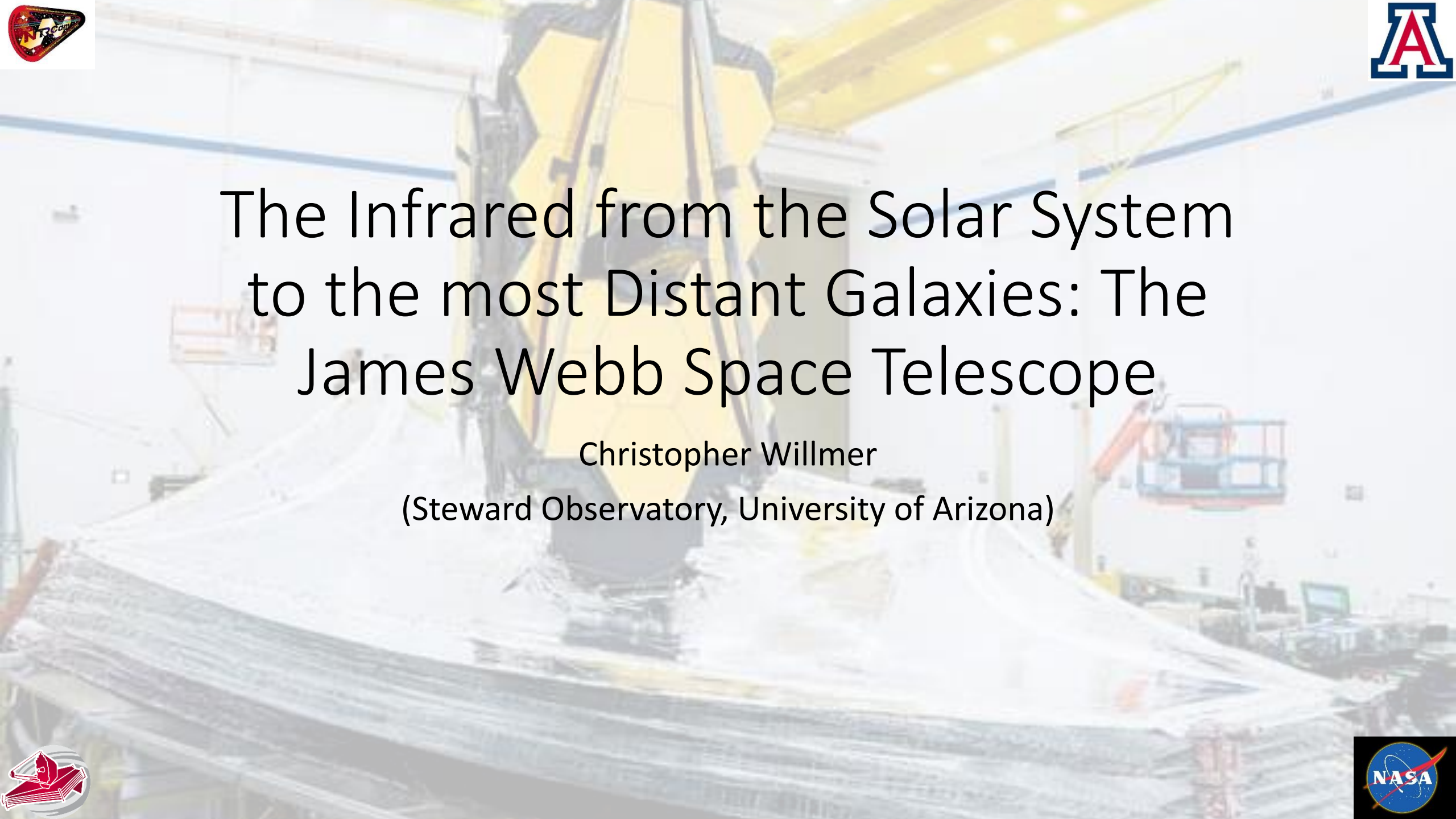
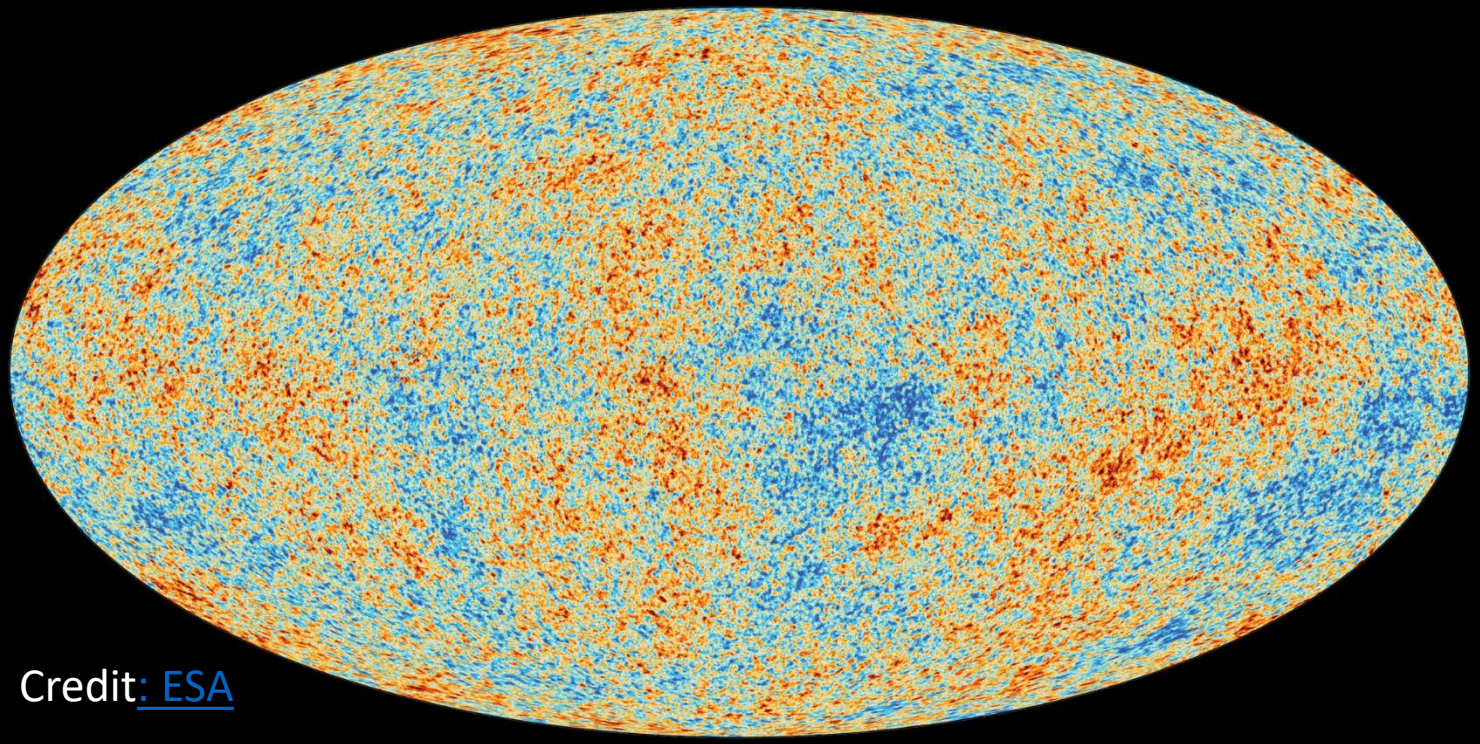


The Infrared from the Solar System to the most Distant Galaxies: The James Webb Space Telescope

Christopher Willmer

(Steward Observatory, University of Arizona)

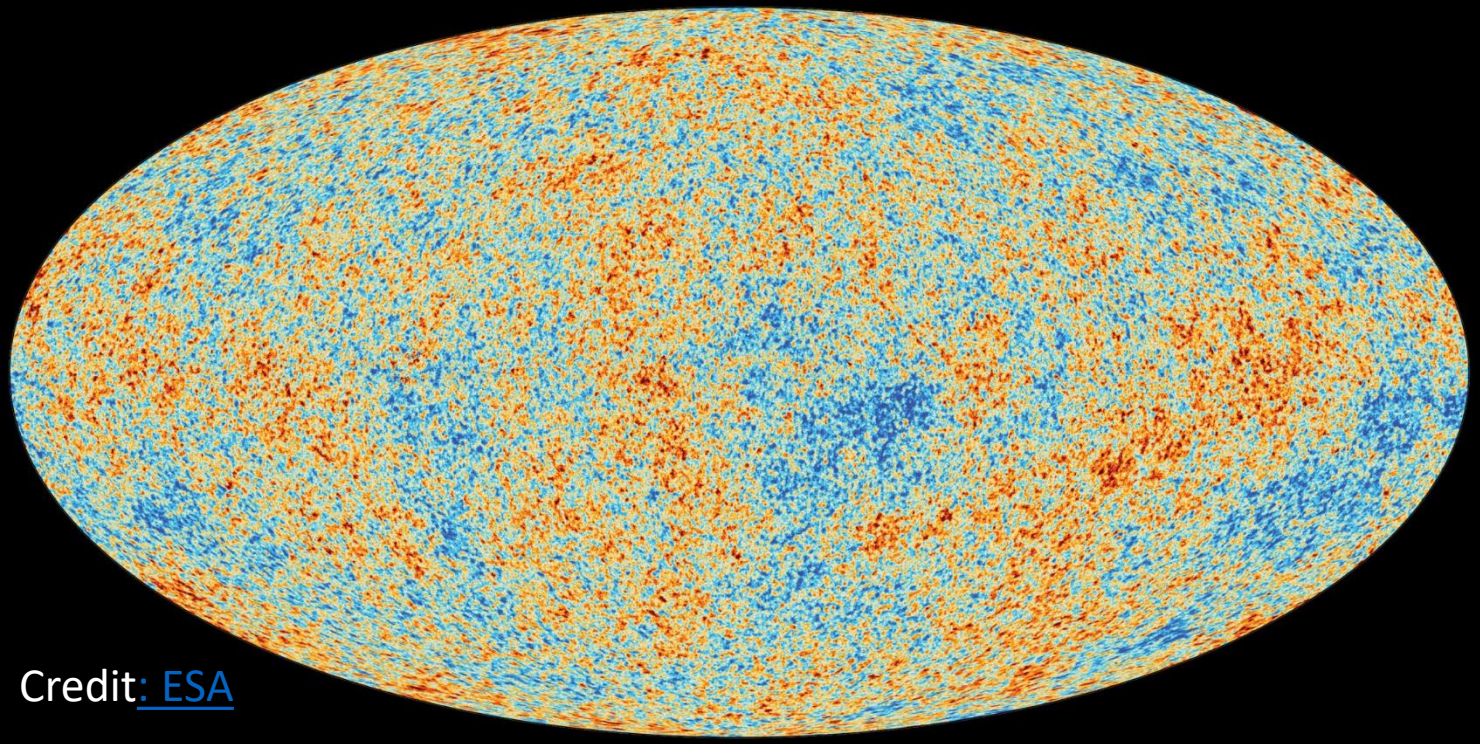
NASA's Cosmic Origins program seeks to explain the evolutionary connection between the



Credit: ESA

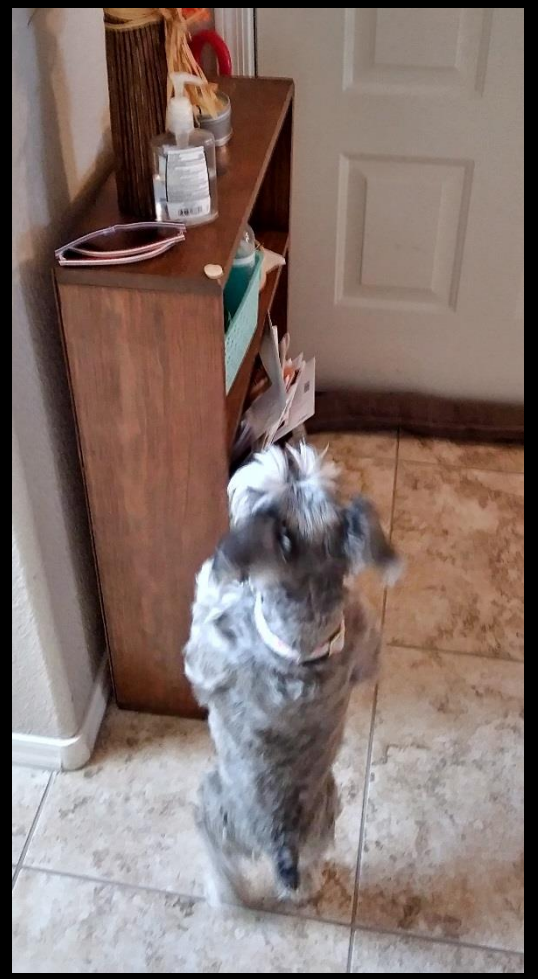
primordial fluctuations detected in the Cosmic Microwave background

NASA's Cosmic Origins program seeks to explain the evolutionary connection between the



Credit: ESA

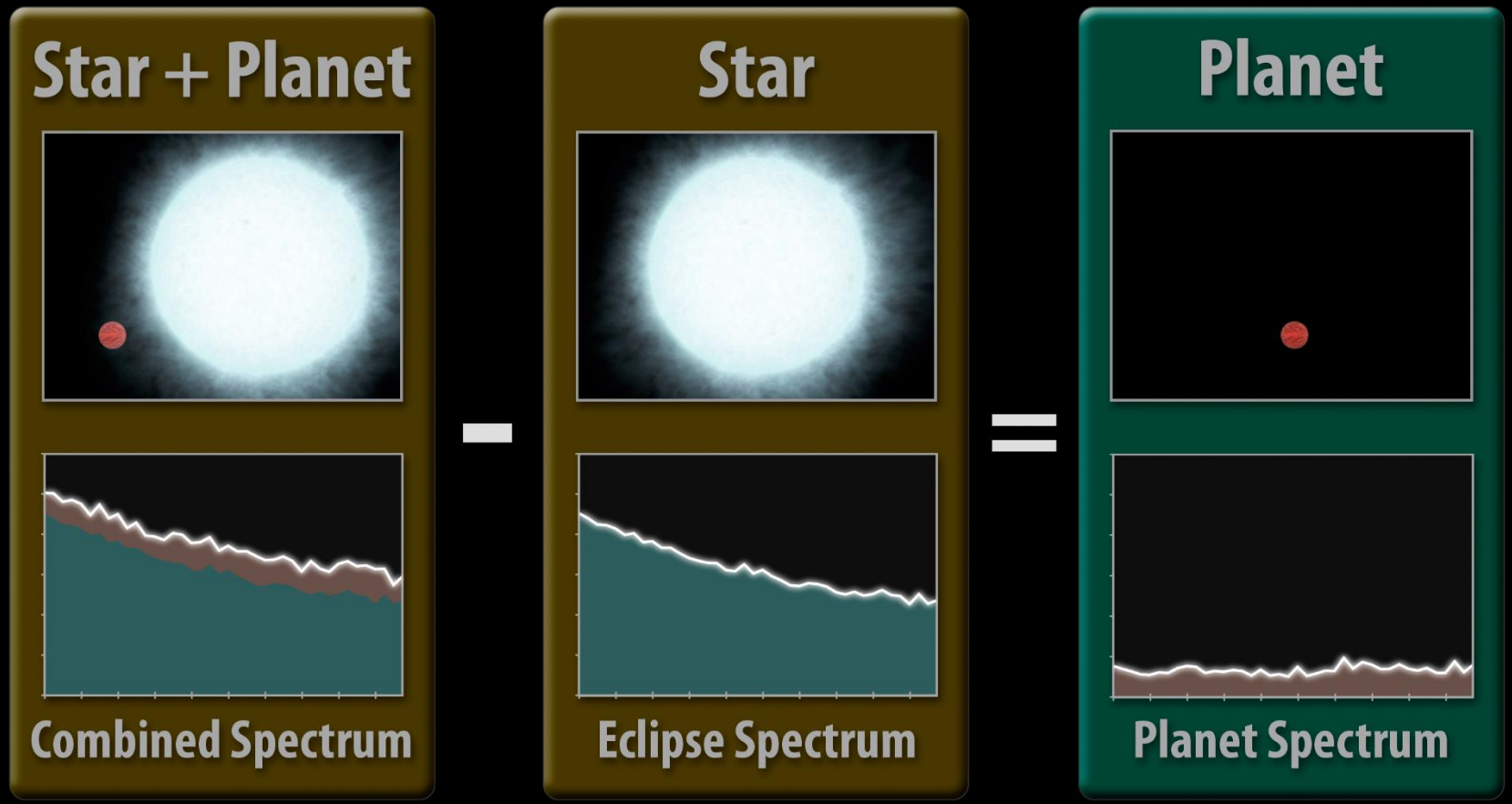
primordial fluctuations detected in the Cosmic Microwave background



and conditions enabling habitability (and possibly life) on planets.

- The James Webb Space Telescope is part of Cosmic Origins.
- To investigate this connection JWST will address:
  - How did the first stars and galaxies form ?
  - What are the stellar life cycles and the evolution of elements ?
  - How did galaxies and super-massive black holes evolve?
  - What is the evolutionary history of the Milky Way and its neighbors?
  - How do planetary systems form and evolve ?

- These themes require observing in the Infrared (“IR”):
  - Because planets are colder than stars, the greatest contrast relative to their hosts is in the IR;



Isolating a Planet's Spectrum

- These themes require observing in the Infrared (“IR”):
  - Because planets are colder than stars, the greatest contrast relative to their hosts is in the IR;
  - Dust absorption is smaller than in visible wavelengths – and actually *emits* in the longer wavelengths accessible to JWST

The Eagle Nebula (M16)

Visible: dust absorbs

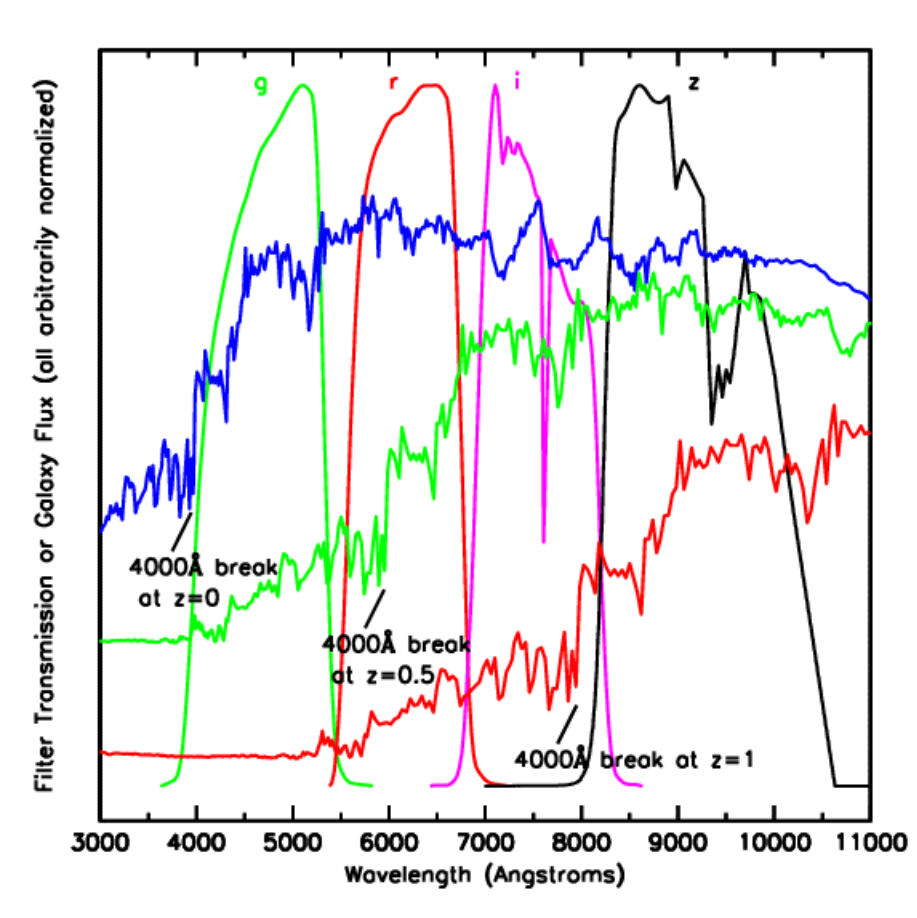
Near-IR: dust is transparent

Mid-IR: dust emits

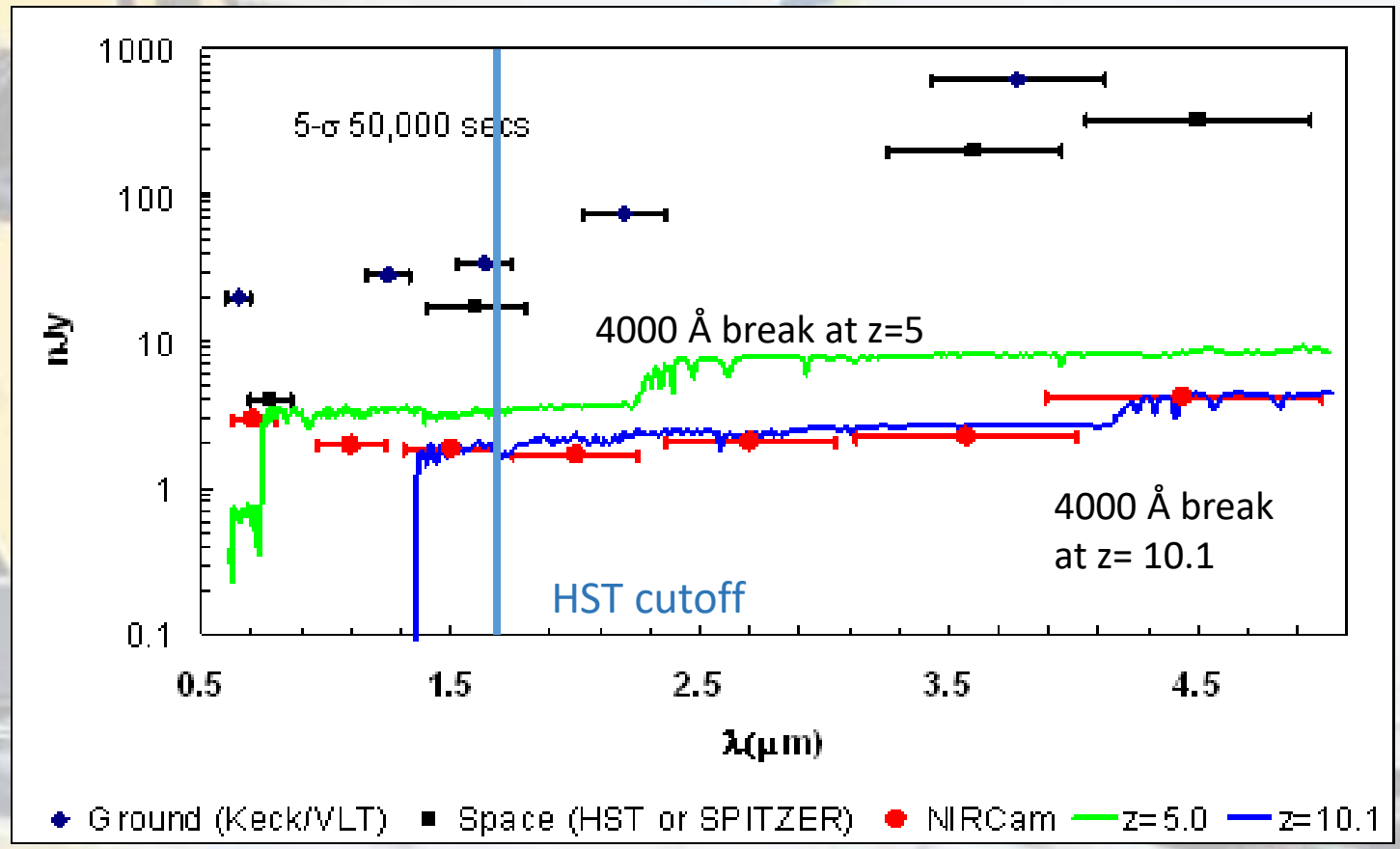
Credit: Hubblesite.org

- These themes require observing in the Infrared (“IR”):
  - Because planets are colder than stars, the greatest contrast relative to their hosts is in the IR;
  - Dust absorption is smaller than in visible wavelengths – and actually *emits* in the longer wavelengths accessible to JWST
  - As we look at progressively more distant galaxies, their light is gets shifted to longer wavelengths because of the expansion of the universe;

Because of the expansion of the Universe, the farther a galaxy is from an observer, the faster it is moving away.

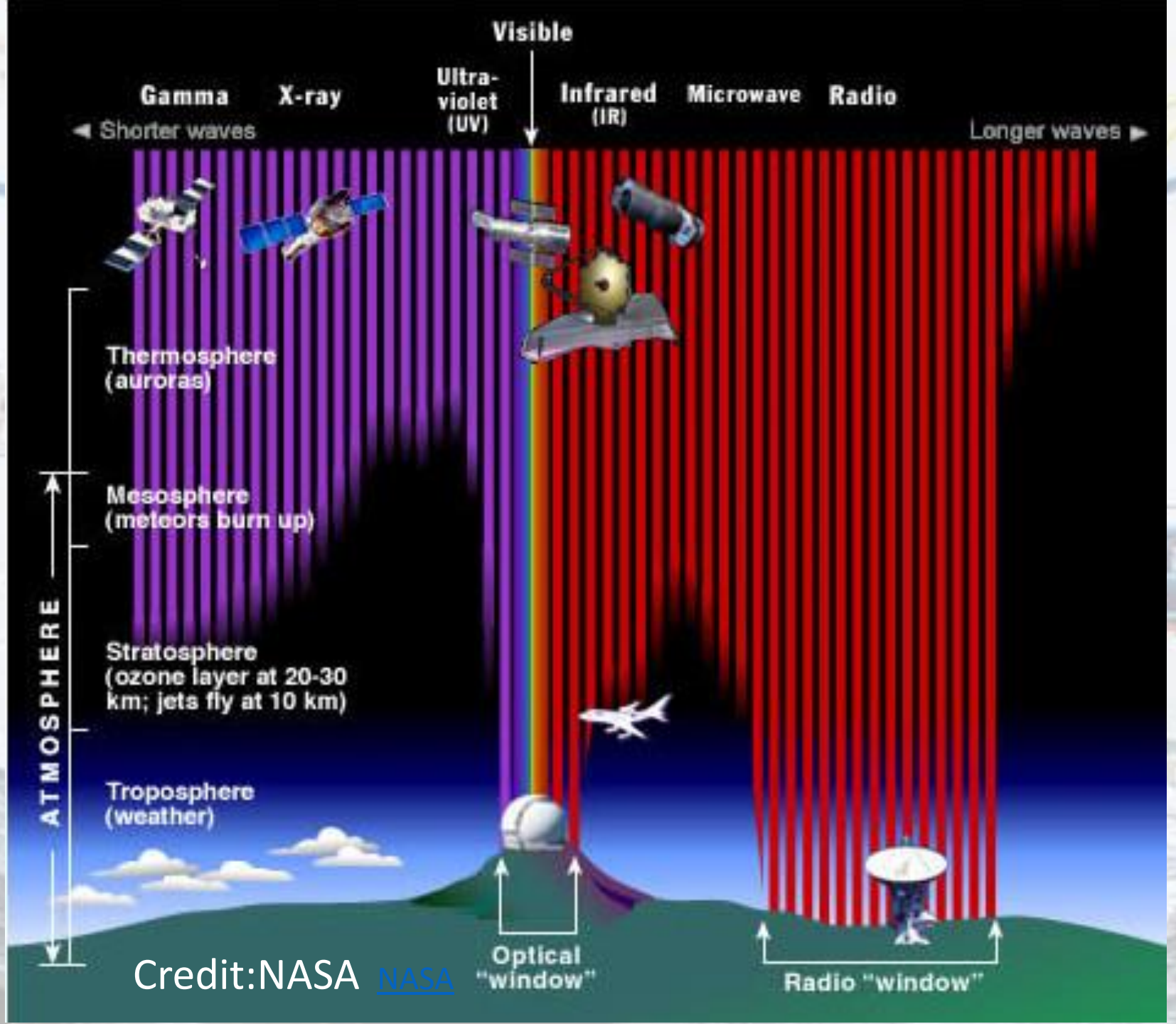


Credit: R. Wechsler



Credit: M. Rieke

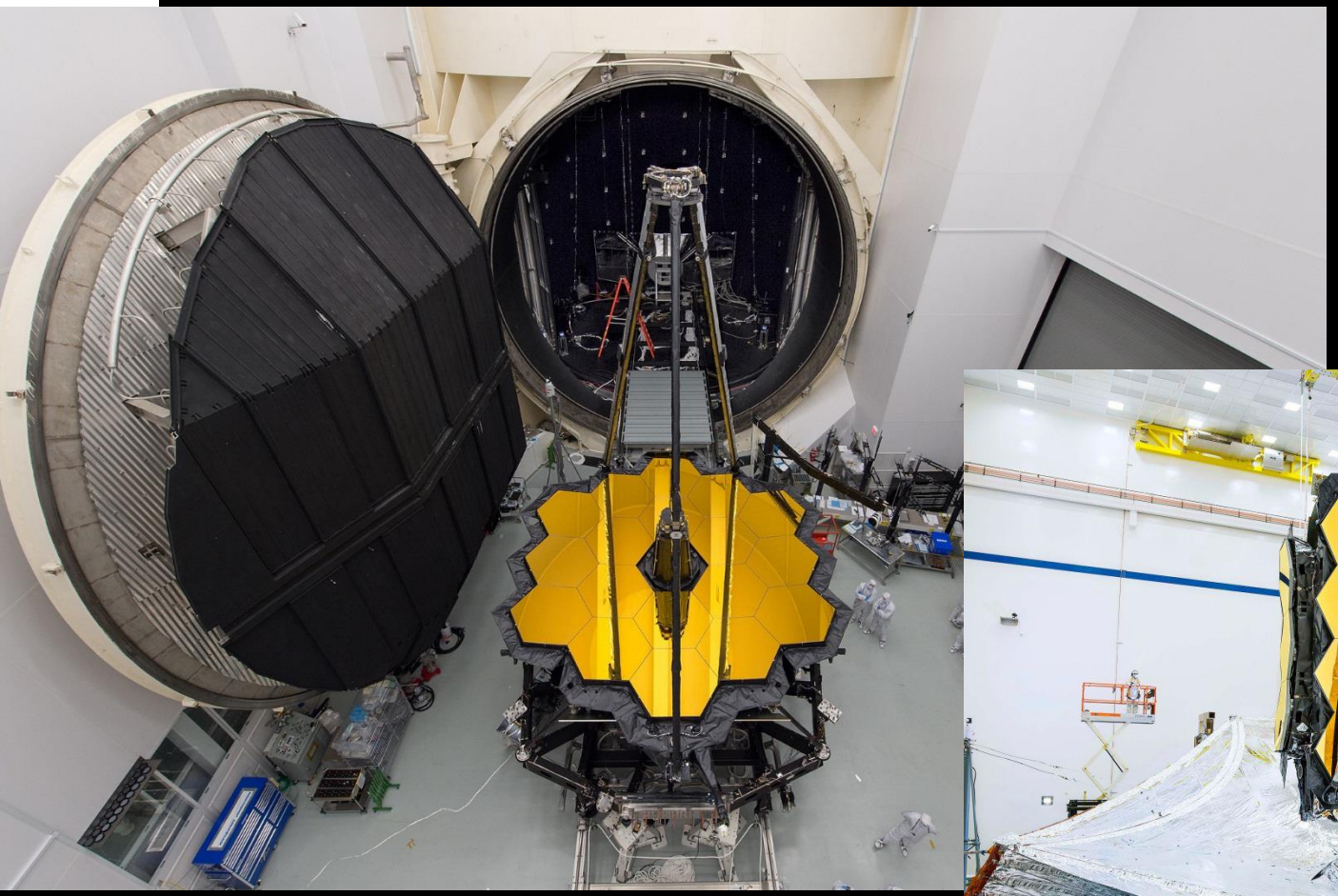
- IR observations from ground-based observatories are severely impacted by the emission from the atmosphere and telescopes themselves.
- In addition, there are wavelength ranges where the atmosphere is opaque, and no light from the sources is detected, creating gaps in coverage.
- For these reasons, to properly address the Origins science themes, the observations need to be carried out from space.
- While Hubble Space Telescope is in space, its instruments are not cooled to the level where detector noise becomes negligible.



Credit:NASA [NASA]

The James Webb Space Telescope in a nutshell

- Joint project of NASA, ESA and CSA.
- Infrared optimised mirror with a diameter of 6.5m (21’ 4”) composed of 18 gold-coated beryllium segments.
- It carries a payload of 4 scientific instruments.
- To keep instruments operating at temperatures of 37 K (-393 F) a 5 layers sunshield is used, which has an SPF greater that 1 million, and covers a comparable area to a tennis court.
- To fit JWST in the fairing of an ARIANE-5 rocket, the whole telescope has to be folded.



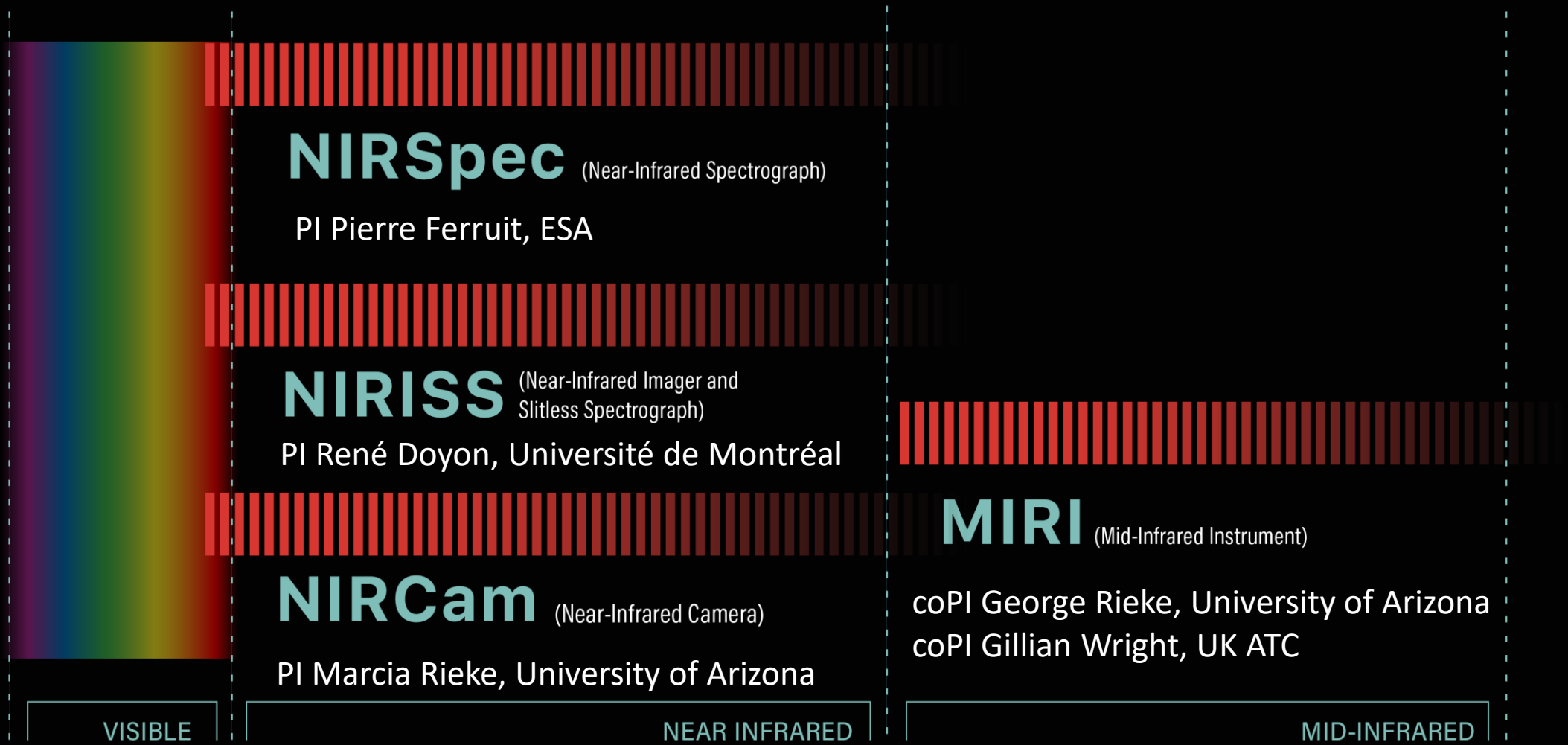
Johnson Space Center Summer 2017

Credit: NASA Flickr

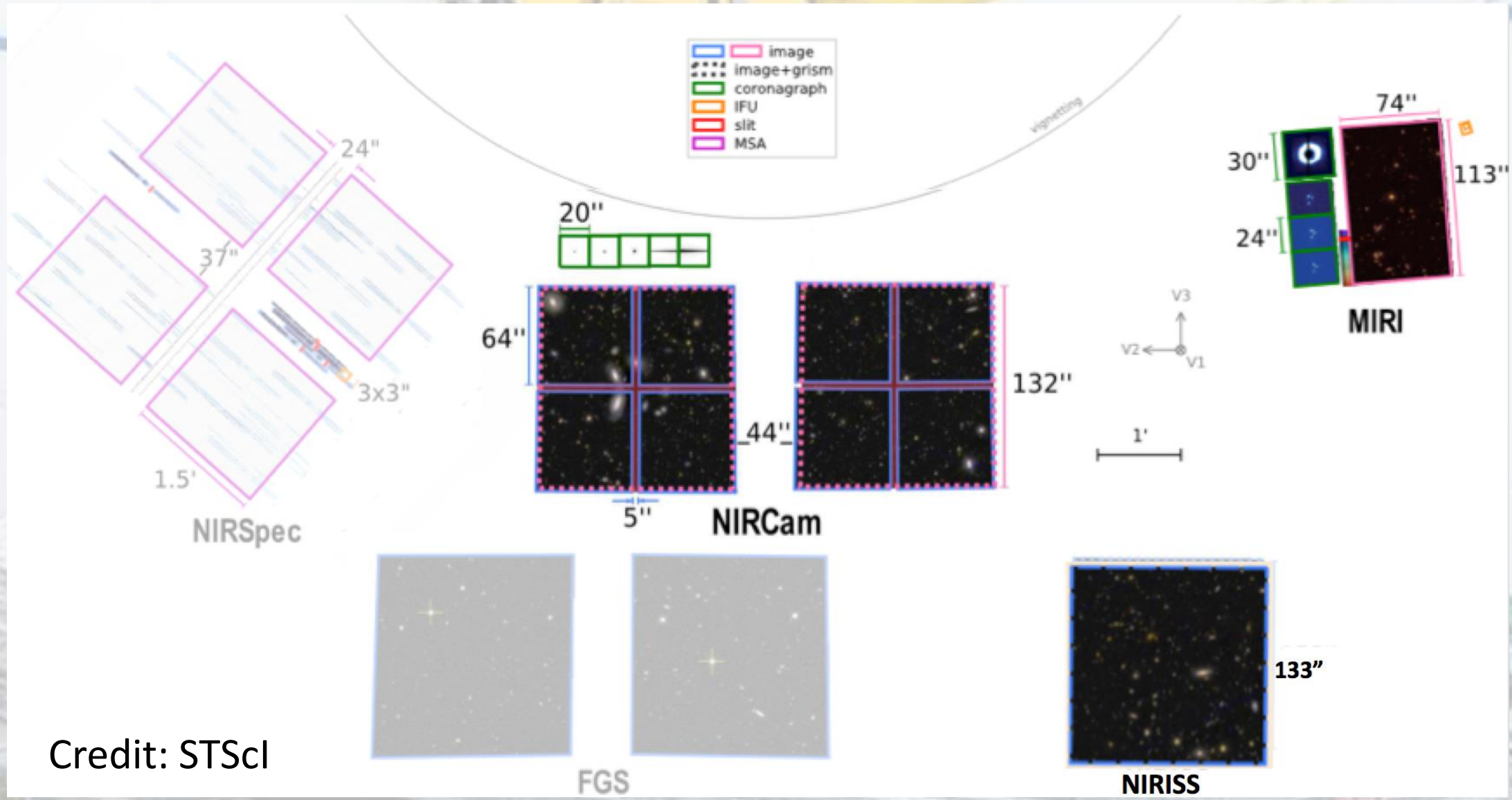
Northrop Grumman October 2021

Northrop Grumman
October 2019

Webb's Powerful Hardware

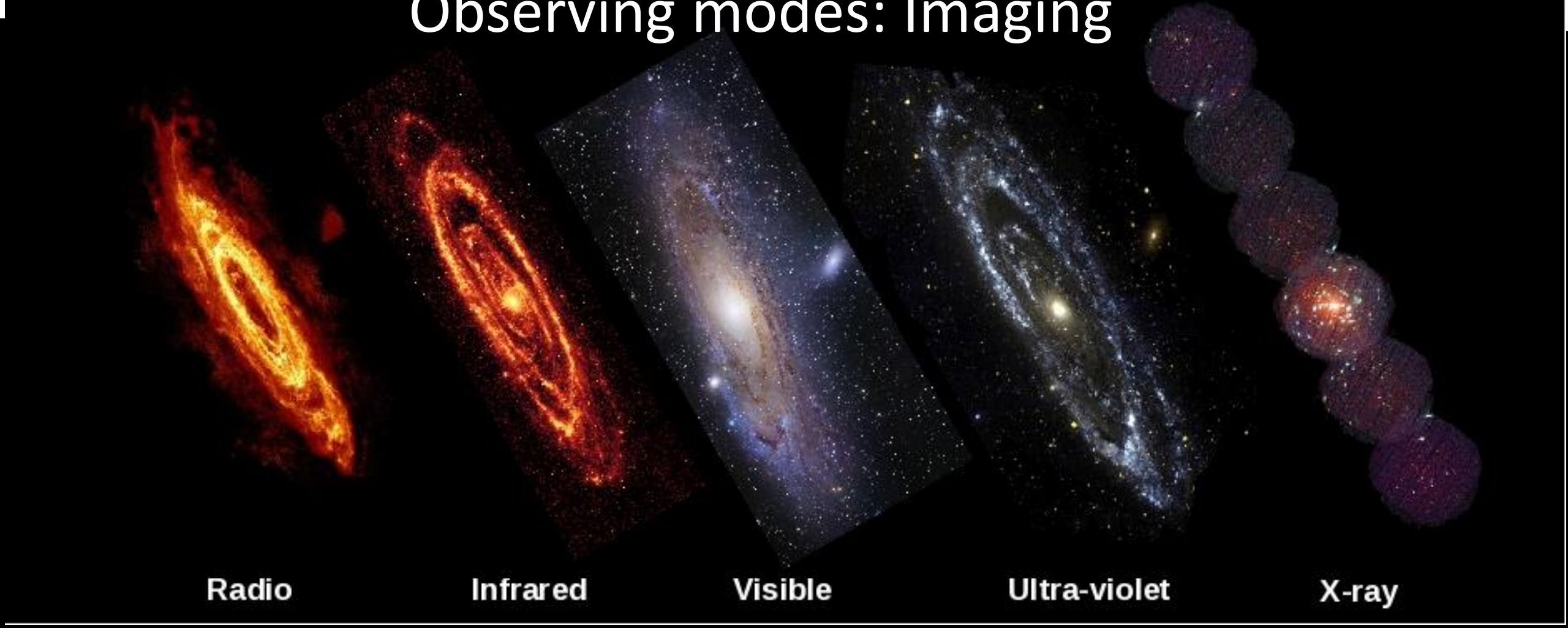


Location of instruments on the JWST Focal Plane



Credit: STScI

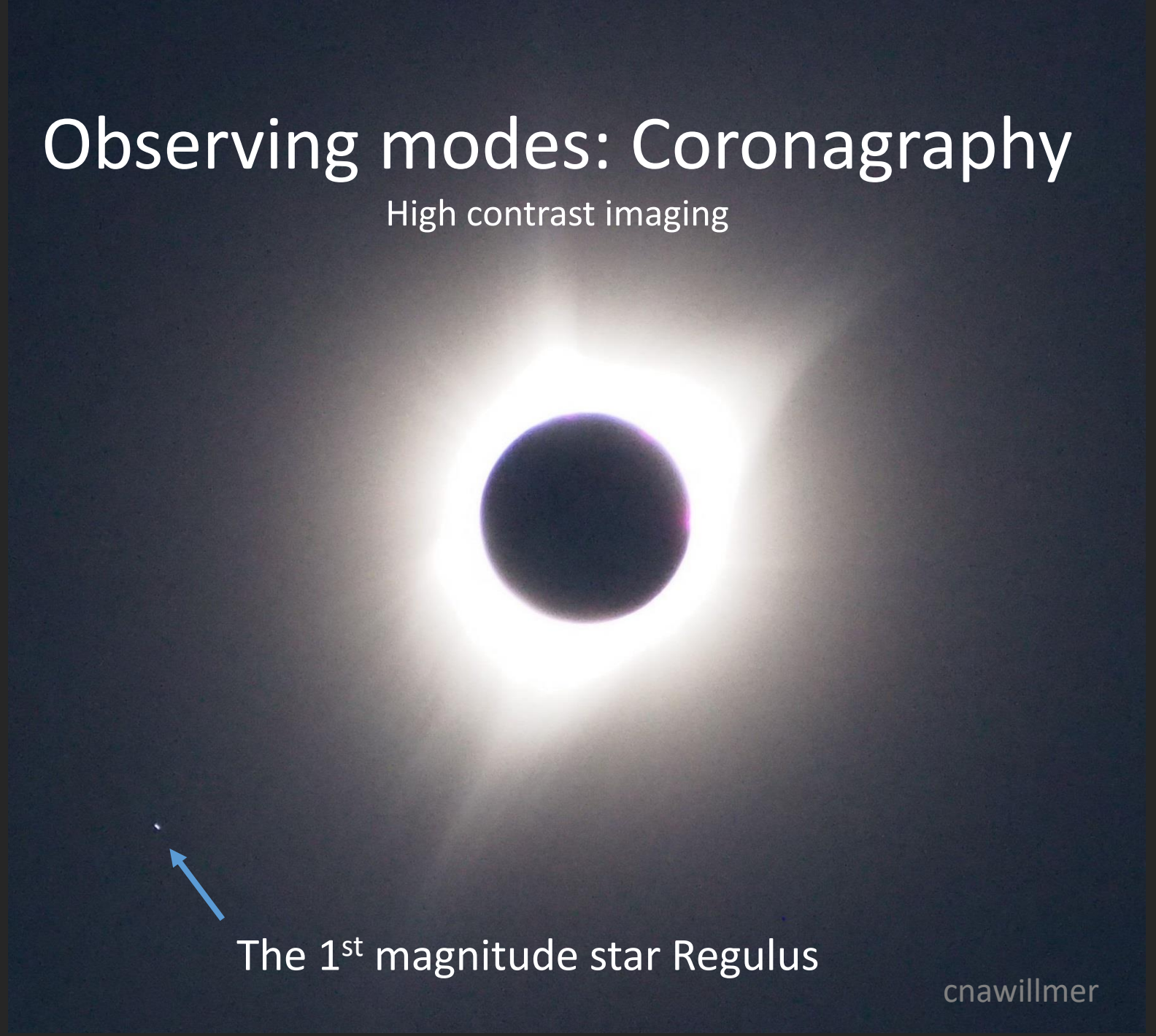
Observing modes: Imaging



Multi-wavelength images of the Andromeda galaxy (Credit:Planck Collaboration)

Observing modes: Coronagraphy

High contrast imaging



The 1st magnitude star Regulus

cnawillmer

Observing modes:Spectroscopy

Source

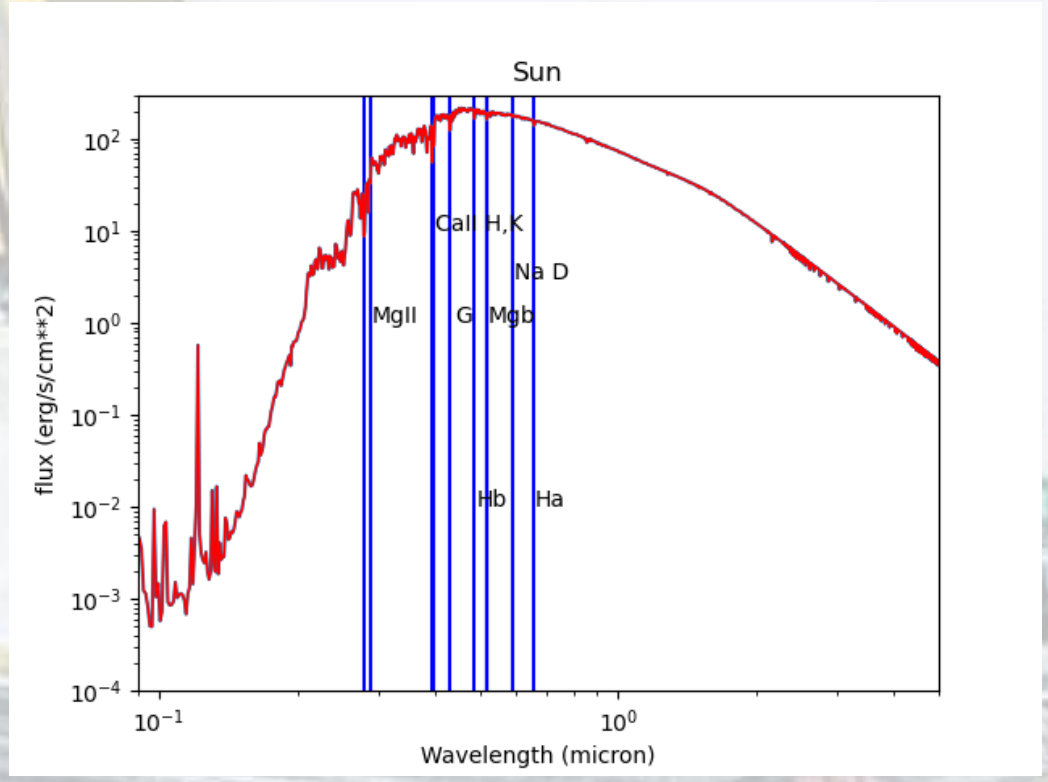
Disperser

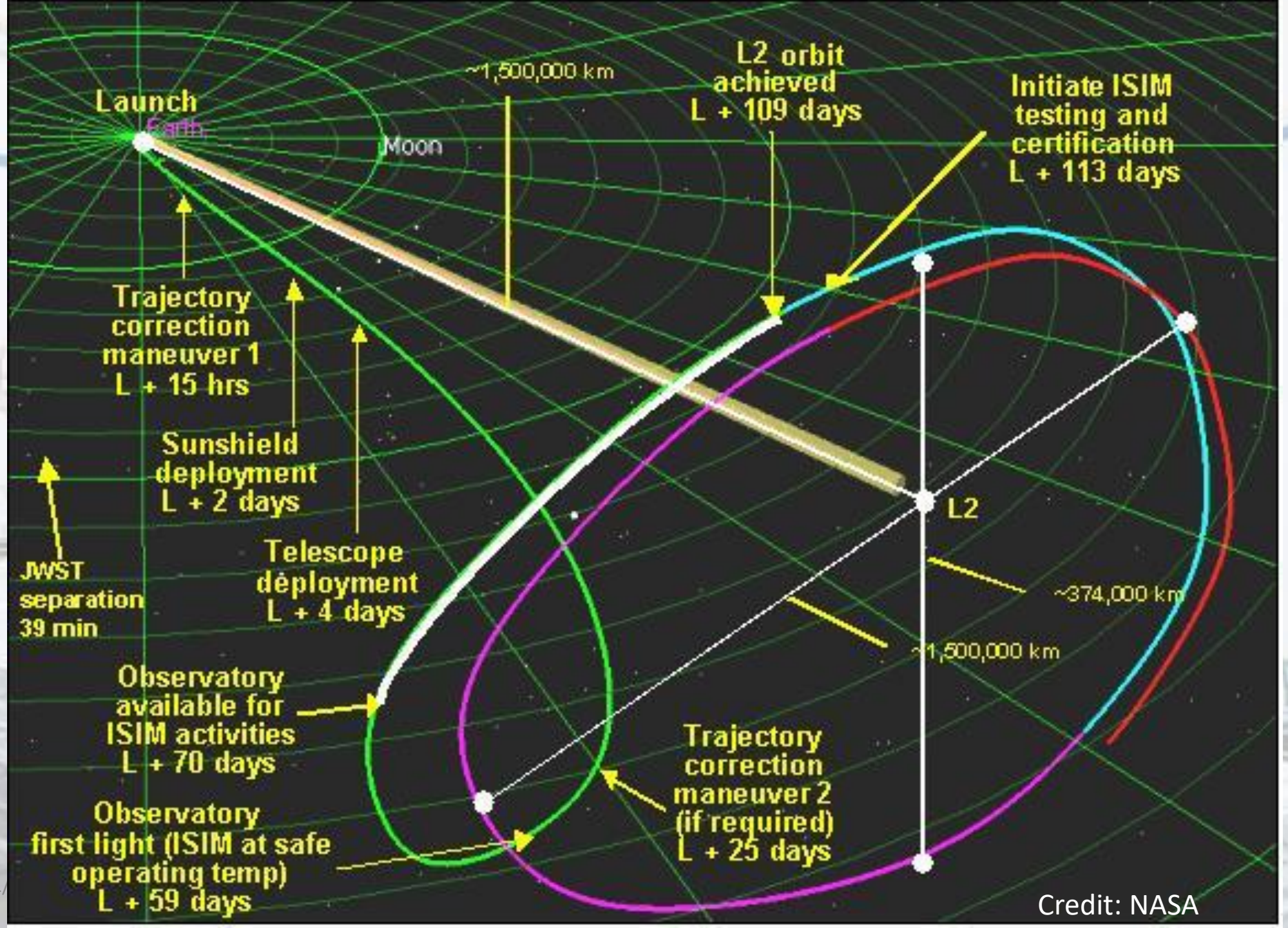
Spectrum

What does a spectrum tell us ?

Filters are used to restrict the range of “colors” (wavelengths) that reach a detector

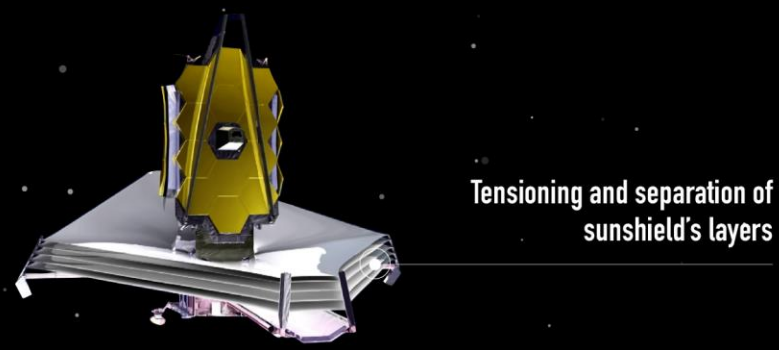
Spectra can be thought of sampling the light in much finer detail, and allow measuring the chemical composition using spectral lines.

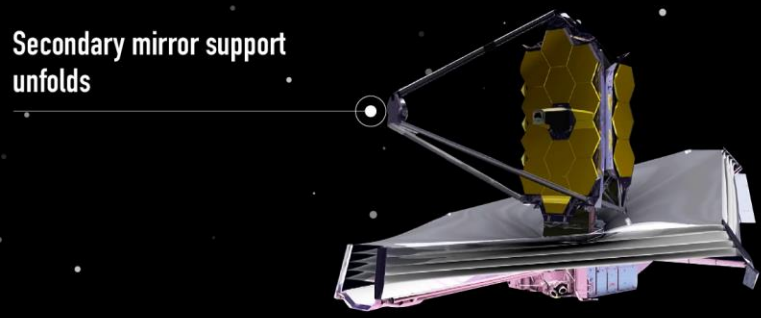


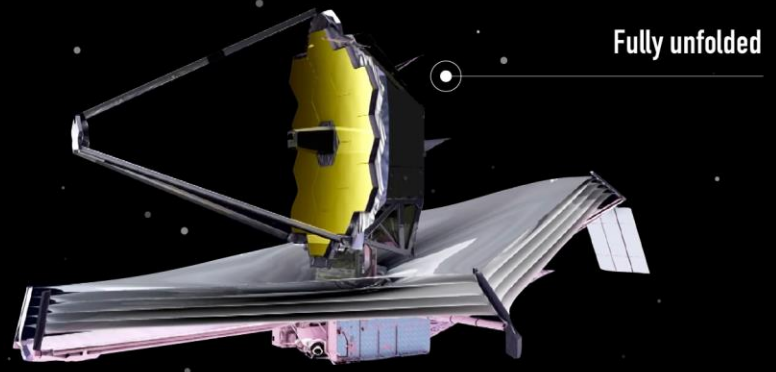

Launch
Earth
Moon
~1,500,000 km
L2 orbit achieved
L + 109 days
Initiate ISIM testing and certification
L + 113 days
Trajectory correction maneuver 1
L + 15 hrs
Sunshield deployment
L + 2 days
Telescope deployment
L + 4 days
JWST separation
39 min
L2
~374,000 km
~1,500,000 km
Observatory available for ISIM activities
L + 70 days
Trajectory correction maneuver 2 (if required)
L + 25 days
Observatory first light (ISIM at safe operating temp)
L + 59 days

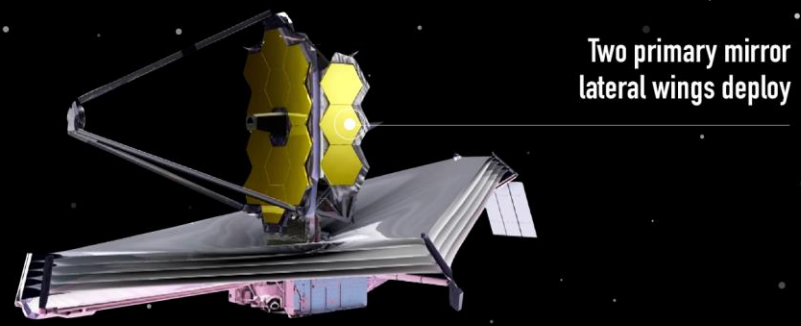
Credit: NASA

Webb's Unfolding Sequence









Credit: NASA

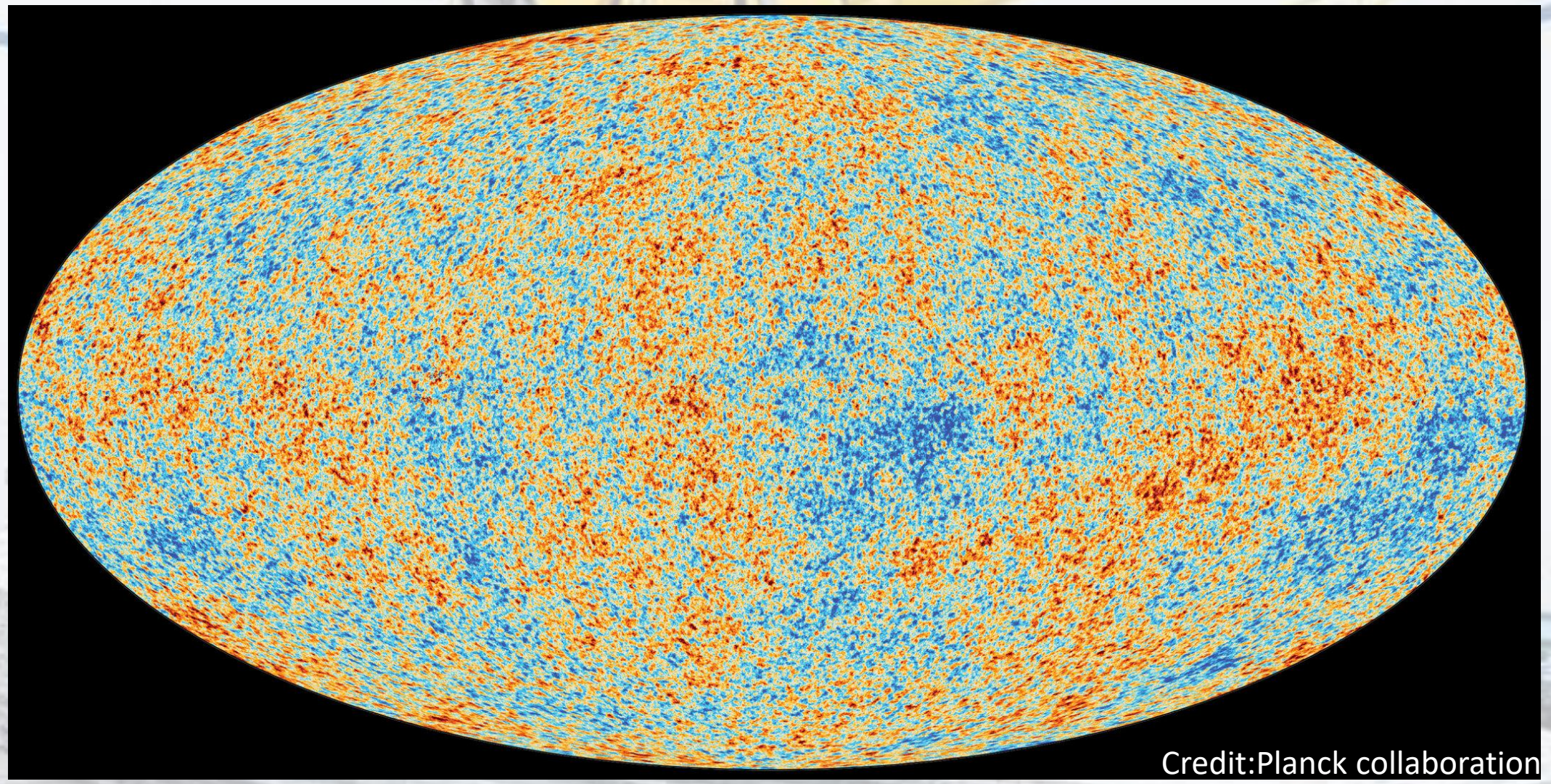
Types of sources JWST will observe
(not a complete list!)

- Galaxies
  - Very distant galaxies probing the redshift frontier
  - Very high redshift quasars
  - Resolved galaxies at low redshift
- Interstellar Medium of the Galaxy
  - Dark clouds
  - Young Stellar Objects
  - Debris disks
  - Brown dwarfs
- Exoplanets
- Solar System
  - Planets
  - Asteroids, Kuiper Belt Objects
- Full list of Cycle 1 approved programmes

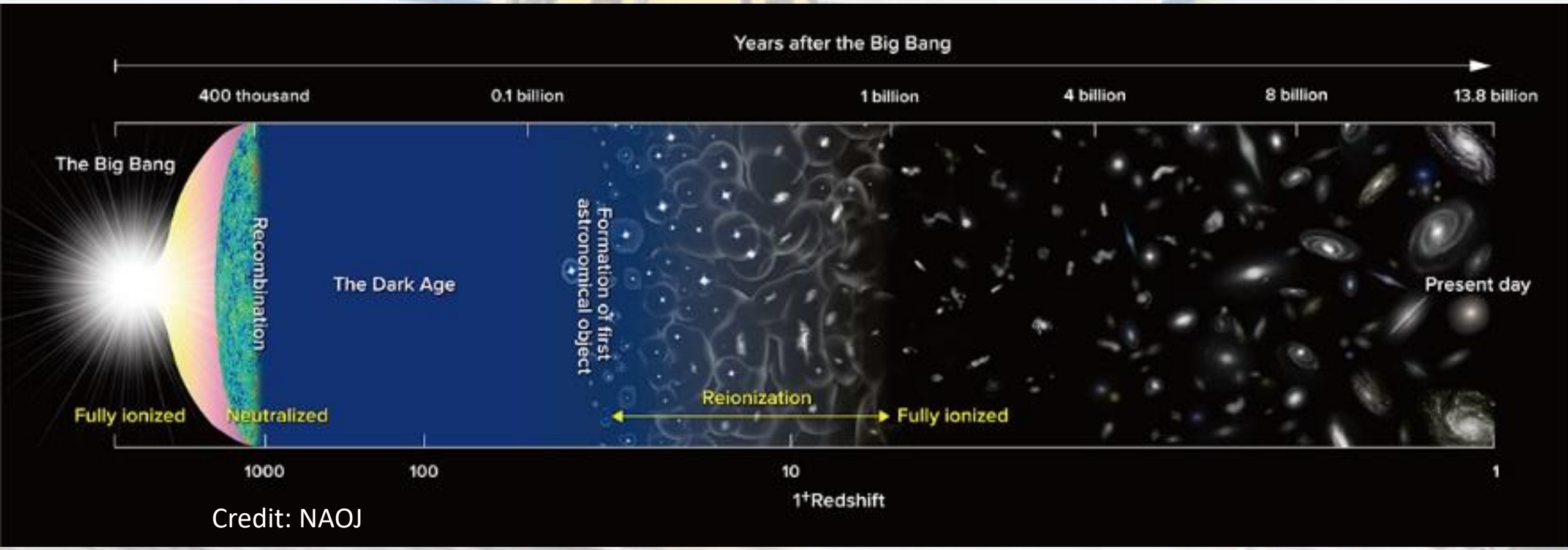
JWST as a “time-machine”

Probing the Redshift Frontier

- Light has a finite travel time and as we measure objects at greater distances we are also looking farther into the past.
- The Cosmic Microwave Background (CMB) is the most distant feature that can be observed.
- At the epoch CMB radiation was emitted, only the primordial elements (hydrogen, deuterium, helium, lithium) existed.

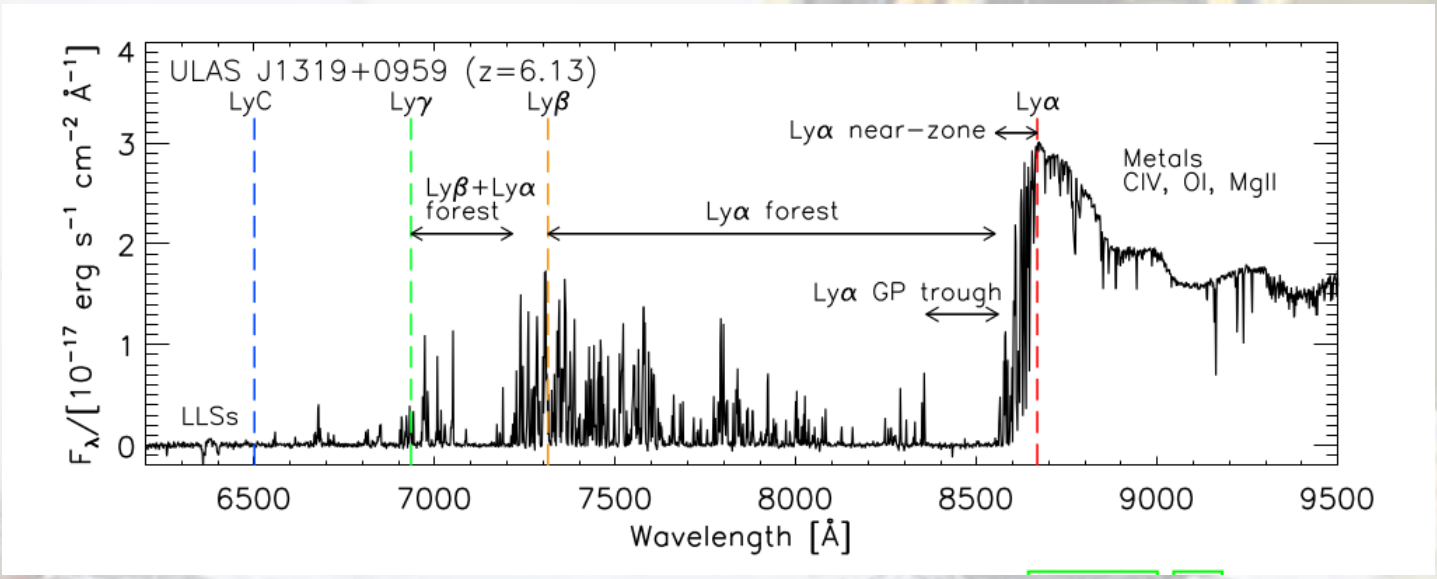

Credit:Planck collaboration

Timeline of the Universe

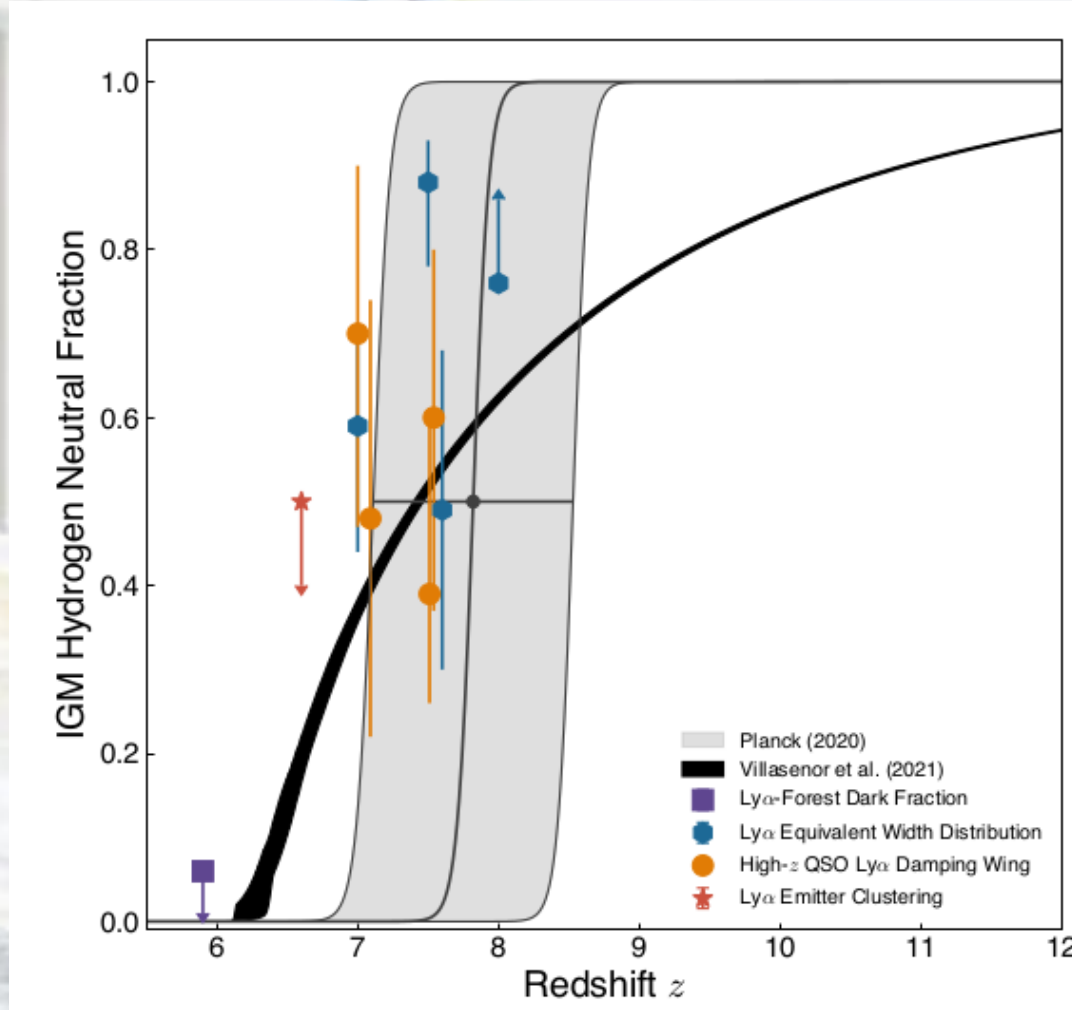


Credit: NAOJ

The attenuation of ultra-violet light coming from early galaxies increases as we reach into and beyond the Era of Reionization

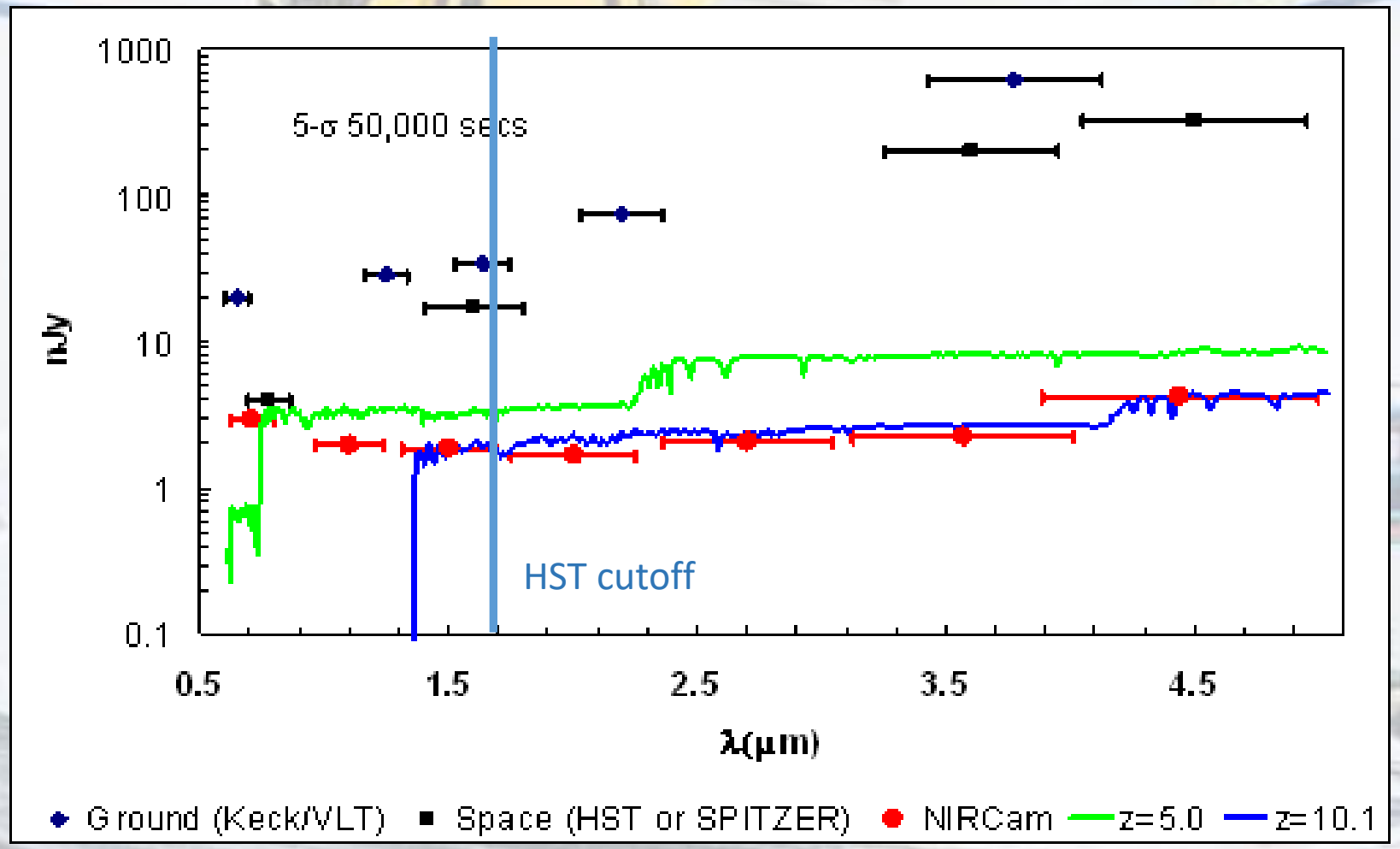


Credit: [Becker+2015]

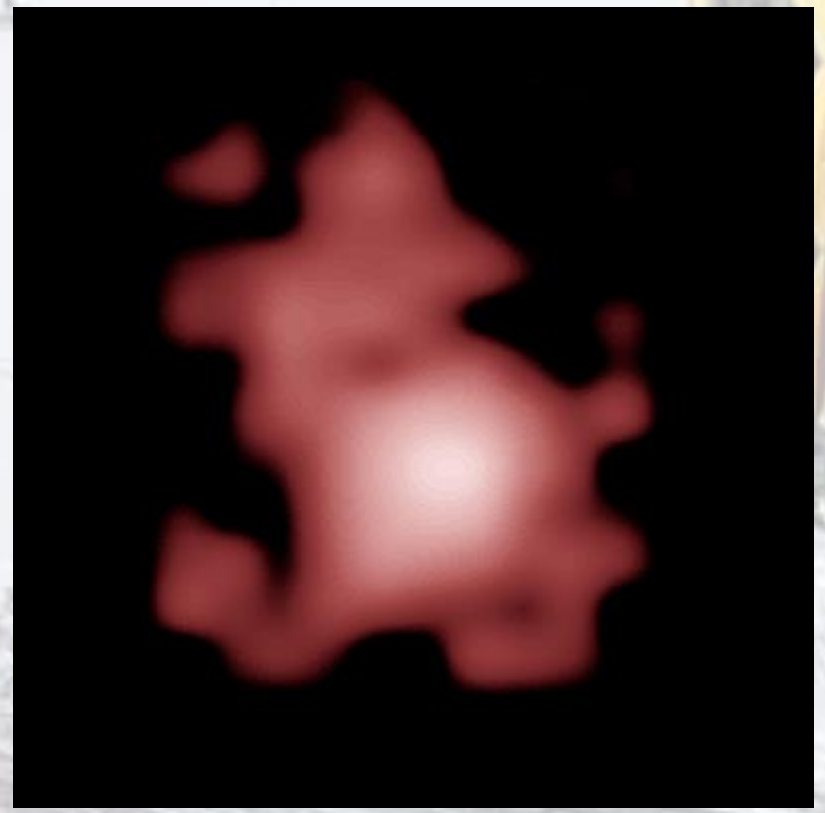


Credit: [Robertson 2021]

JWST NIRCam will observe the rest-frame visible of galaxies at z>10

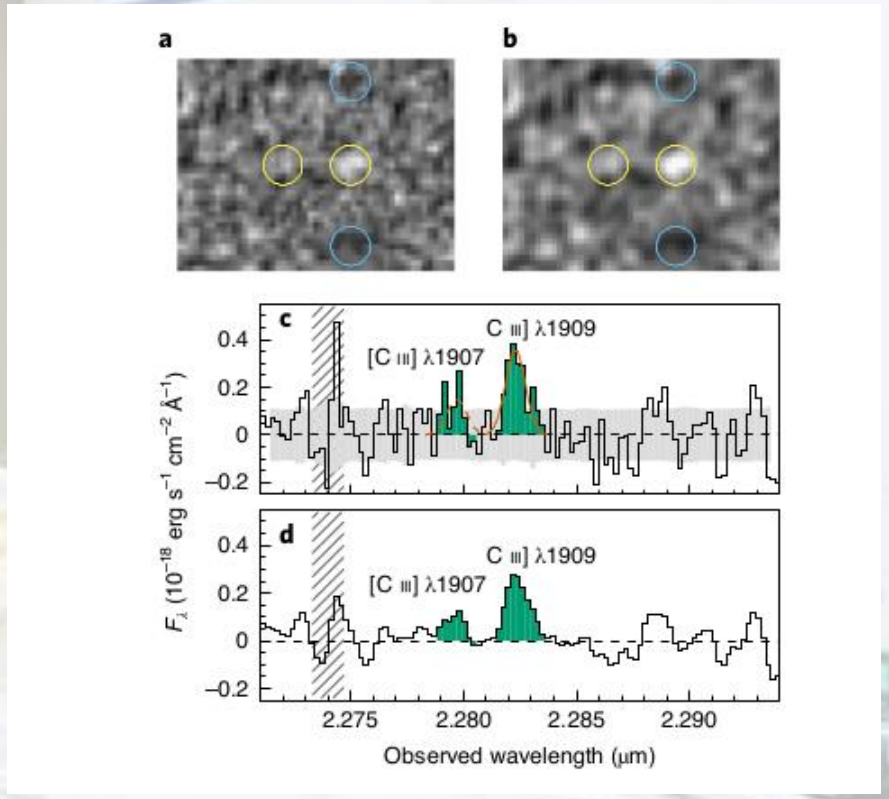


The Most Distant Galaxy (to date): GN-z11 at z = 10.957



Credit: NASA, ESA (Oesch+2016)

Carbon lines



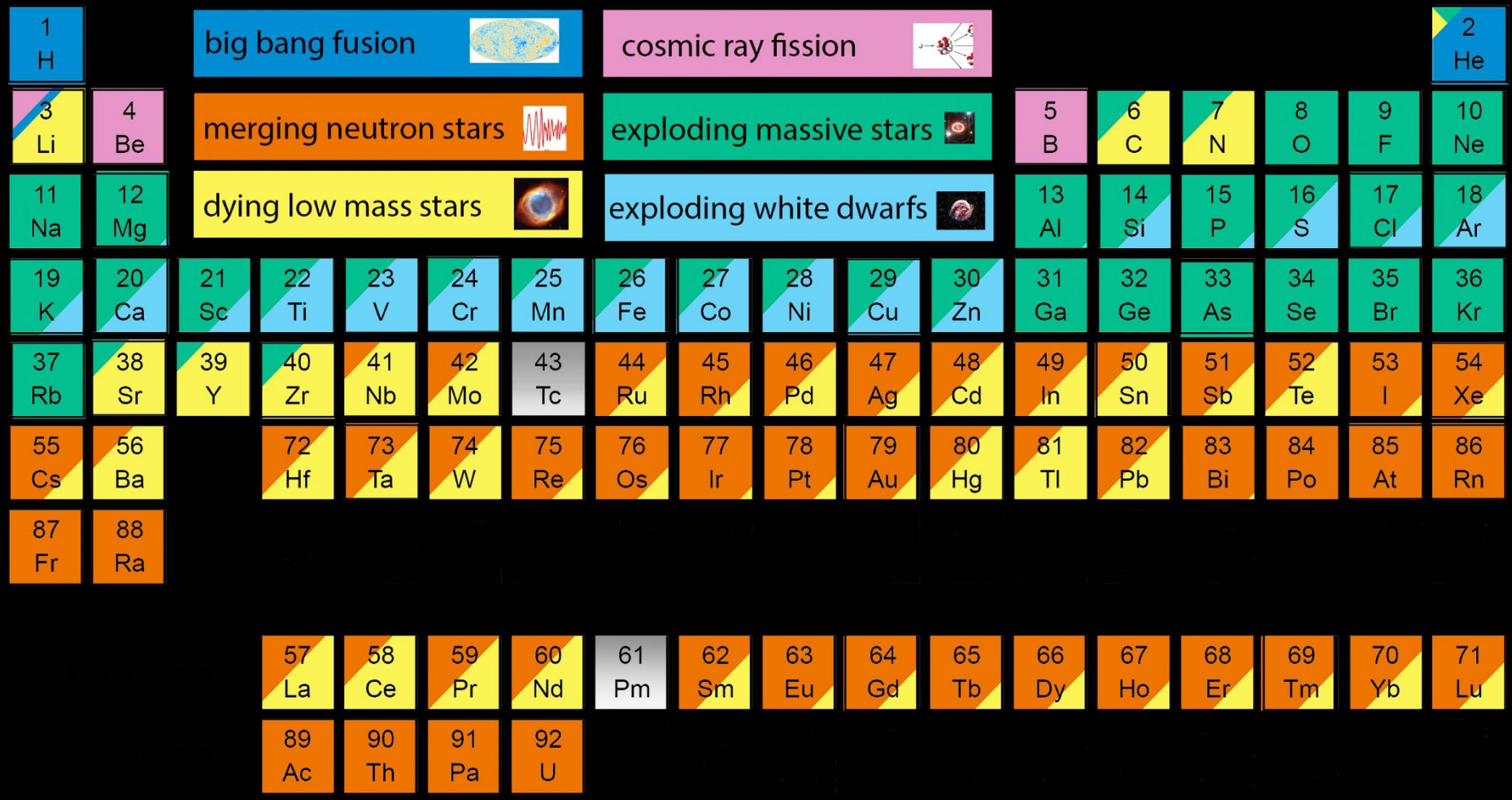
Credit: Jiang+ 2021

JWST as a “time-machine”

Probing the Redshift Frontier

- The presence of carbon lines in GN-z11 demonstrates that between the CMB epoch and the time stars in GN-z11 was formed a generation of stars had already enriched the inter-galactic and inter-stellar medium.

The Origin of the Solar System Elements

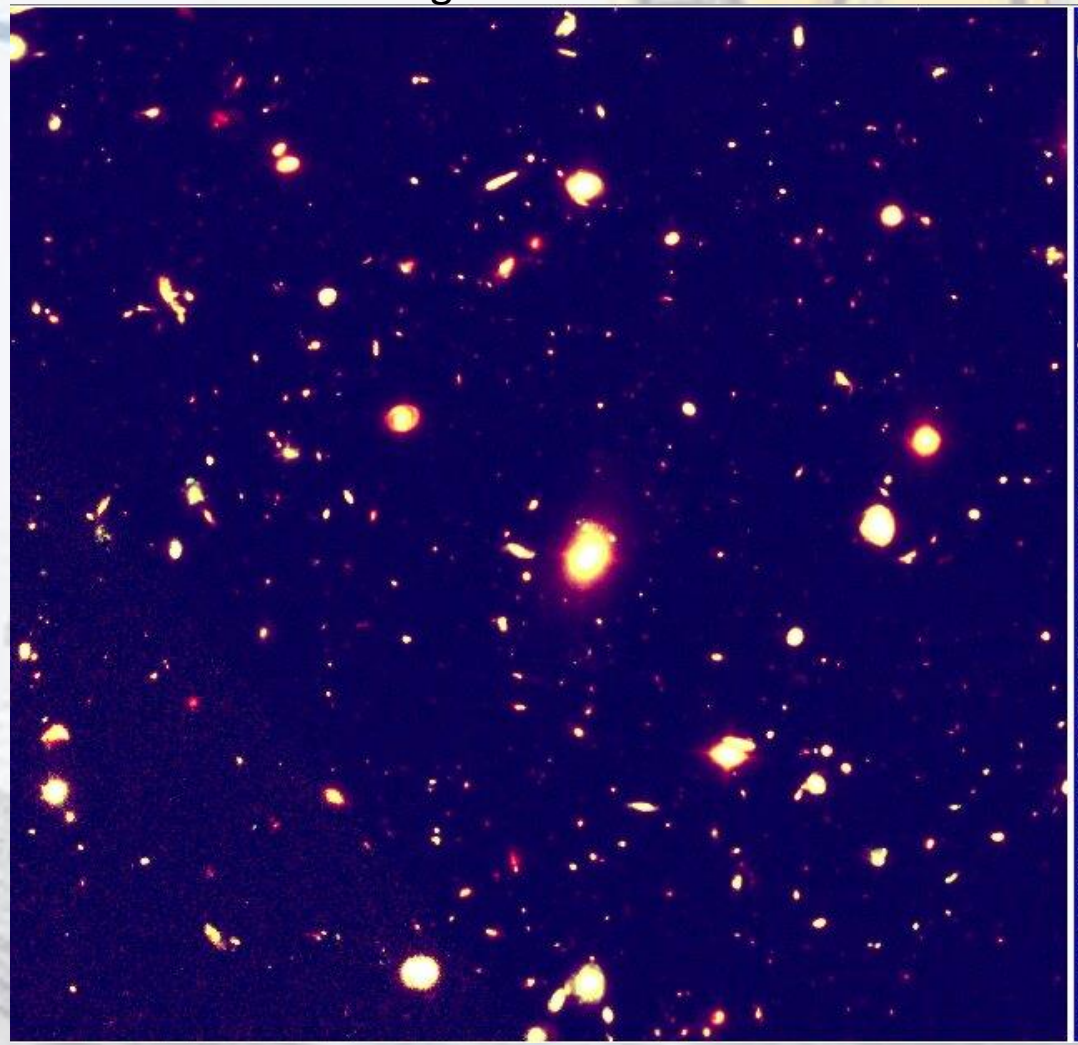


Graphic created by Jennifer Johnson

Astronomical Image Credits:
ESA/NASA/AASNova

HST in the XDF

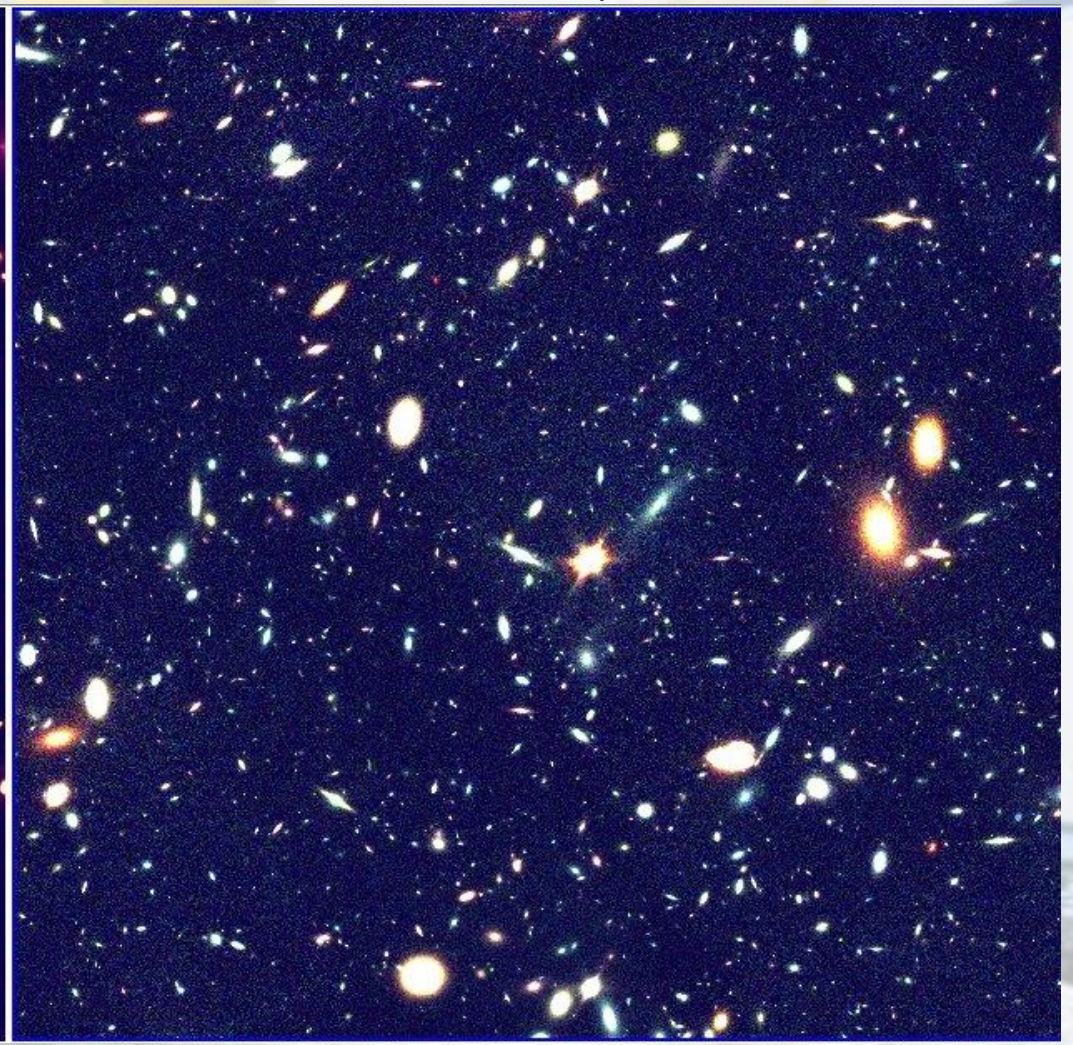
Illingworth+ 2013



F850LP, F105W, F160W

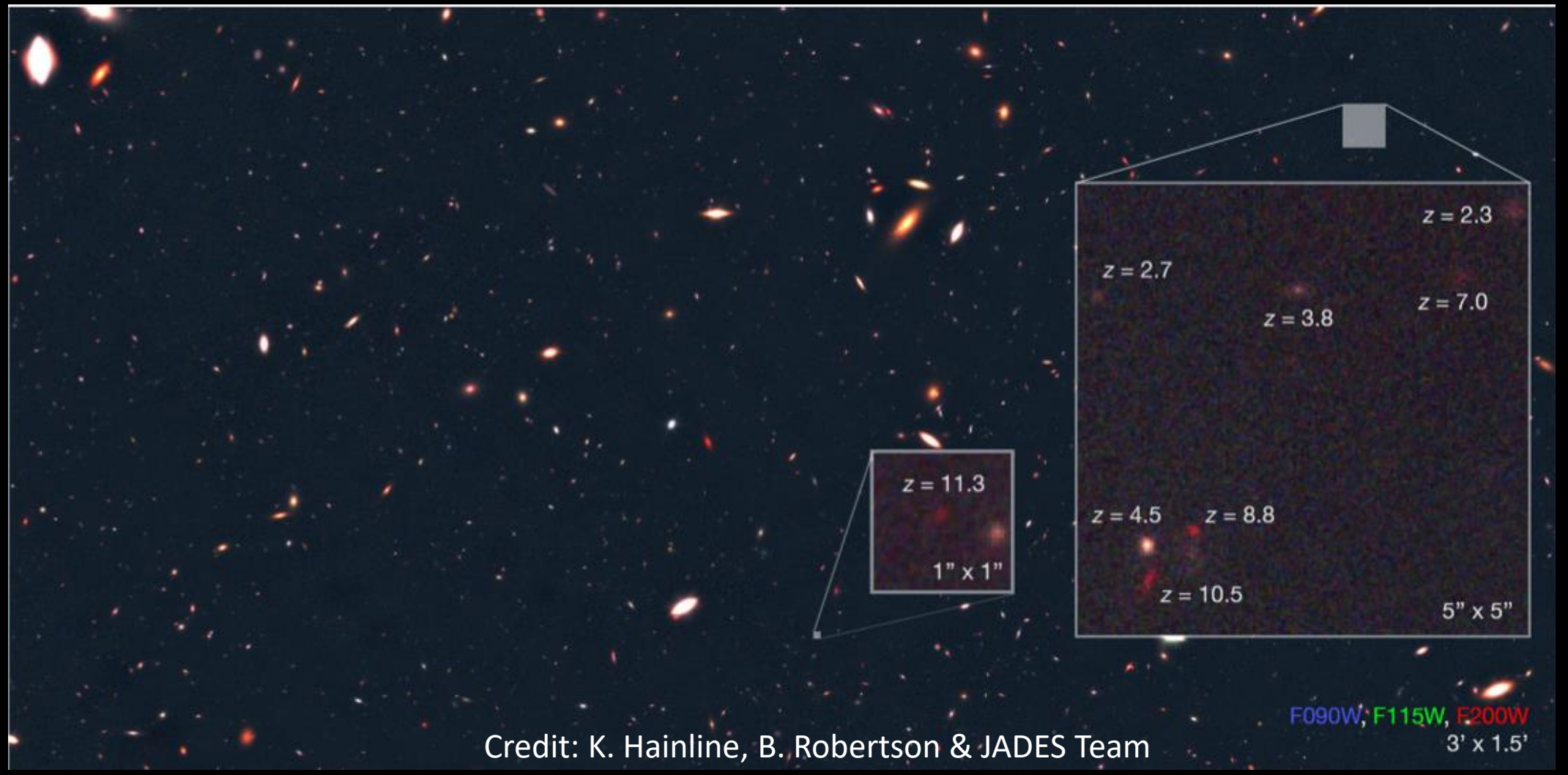
Simulated NIRCam

JADES Team 2020/2021



F090W,F115W,F200W

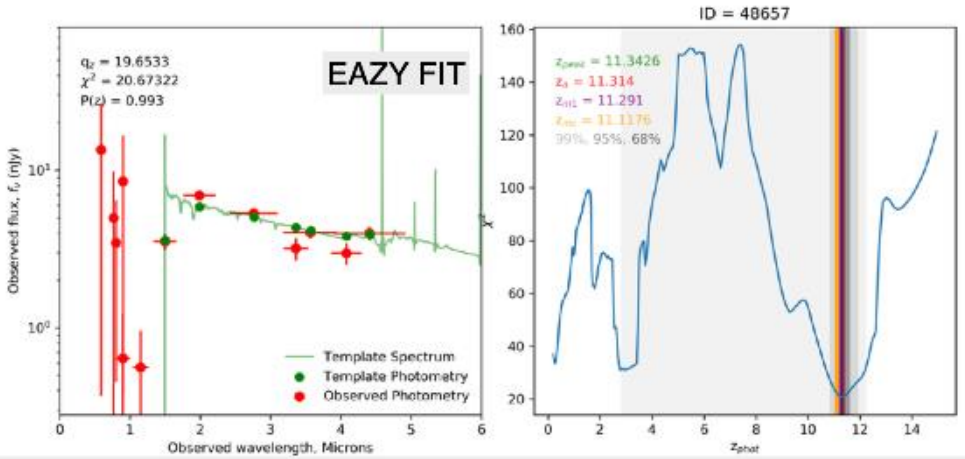
Finding very high-z galaxies

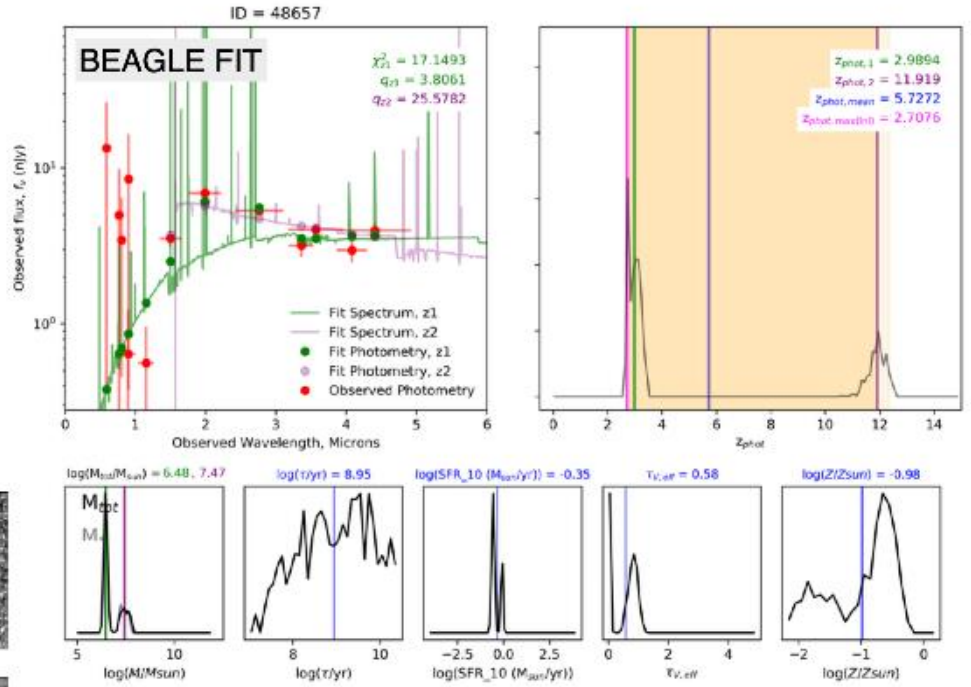


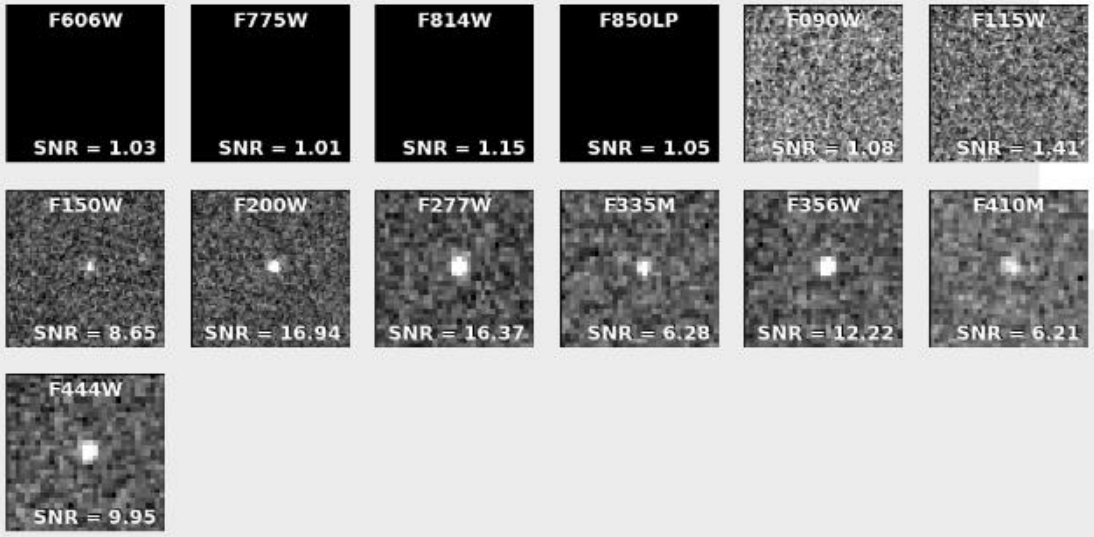
Credit: K. Hainline, B. Robertson & JADES Team

JADESView

https://github.com/kevinhainline/JADESView







RA/DEC size 2.0 arcseconds Change

Stretch Linear Log Asinh

Bad Fit | High Redshift | Bad Data

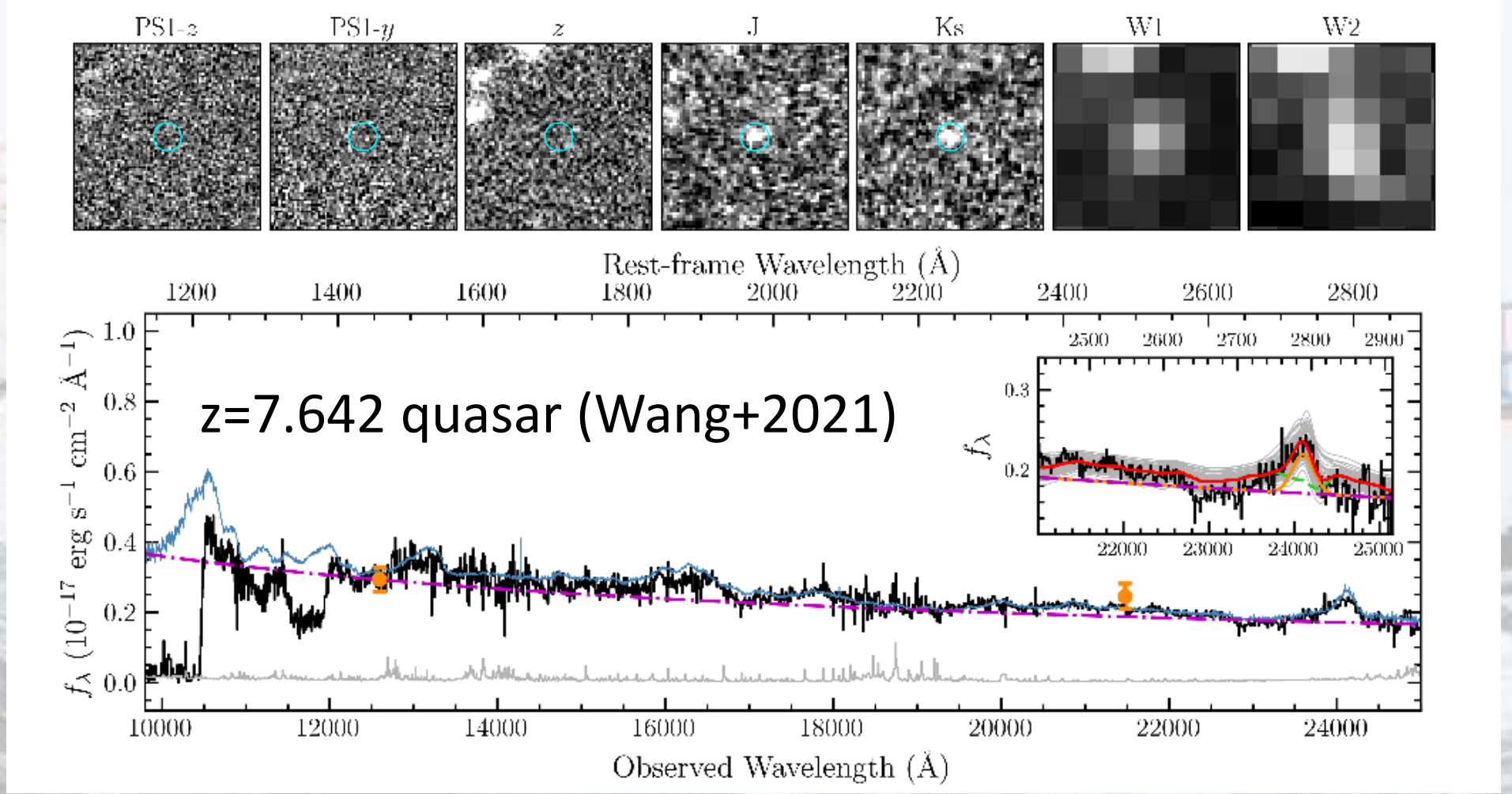
Previous Object | Next Object

Notes

Display Object: Go

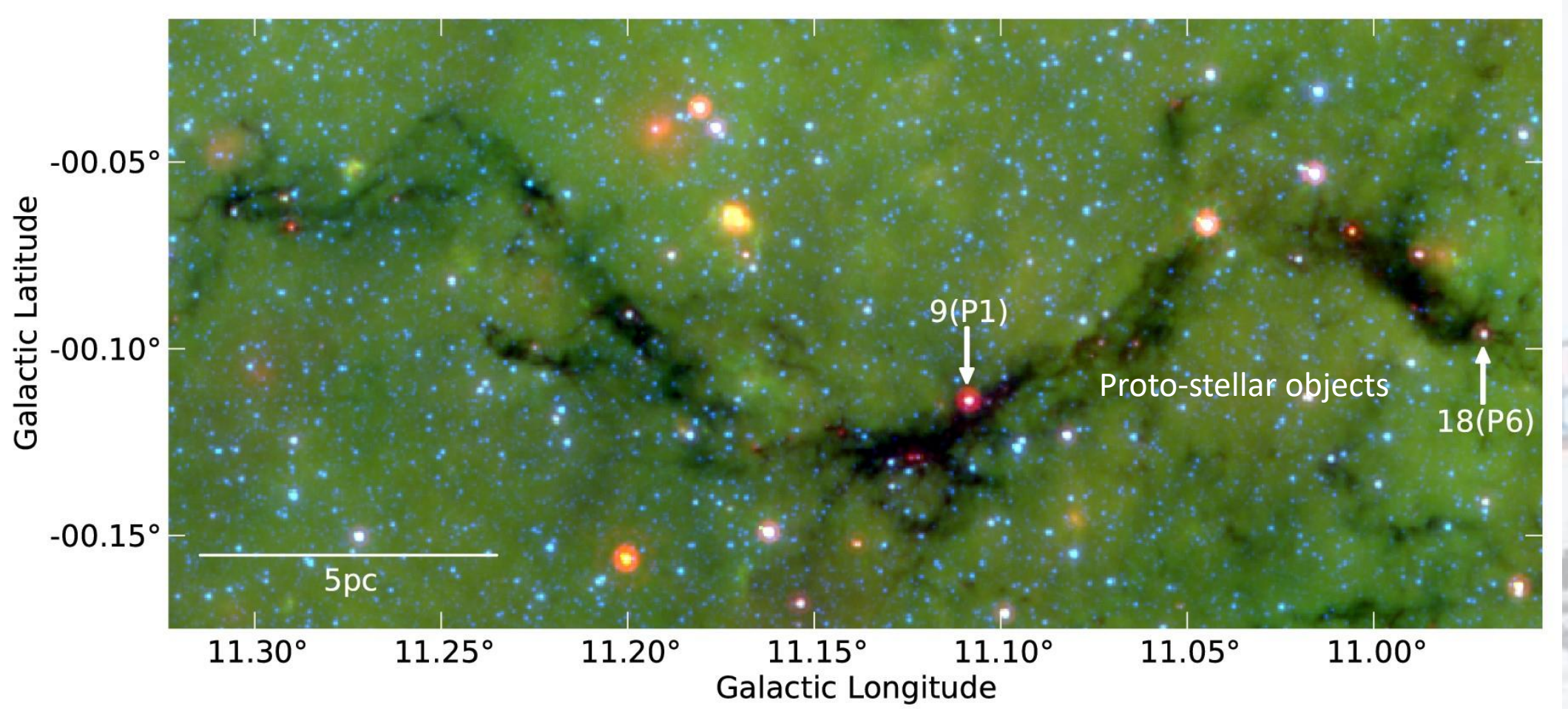
Save Canvas | Quit

Finding a Super-Massive Black hole some 670 million years after the Big Bang challenges theoretical models of how these types of objects grow.



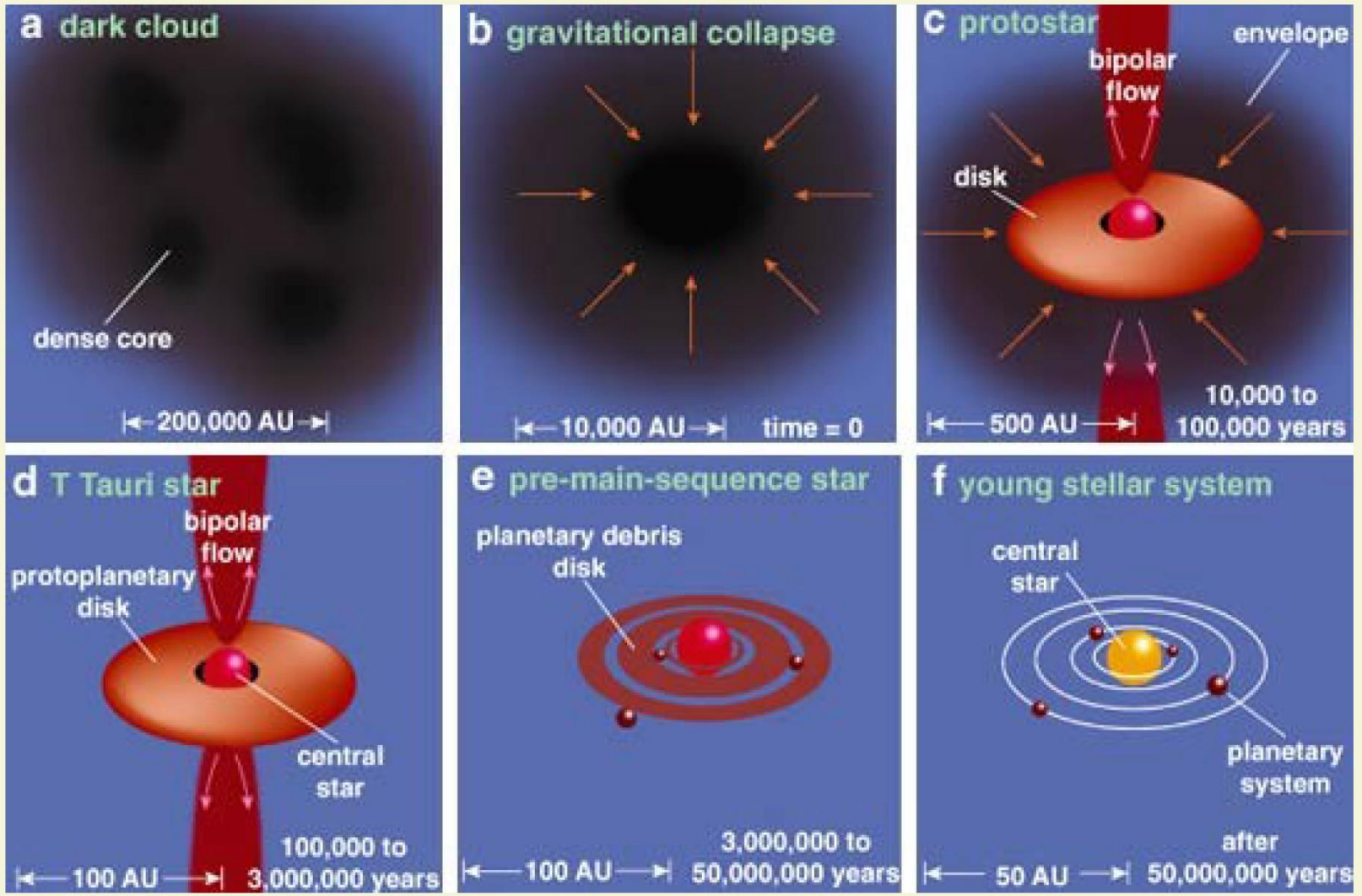
Formation of Stars and Planets

Dust clouds and Young Stellar Objects



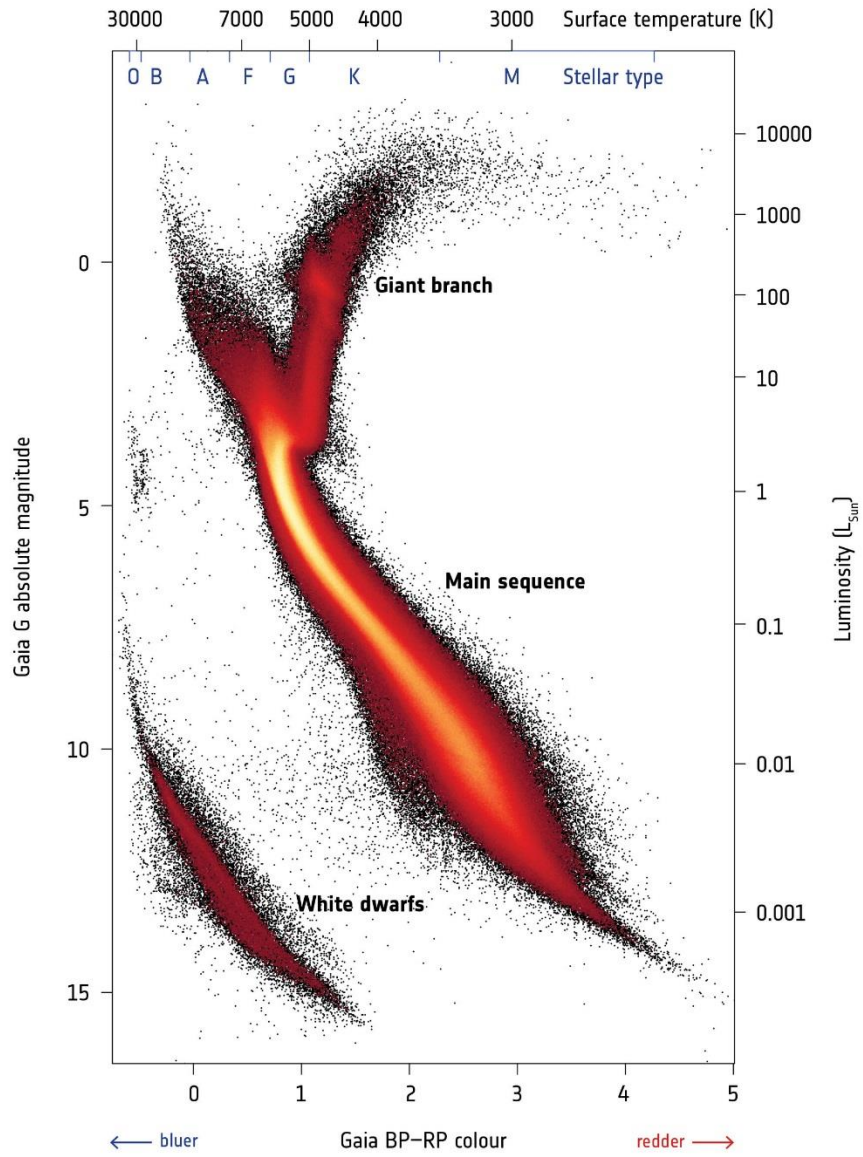
G11.11-12 (Source: Wang+2018)

Formation of planetary systems



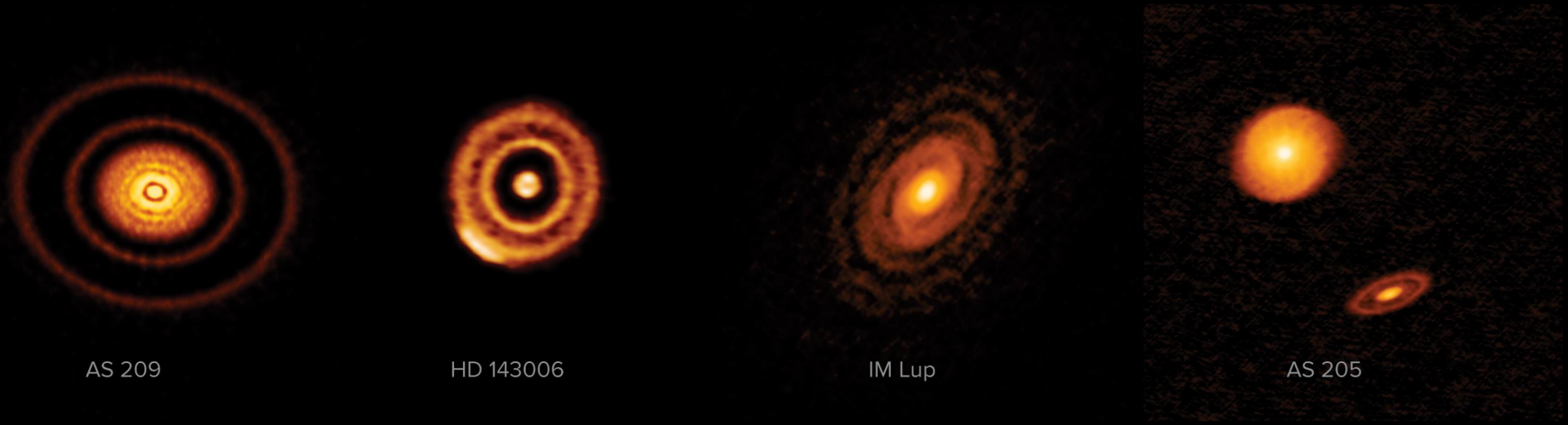
Greene (2001)

➔ GAIA'S HERTZSPRUNG-RUSSELL DIAGRAM



Credit: ESA

Proto-planetary disks imaged with ALMA

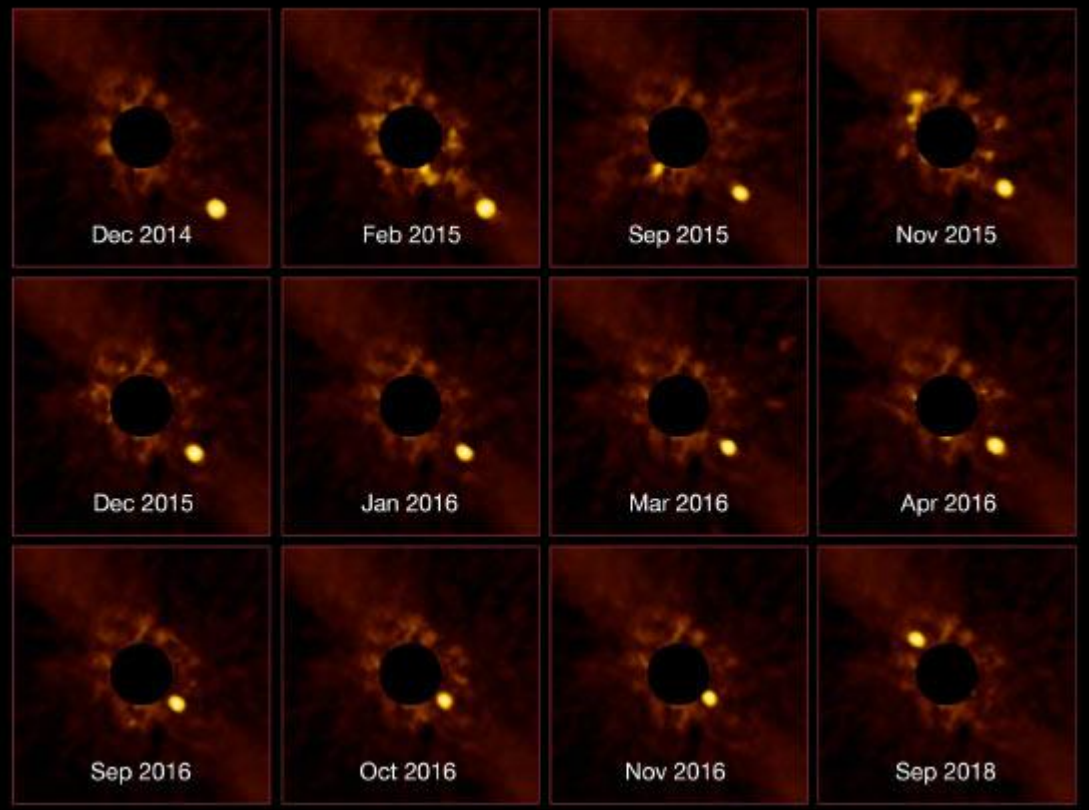


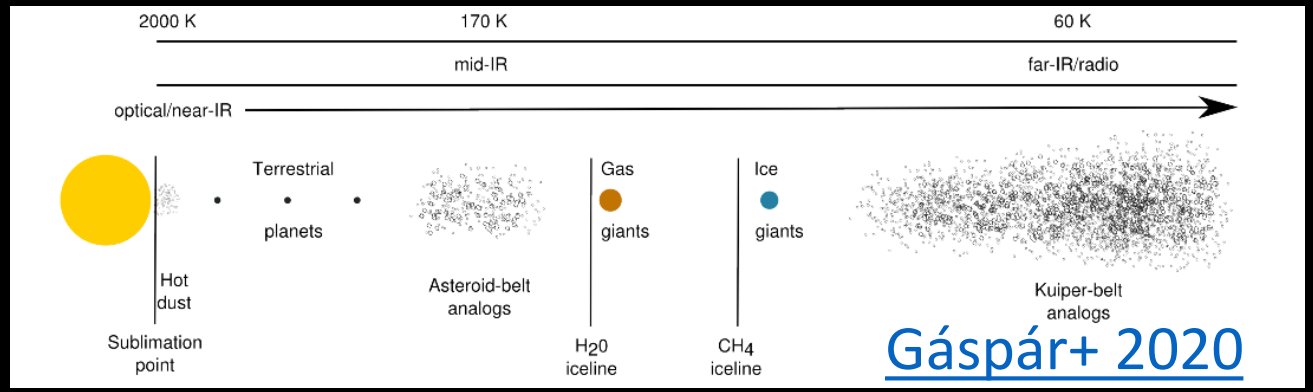
Credit: NRAO

Debris disks and planets

β Pic 2012 HST

Apai, Schneider

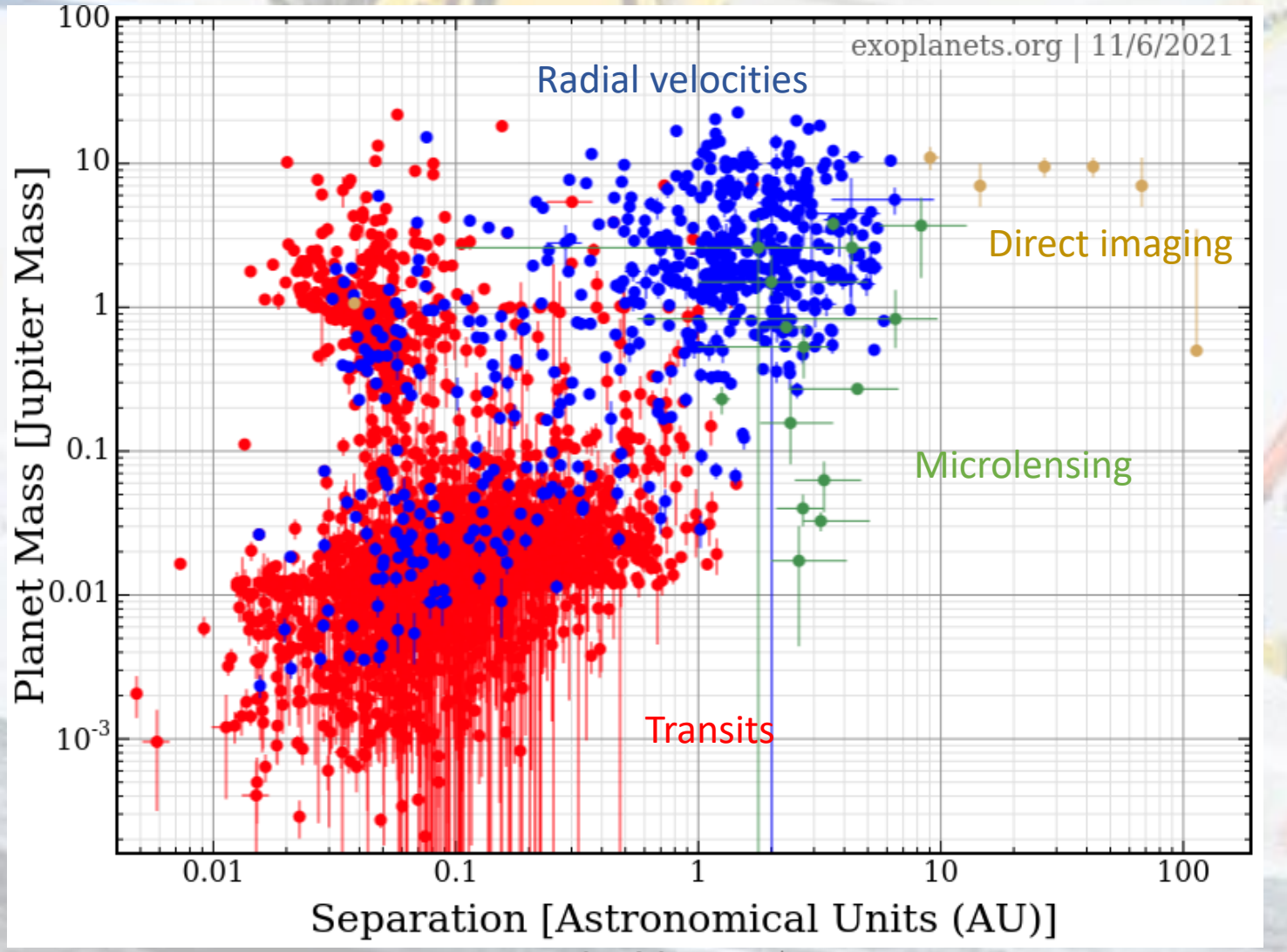




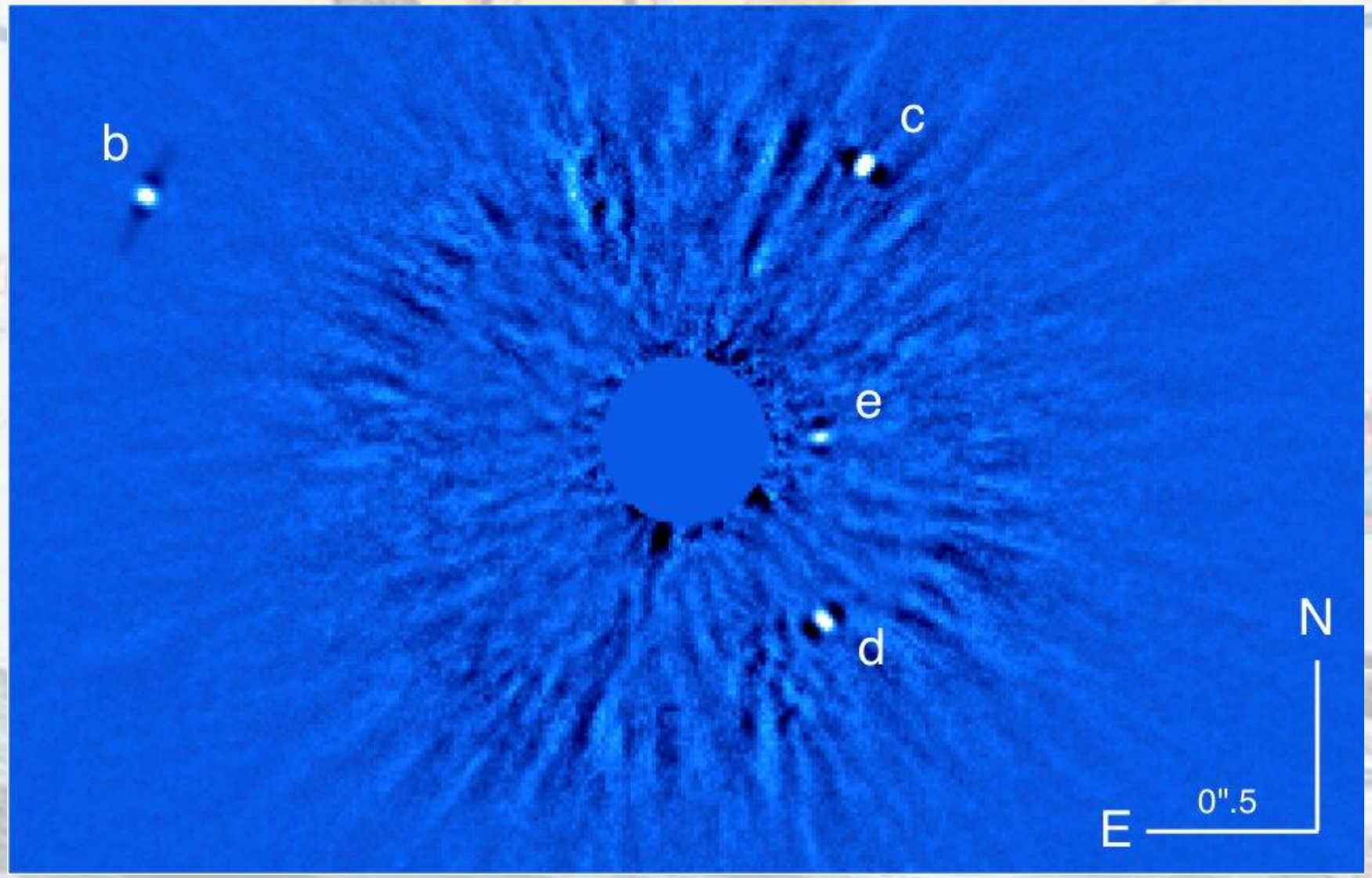
Gáspár+ 2020

β Pic b with ESO SPHERE credit: Lagrange+2019

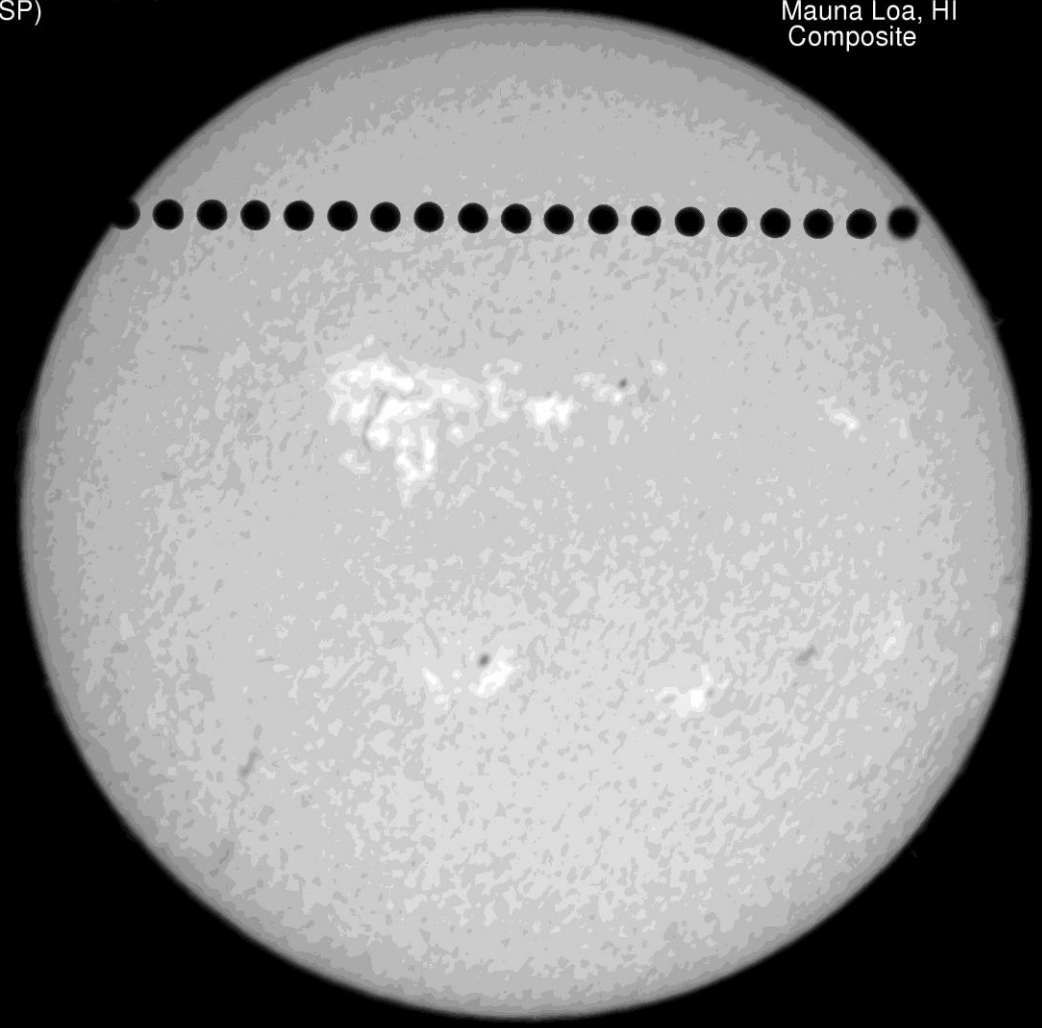
Exoplanets: census by detection method



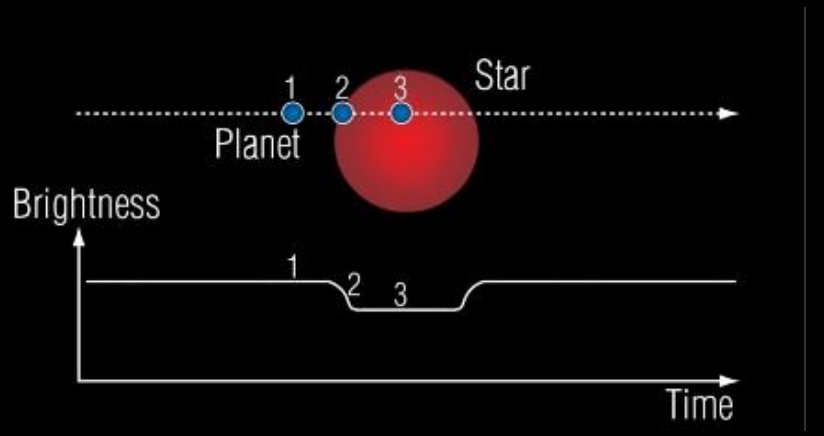
Direct Imaging :HR8799 (Wertz+ 2017)



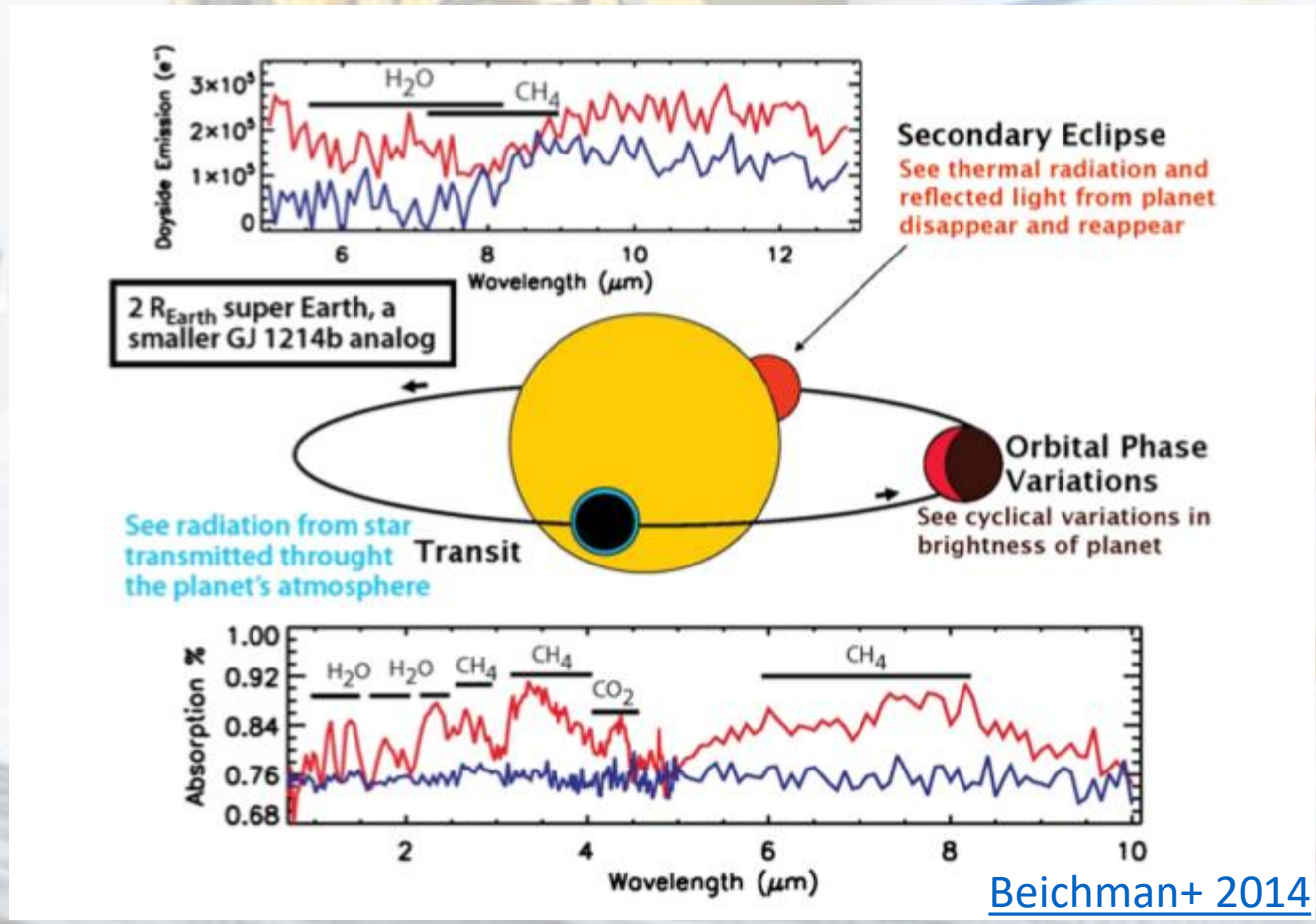
Planetary Transits



light curve



Planetary transit: spectroscopy



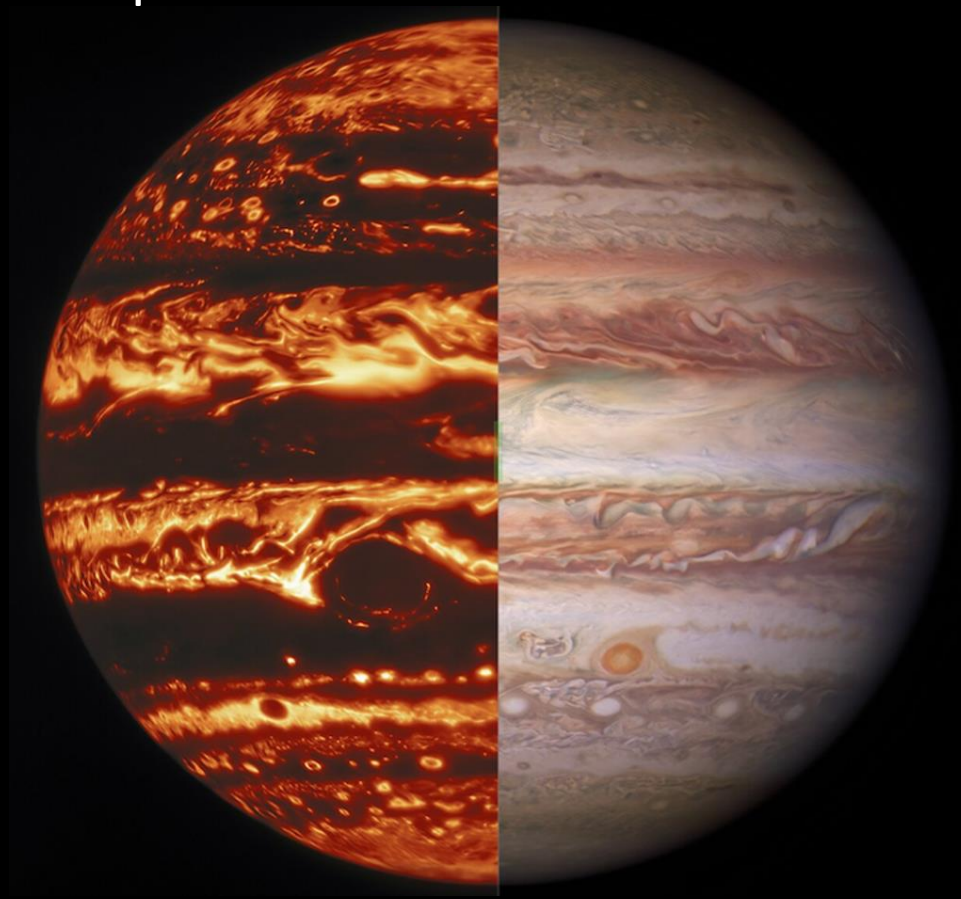
Beichman+ 2014

Solar System

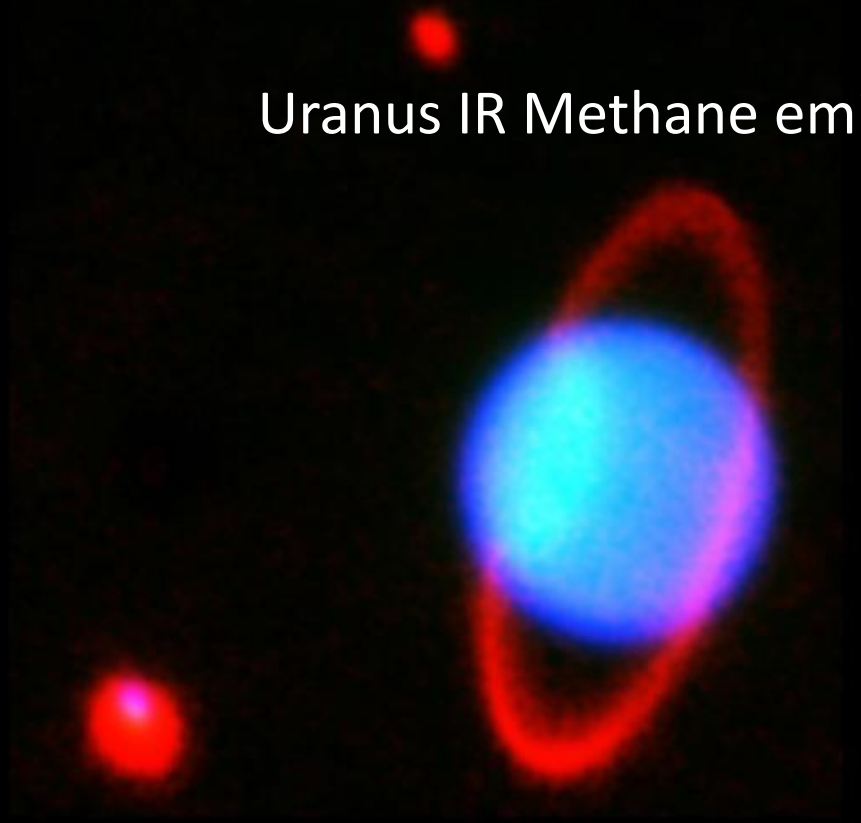
- Planets
  - Terrestrial
  - Gas giants
  - Dwarf planets
- Asteroid belt
- Kuiper Belt
- Zodiacal dust
- Oort Cloud

Solar System

Jupiter infrared and visible



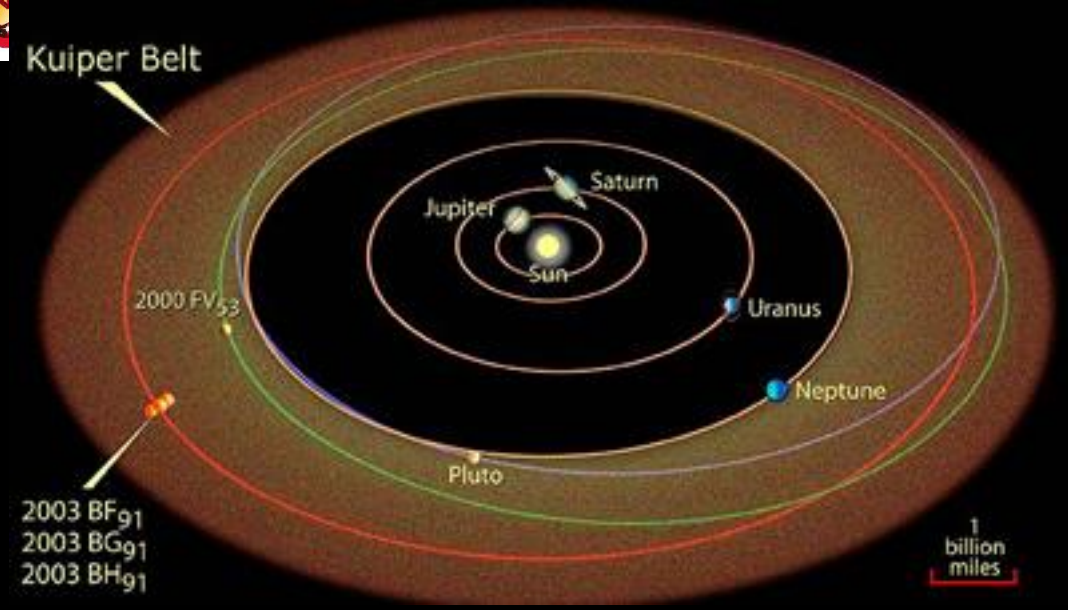
Uranus IR Methane emission



Credit: Subaru Telescope, NAOJ

https://www.nasa.gov/press-release/nasa-s-juno-science-results-offer-first-3d-view-of-jupiter-atmosphere

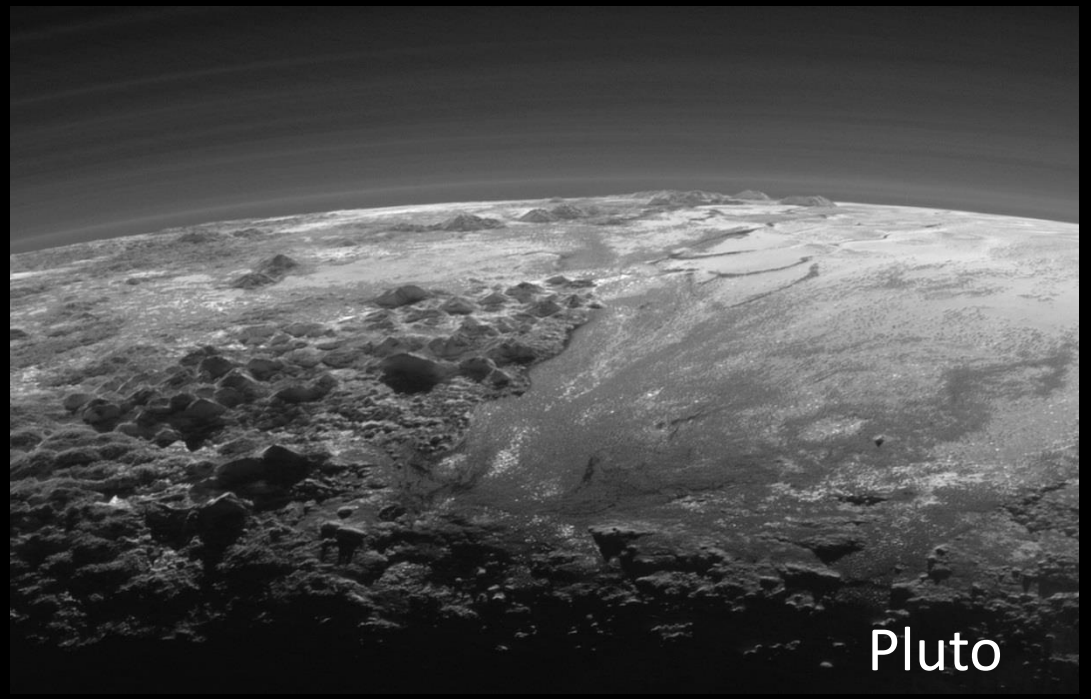
Kuiper Belt Objects



https://astronomy.swin.edu.au/cms/cpg15x/albums/userpics/kuiperbelt.jpg

Arrokoth

https://solarsystem.nasa.gov/resources/2449/t



https://solarsystem.nasa.gov/planets/dwarf-planets/pluto/

Concluding remarks

- JWST will provide vital data to constrain how galaxies evolved as the barrier imposed by the Gunn-Peterson absorption will be overcome.
- By expanding the number of well studied exoplanets and distant Solar System bodies we will gain a better understanding on how planets form and evolve and how common are the properties necessary for habitability.
- This presentation barely scratches the surface of the science that JWST enables.
- Because of JWST's unique capabilities, it will probably make several unexpected discoveries during its lifetime.

On Track for Late 2021 Launch !

- **An Ariane V launch from the Kourou Space Center in French Guiana.**

Figure courtesy of Prof. Marcia Rieke


Credit: Northrop-Grumman
Thank you for
Your attention!

Links for further information

- JWST for the General Public :https://webbtelescope.org/
- JWST for Scientists: https://www.stsci.edu/jwst
- Approved programs: https://www.stsci.edu/jwst/science-execution/approved-programs
- Cosmic Origins Program