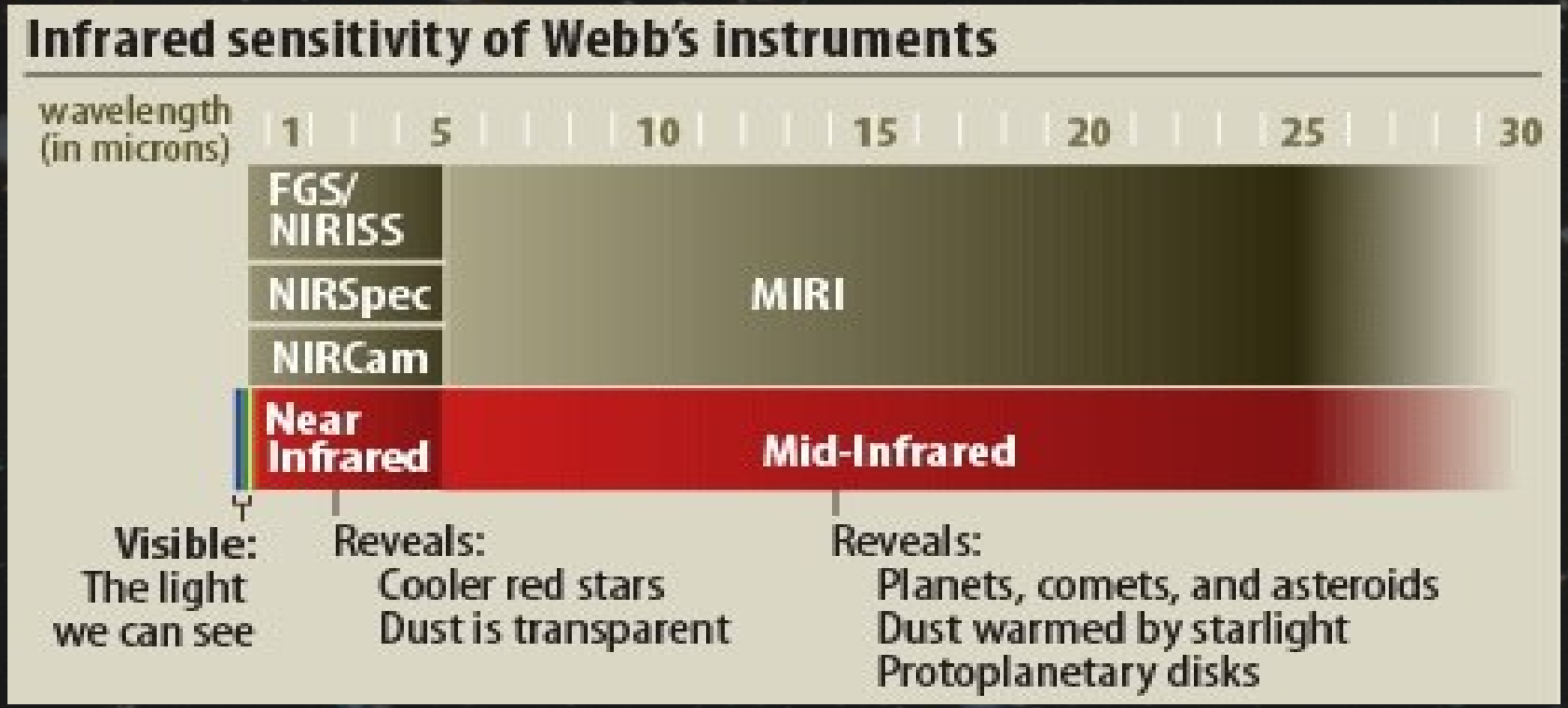
- Will observe at wavelengths of 0.6 to 28.5 μm (red light to mid-infrared).
  - Must be kept cold, so has a large sunshield and will orbit at 1.5X10^6 *km* from the Earth at the Sun-Earth L_2 Lagrange point.



Webb Orbit https://webb.nasa.gov/content/about/orbit.html

JWST

- Instruments:
  - NIRCam - Near-IR camera (0.6 – 5.0 μm)
  - NIRSpec – Near-IR Spectrograph (0.6– 5.0 μm)
  - MIRI – Mid-IR Instrument (camera & spectrograph, 5 – 27 μm)
  - FGS – Fine Guidance Sensor (0.8 – 5 μm).
  - NIRISS – Near-IR Imager & Slitless Spectrograph (0.8 – 5 μm).



https://jwst.nasa.gov/content/observatory/instruments/nircam.html

JWST

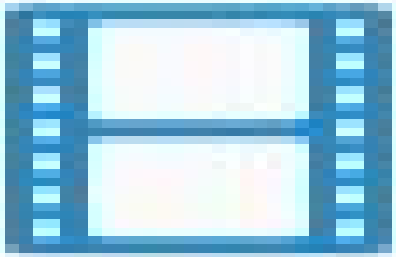
- The JWST is the successor to the Hubble Space Telescope!
- It's also a successor to the Spitzer Space Telescope.

Selected space telescopes and instruments[71]

Name	Year	Wavelength (μm)	Aperture (m)	Cooling
Spacelab Infrared Telescope (IRT)	1985	1.7–118	0.15	Helium
Infrared Space Observatory (ISO)[72]	1995	2.5–240	0.60	Helium
Hubble Space Telescope Imaging Spectrograph (STIS)	1997	0.115–1.03	2.4	Passive
Hubble Near Infrared Camera and Multi-Object Spectrometer (NICMOS)	1997	0.8–2.4	2.4	Nitrogen, later cryocooler
Spitzer Space Telescope	2003	3–180	0.85	Helium
Hubble Wide Field Camera 3 (WFC3)	2009	0.2–1.7	2.4	Passive, and thermo-electric[73]
Herschel Space Observatory	2009	55–672	3.5	Helium
JWST	2021	0.6–28.5	6.5	Passive, and cryocooler (MIRI)

https://en.wikipedia.org/wiki/James_Webb_Space_Telescope

JWST



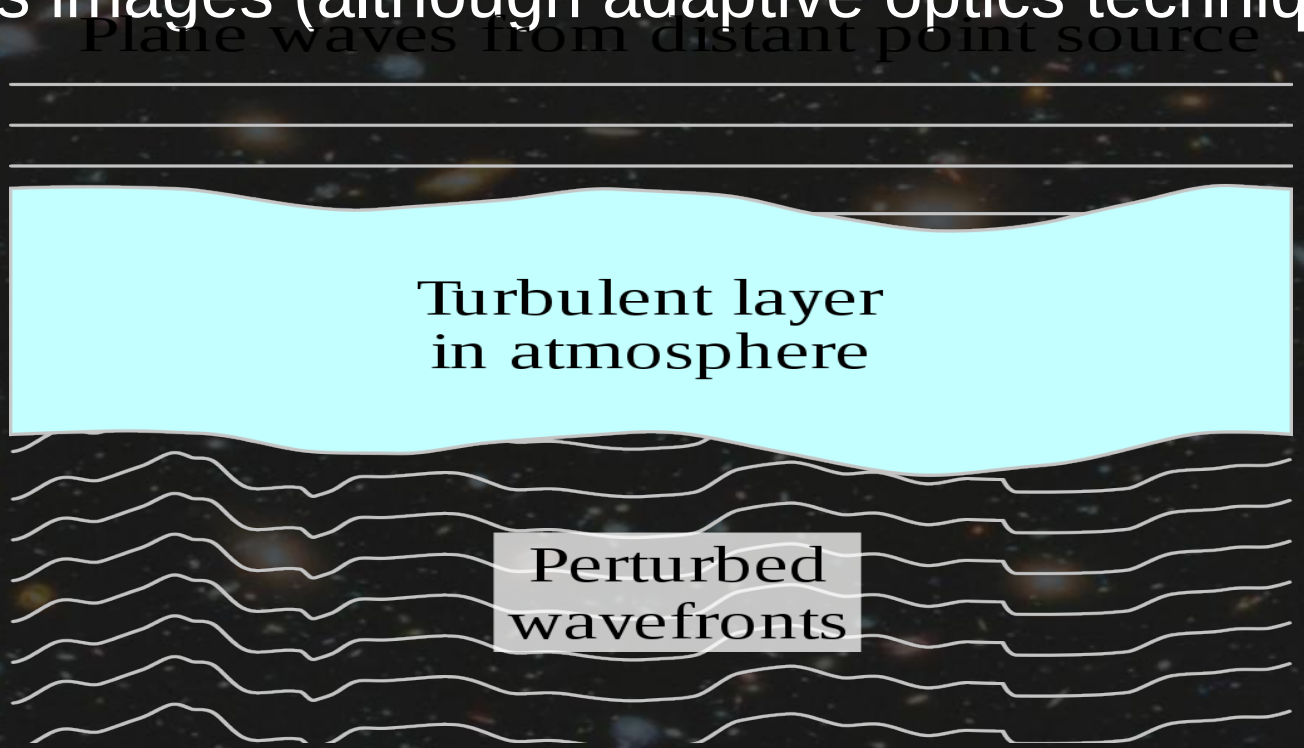
Primary Mirror Size Comparison Between Webb and Hubble

https://www.youtube.com/watch?v=j3mk6tUokm4&list=TLGG9AelNnPkoFQzMTEyMjAyMQ&t=6s

JWST

Why have telescopes in space?

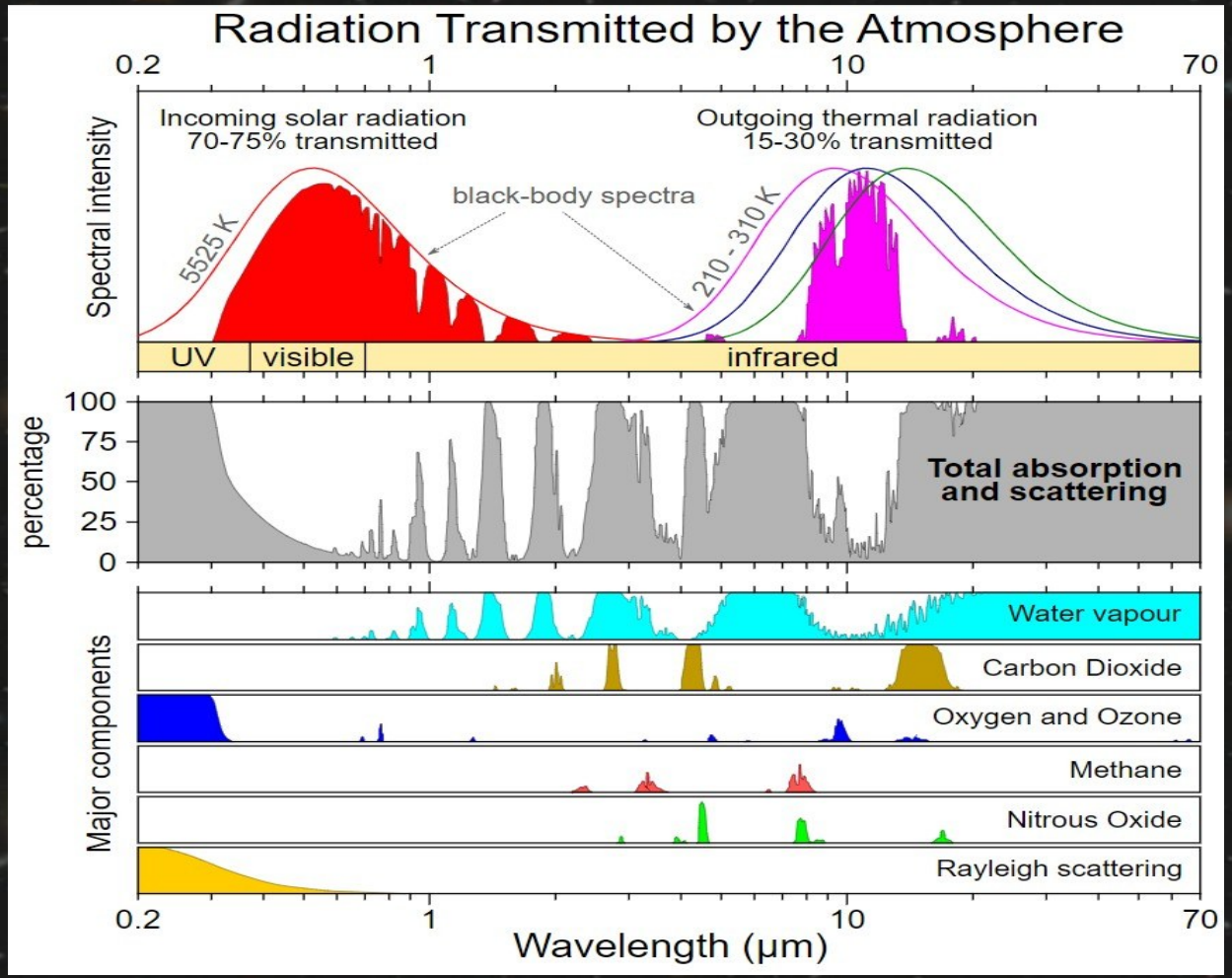
- The Earth’s atmosphere hinders observations...
  - Turbulence blurs images (although adaptive optics techniques are improving).



https://en.wikipedia.org/wiki/Astronomical_seeing

JWST

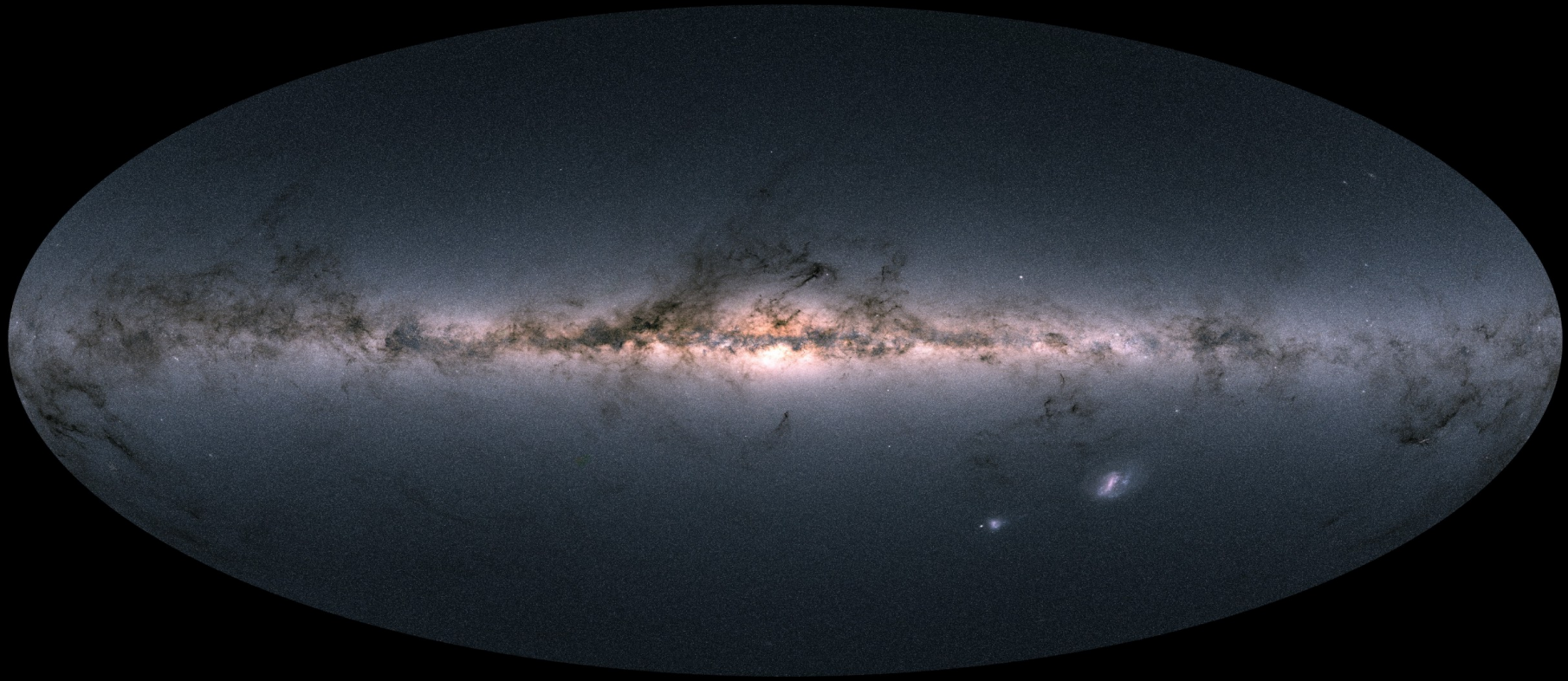
- Atmosphere adds noise to images, especially in IR.
- Atmospheric opacity reduces signal strength...
  - *Can block observations at many wavelengths (i.e., UV, IR)!*



https://en.wikipedia.org/wiki/James_Webb_Space_Telescope

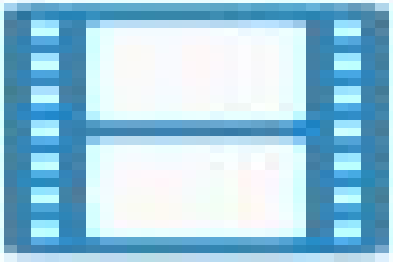
JWST

- Can access the *entire* sky when in space.



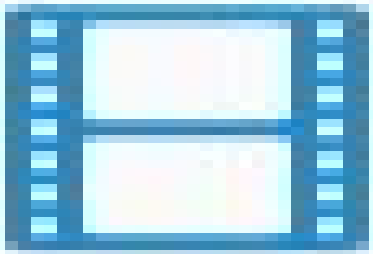
https://www.esa.int/ESA_Multimedia/Images/2018/04/Gaia_s_sky_in_colour2

JWST



James Webb Space Telescope Deployment Sequence (Nominal)
https://www.youtube.com/watch?v=RzGLKQ7_KZQ

JWST



Webb Orbit

https://www.youtube.com/watch?v=524fcGyki5c

JWST

Ground-based, NO Adaptive Optics

Hartigan et al. 2020, ApJL, 902, L1

JWST

HST- “equivalent” (Really just a crude equivalence.)

Hartigan et al. 2020, ApJL, 902, L1

JWST

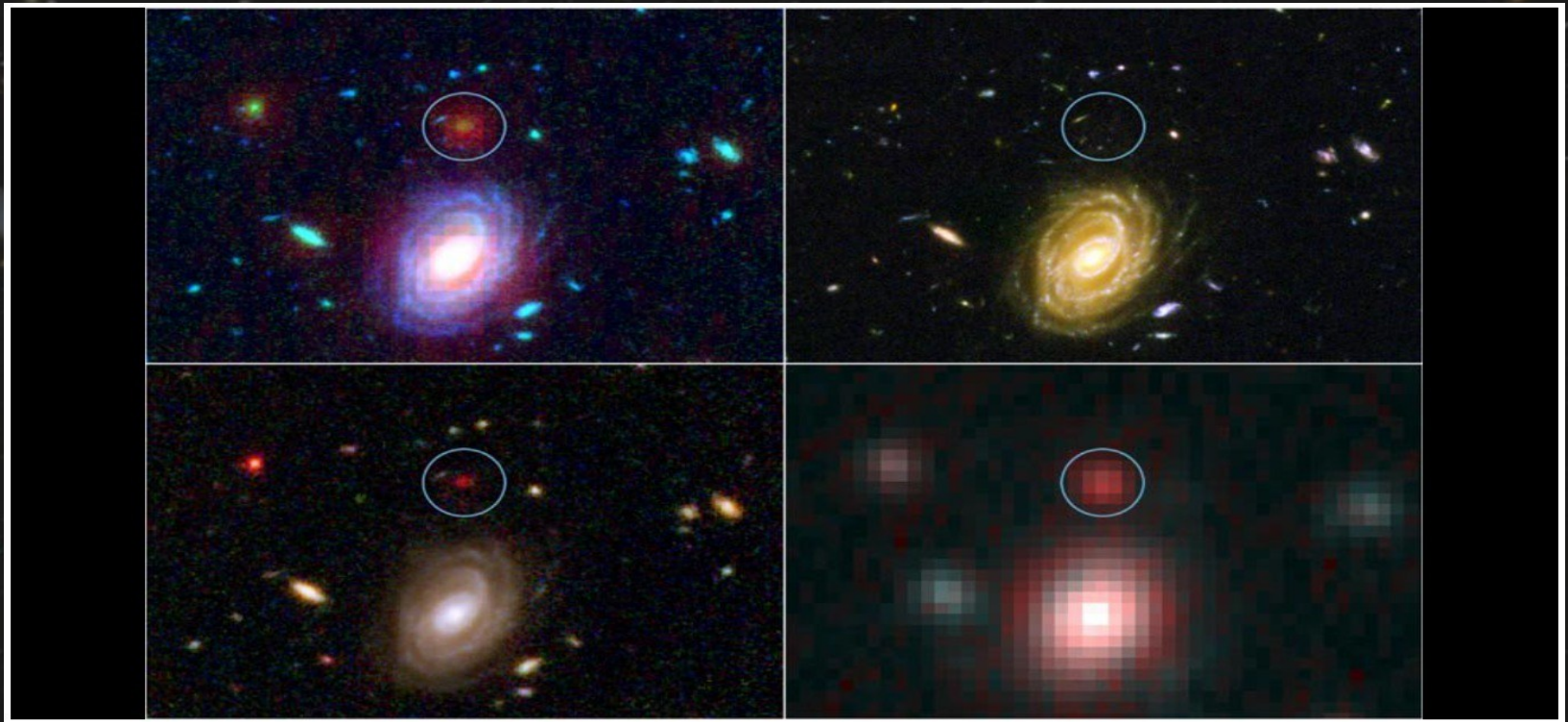
JWST- “equivalent” (Really just a ground-based image with adaptive optics.)

Hartigan et al. 2020, ApJL, 902, L1

JWST – Discoveries?!!

SPITZER SPACE TELESCOPE DISCOVERIES/ADVANCES

- “Big-Baby” galaxy observed at 800 Myr after Big Bang!



A combined visible and infrared view of galaxy HUDF-JD2. In the browse image, Hubble's visible light image is in the upper right, Hubble's near infrared view is in the lower left, Spitzer's infrared camera is in the lower right and the combined view of all three images in the upper left.

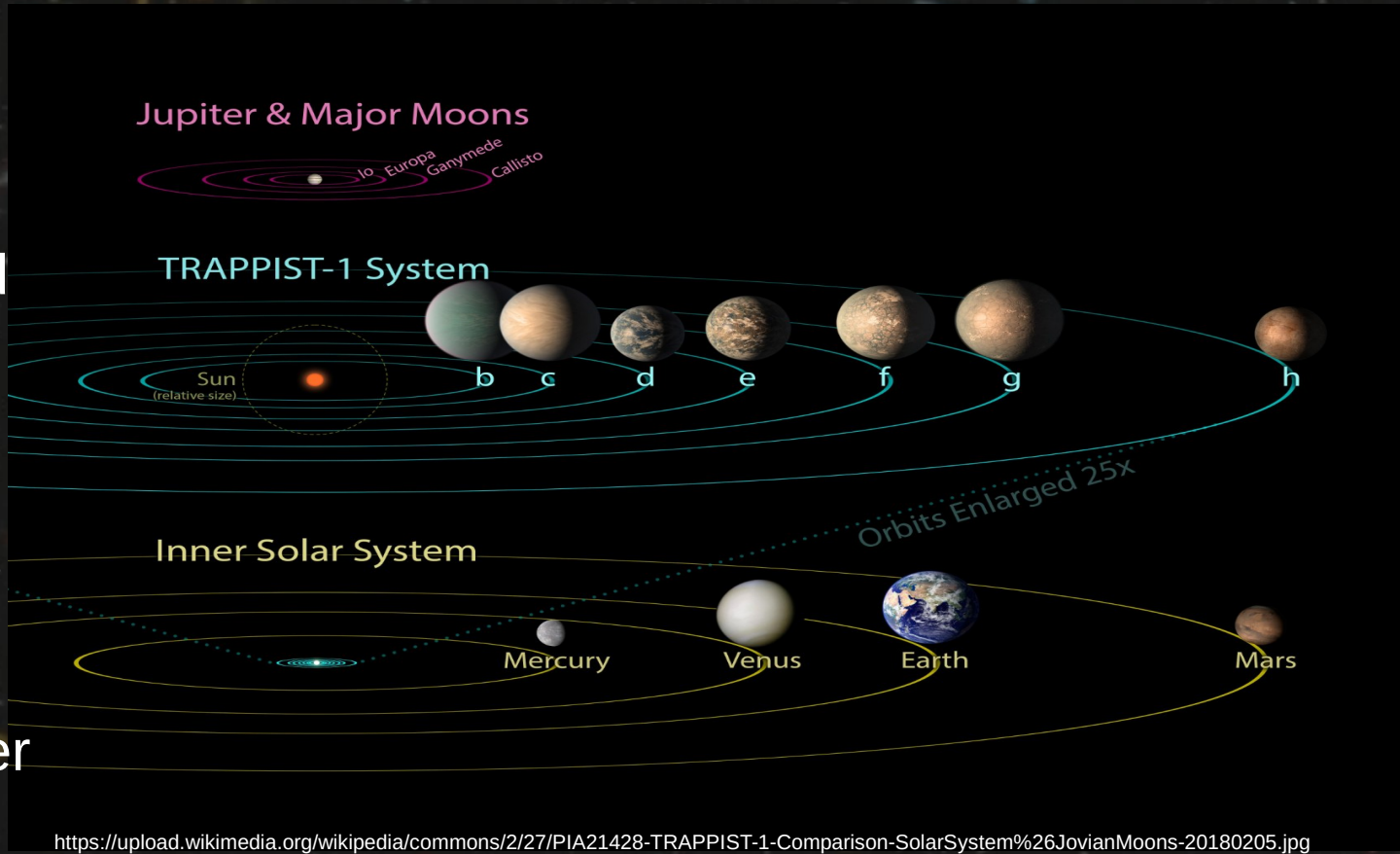
https://www.jpl.nasa.gov/news/nasa-finds-big-baby-galaxies-in-newborn-universe

JWST – Discoveries?!!

SPITZER SPACE TELESCOPE DISCOVERIES/ADVANCES

Spitzer finds 4 more planets in TRAPPIST-1 system!

- A total of 7 Earth-sized rocky planets in the system.
- Hubble spectroscopy found no atmospheres of hydrogen or helium, but couldn't rule out atmospheres of heavier molecules.

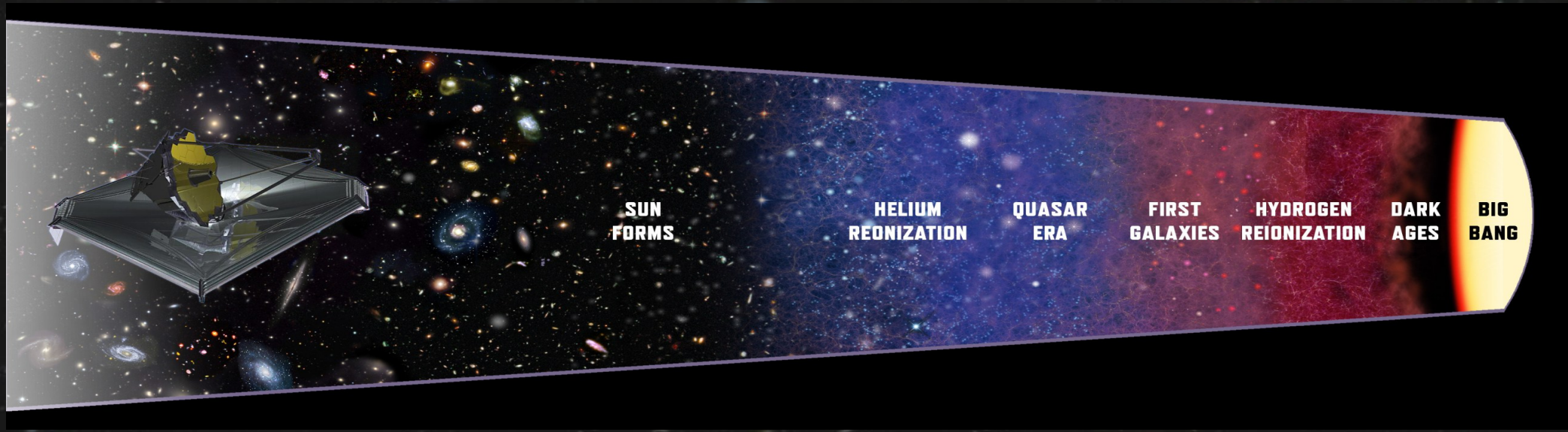


https://upload.wikimedia.org/wikipedia/commons/2/27/PIA21428-TRAPPIST-1-Comparison-SolarSystem%26JovianMoons-20180205.jpg

JWST – Discoveries?!!

HUBBLE SPACE TELESCOPE DISCOVERIES/ADVANCES

- Contributed to establishing the age of universe at 13.8 Gyr.
- Constrained estimates of the expansion rate of the universe.



https://www.stsci.edu/jwst/about-jwst/science-themes

JWST – Discoveries?!!

HUBBLE SPACE TELESCOPE DISCOVERIES/ADVANCES

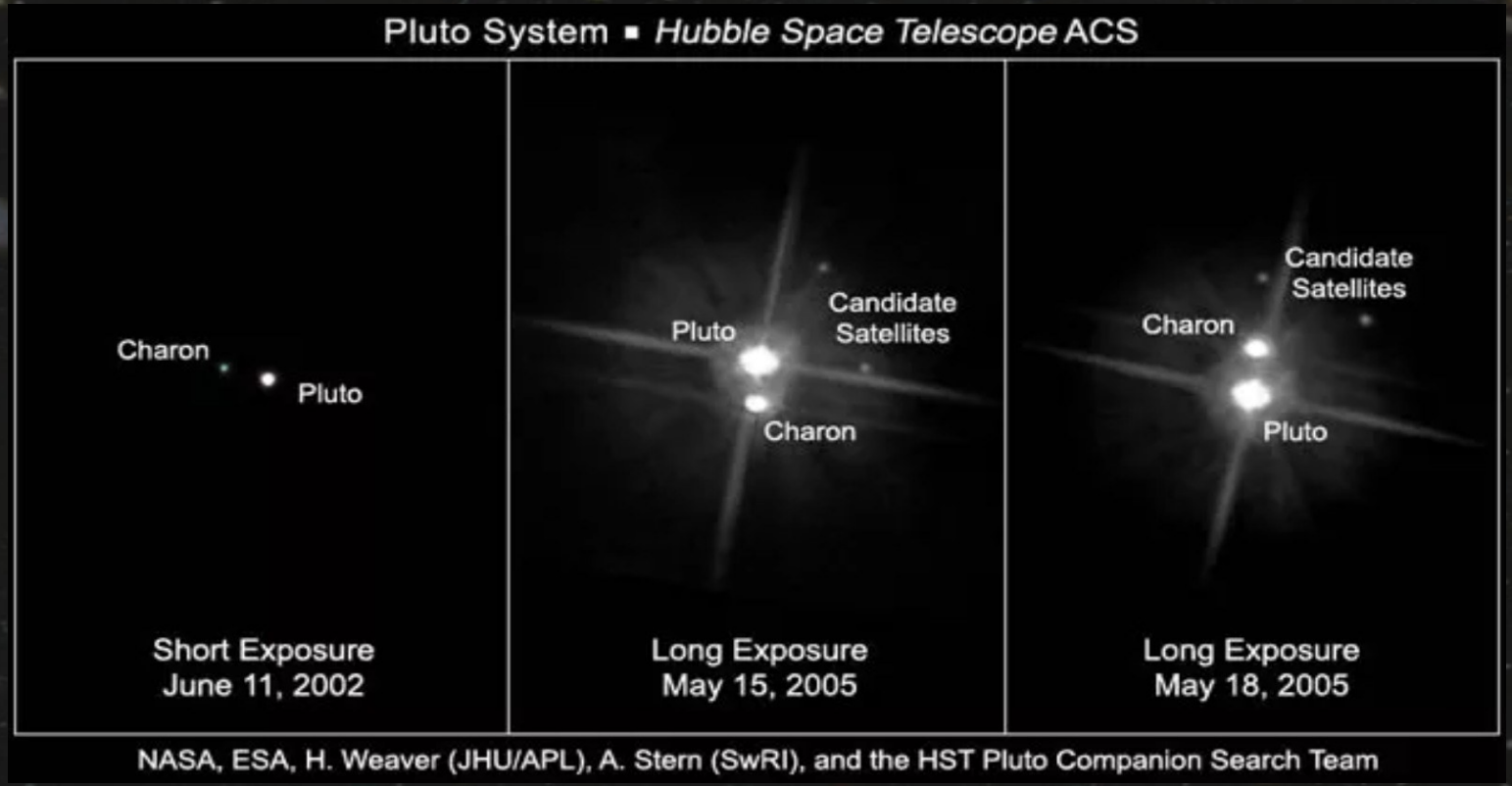
- Discovered that most major galaxies have a supermassive black hole in their centres.

https://newatlas.com/space/restless-supermassive-black-hole-moving/

JWST – Discoveries?!!

HUBBLE SPACE TELESCOPE DISCOVERIES/ADVANCES

- Discovered two moons of Pluto: Nyx and Hydra.



https://www.space.com/2522-pluto-newest-moons-named-hydra-nix.html

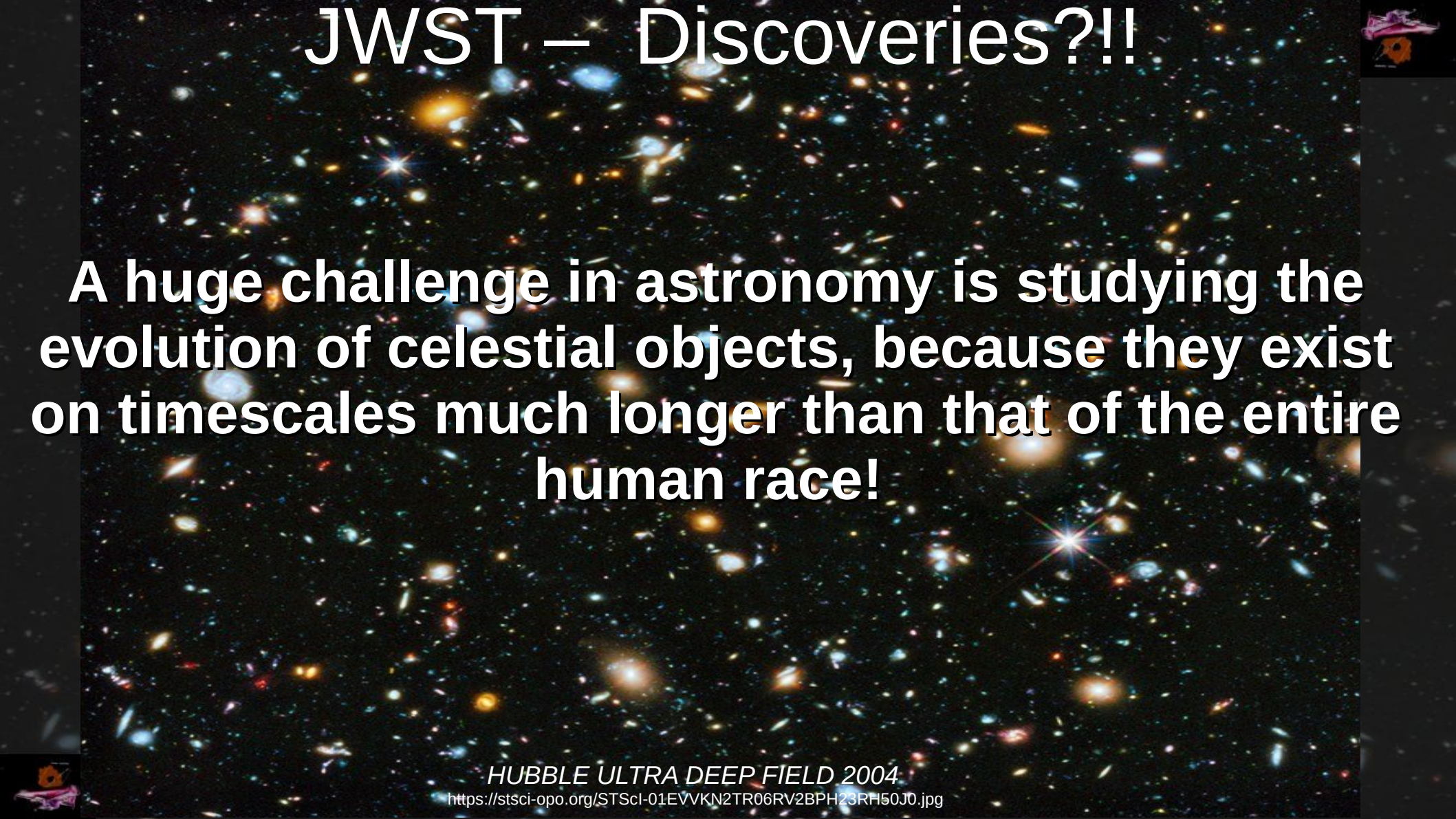
JWST – Discoveries?!!

HUBBLE SPACE TELESCOPE DISCOVERIES/ADVANCES

- **HUBBLE DEEP FIELDS! *IMPRESSIVE*, BECAUSE...**
  - **“Empty field” filled with galaxies implies that observable universe has hundreds of billions of galaxies!**
  - **Back to ~600 *Myr* after Big Bang. (Only ~100 *Myr* for JWST.)**

HUBBLE ULTRA DEEP FIELD 2004
https://stsci-opo.org/STScI-01EVVKN2TR06RV2BPH23RH50J0.jpg

JWST – Discoveries?!!

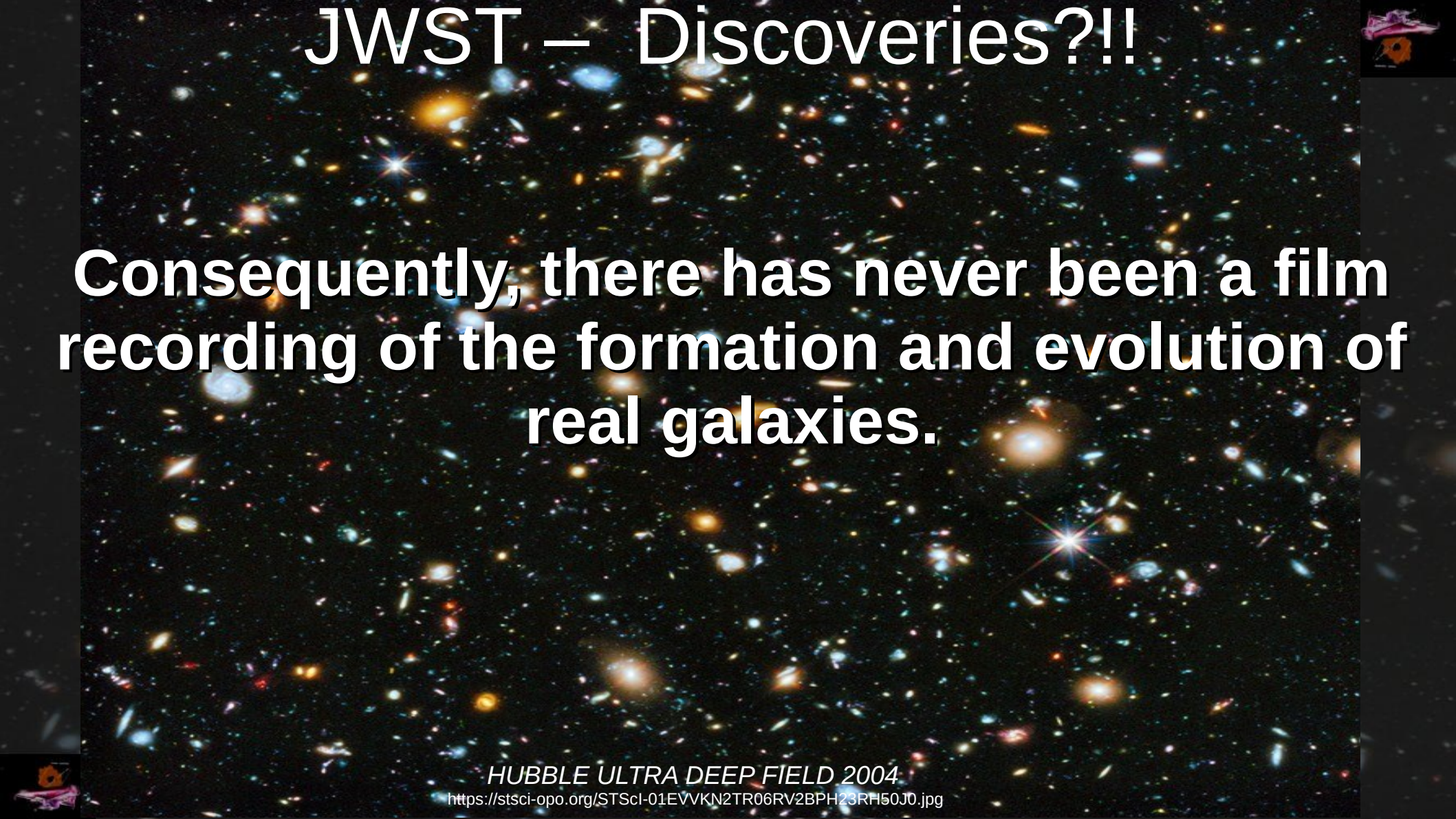


A huge challenge in astronomy is studying the evolution of celestial objects, because they exist on timescales much longer than that of the entire human race!

HUBBLE ULTRA DEEP FIELD 2004
https://stsci-opo.org/STScI-01EVVKN2TR06RV2BPH23RH50J0.jpg

JWST – Discoveries?!!

Consequently, there has never been a film recording of the formation and evolution of real galaxies.



HUBBLE ULTRA DEEP FIELD 2004
https://stsci-opo.org/STScI-01EVVKN2TR06RV2BPH23RH50J0.jpg

JWST – Discoveries?!!

HOWEVER...!

HUBBLE ULTRA DEEP FIELD 2004
https://stsci-opo.org/STScI-01EVVKN2TR06RV2BPH23RH50J0.jpg

JWST – Discoveries?!!

Each Hubble Deep Field is like a film frozen in time with its frames superposed on each other!

So, we can see how galaxies evolve by separating those frames to reconstruct the film. (We do this by looking at object redshifts).

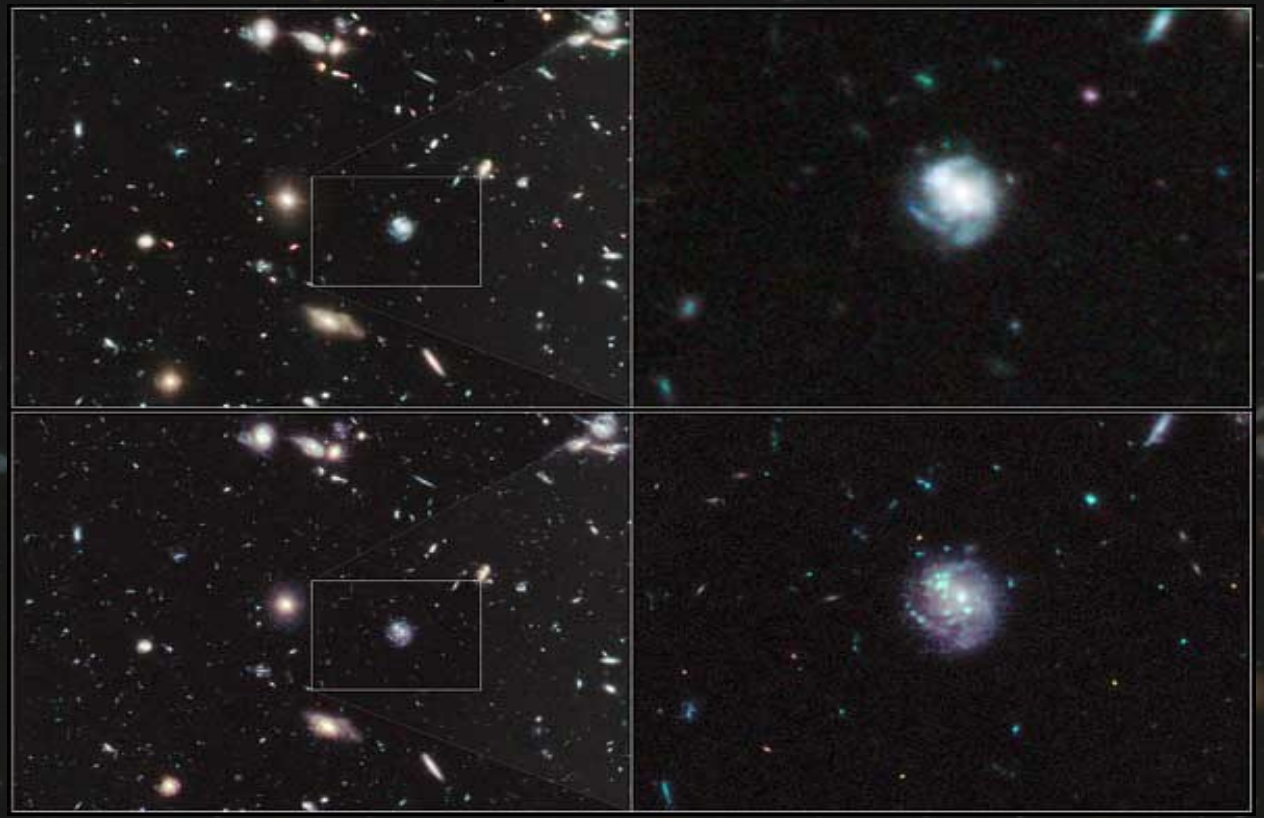
HUBBLE ULTRA DEEP FIELD 2004
https://stsci-opo.org/STScI-01EVVKN2TR06RV2BPH23RH50J0.jpg

JWST – Discoveries?!!

With JWST, we'll create a higher-resolution, and more complete, film.

HUBBLE

JWST
(simulated)



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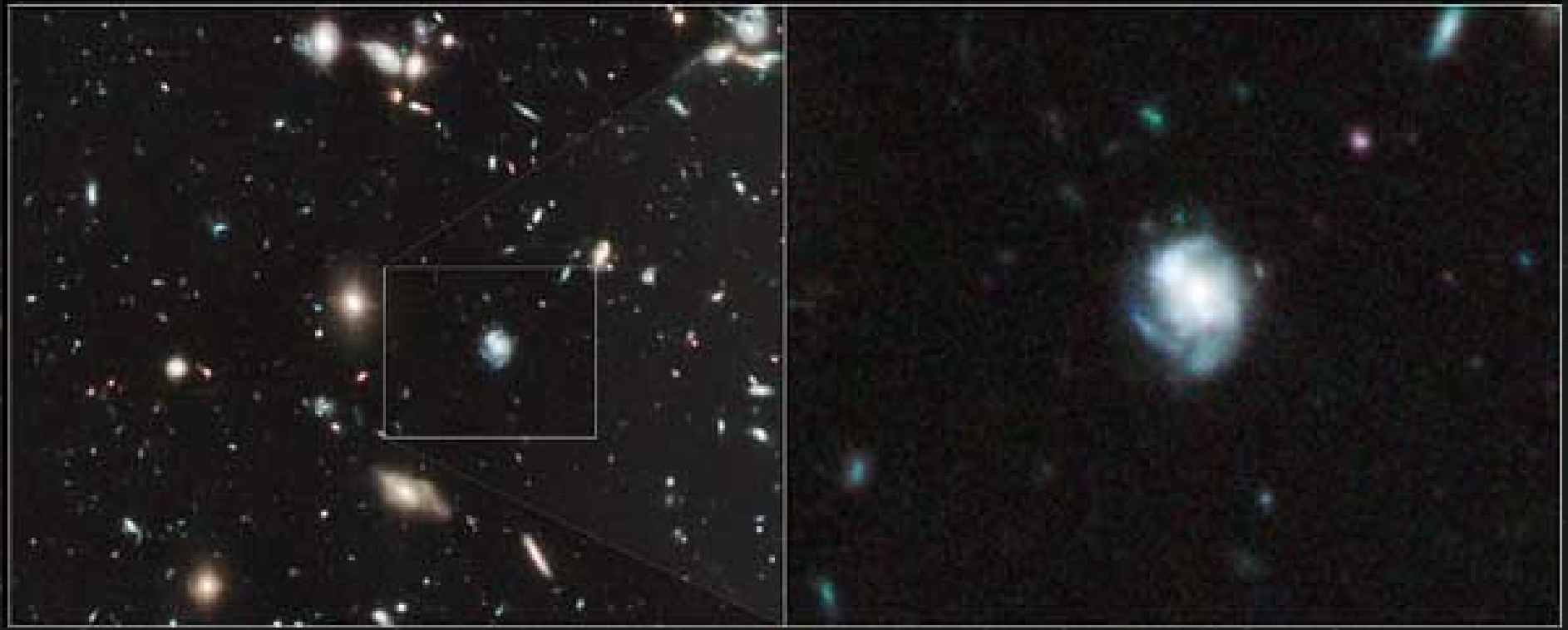
JWST – Discoveries?!!

With JWST, we'll have a clearer, more complete picture of how galaxies formed / evolved.

HUBBLE



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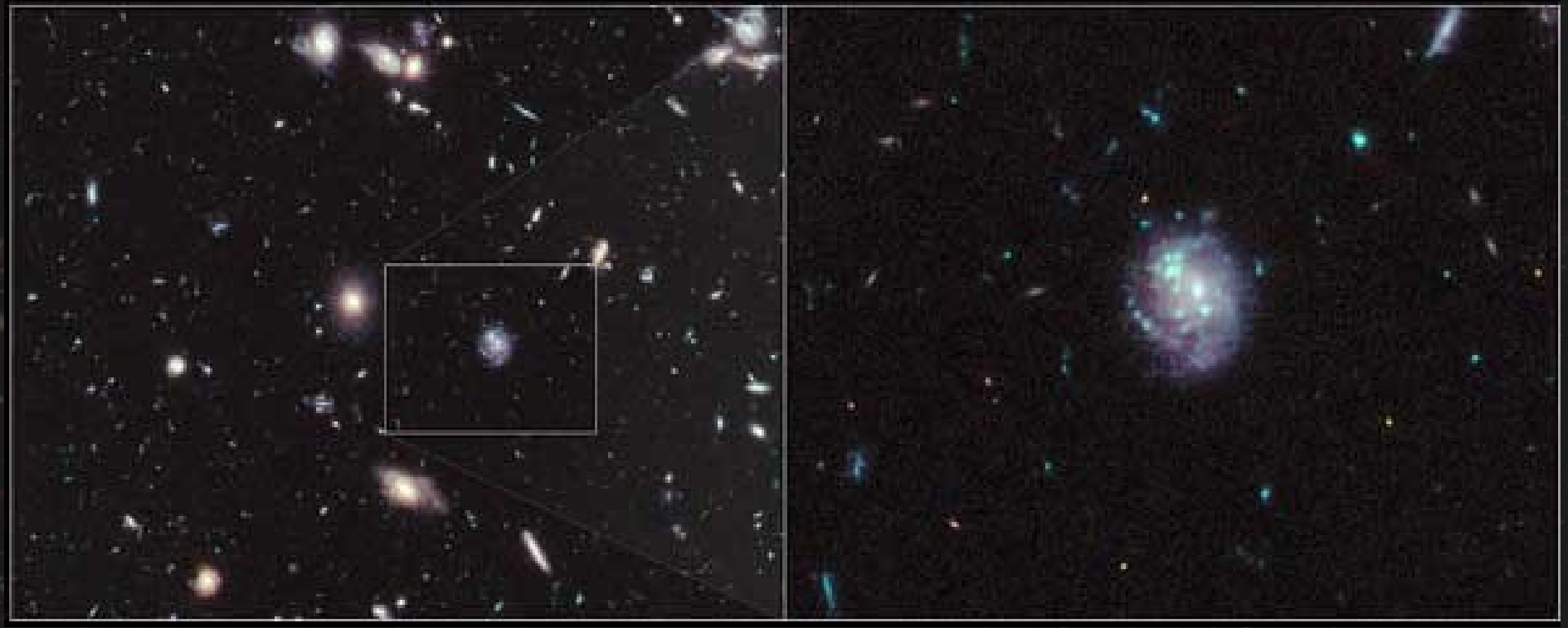
JWST – Discoveries?!!

With JWST, we'll have a clearer, more complete picture of how galaxies formed / evolved.

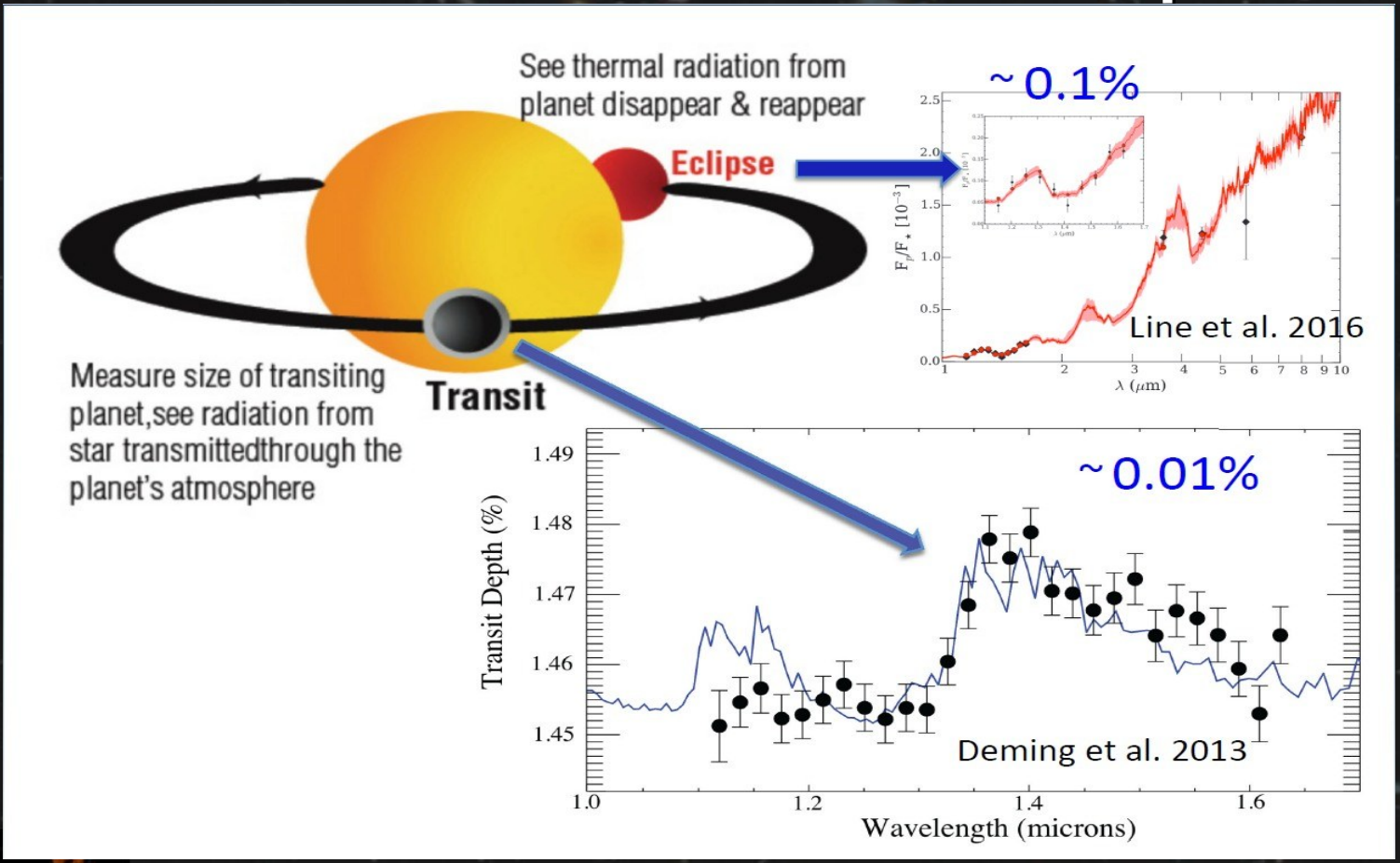
JWST **(simulated)**



https://www.stsci.edu/jwst/about-jwst/science-themes

JWST – Discoveries?!!

Let's talk about exoplanets!



Transit (or transmission) spectra
(Sensitive to trace molecules, but also easily obscured by clouds.)

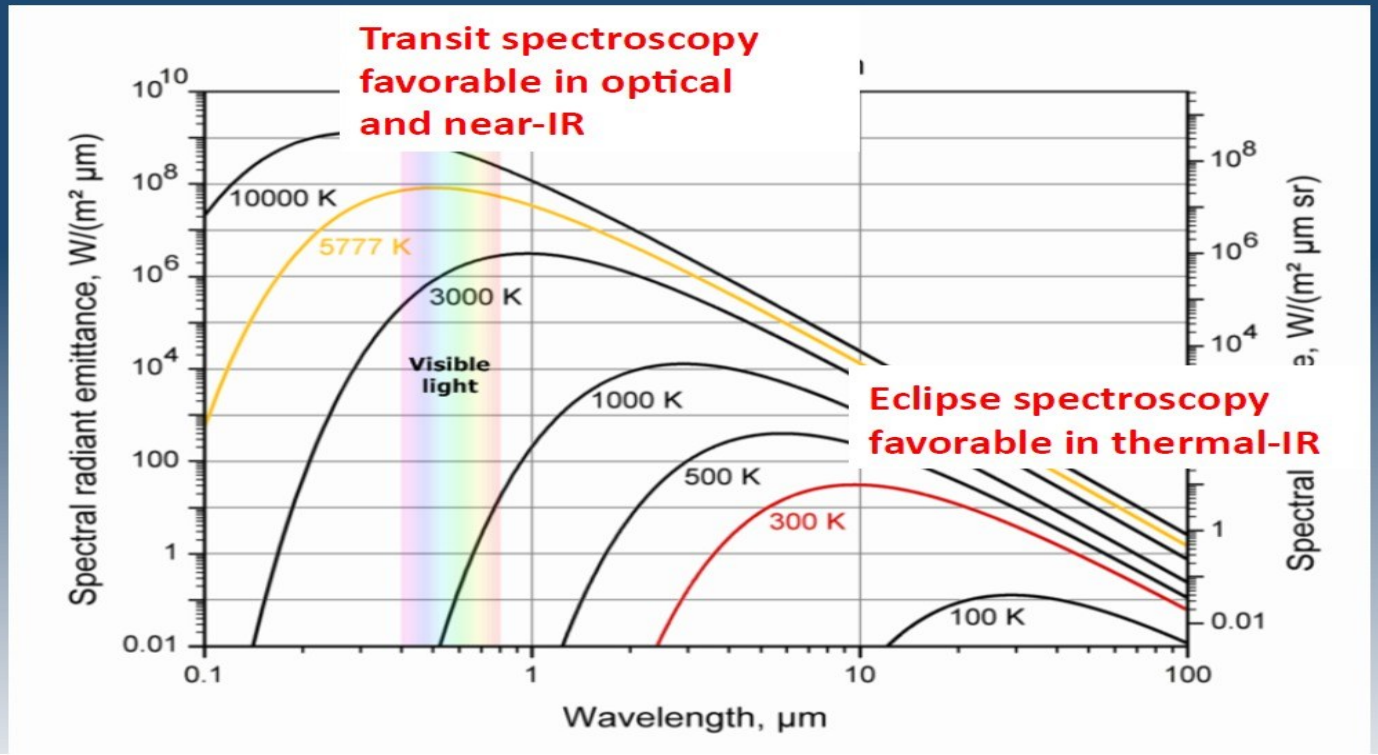
versus

Emission (or secondary eclipse) spectra
(Not strongly affected by clouds, but insensitive to trace molecules.)

JWST – Discoveries?!!

Let's talk about exoplanets!

Signal-to-noise depends on the stellar brightness versus wavelength



Given the photospheric temperature of TRAPPIST-1 – i.e., 2560*K* – and *JWST*'s suite of instruments in the optical, near-IR, and mid-IR (or thermal-IR), *JWST* will be capable of both kinds of spectroscopy.

Deming (2016), *"Transit Spectroscopy:Techniques and Results (or, is there an atom or molecule in my data?),"* Presentation for Sagan Exoplanet Summer Workshop

JWST – Discoveries?!!

What will *JWST* see in the TRAPPIST-1 system?!

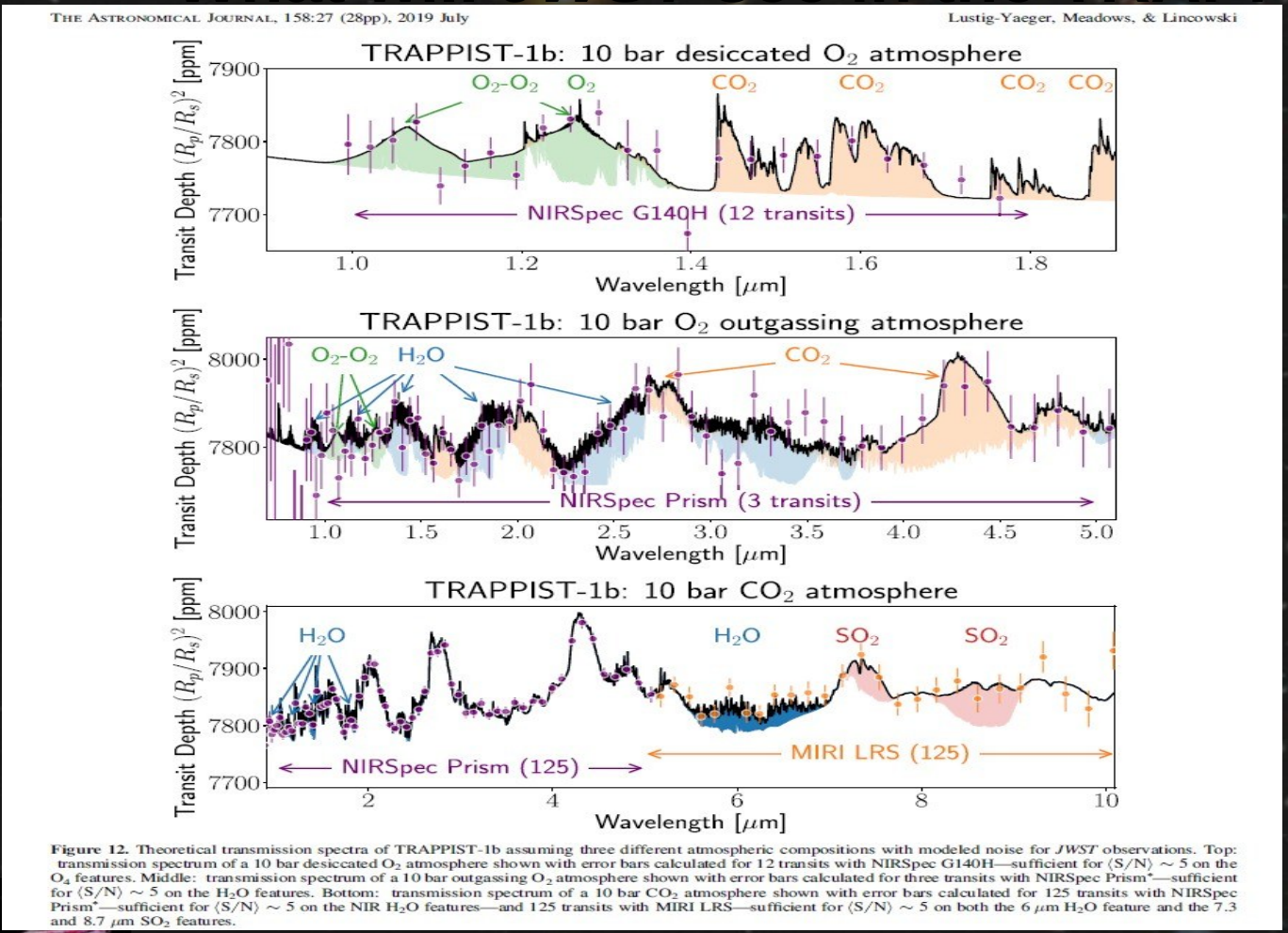


Figure 12. Theoretical transmission spectra of TRAPPIST-1b assuming three different atmospheric compositions with modeled noise for *JWST* observations. Top: transmission spectrum of a 10 bar desiccated O_2 atmosphere shown with error bars calculated for 12 transits with NIRSpec G140H—sufficient for $\langle S/N \rangle \sim 5$ on the O_4 features. Middle: transmission spectrum of a 10 bar outgassing O_2 atmosphere shown with error bars calculated for three transits with NIRSpec Prism*—sufficient for $\langle S/N \rangle \sim 5$ on the H_2O features. Bottom: transmission spectrum of a 10 bar CO_2 atmosphere shown with error bars calculated for 125 transits with NIRSpec Prism*—sufficient for $\langle S/N \rangle \sim 5$ on the NIR H_2O features—and 125 transits with MIRI LRS—sufficient for $\langle S/N \rangle \sim 5$ on both the 6 μm H_2O feature and the 7.3 and 8.7 μm SO_2 features.

Lustig-Yaeger et al. (2019) simulate atmospheres on TRAPPIST-1b, demonstrating (possible) very strong detections of many spectral lines of *oxygen, carbon dioxide, water vapour,* etc.

Such spectra are feasible with *JWST*!!

Lustig-Yaeger et al. 2019, Astronomical Journal 158, 27, *"The Detectability and Characterization of the TRAPPIST-1 Exoplanet Atmosphere with JWST"*

JWST – Discoveries?!!

MY PREDICTION:

There will be newsworthy discoveries from the
JAMES WEBB SPACE TELESCOPE
before the end of 2022!

https://www.stsci.edu/jwst/about-jwst/science-themes

REFERENCES

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- https://jwst.nasa.gov/content/observatory/instruments/nircam.html
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- NASA, ESA, CSA successfully launch the historic James Webb Space Telescope https://www.nasaspaceflight.com/2021/12/ariane-5-webb-launch/
- https://en.wikipedia.org/wiki/James_Webb_Space_Telescope
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