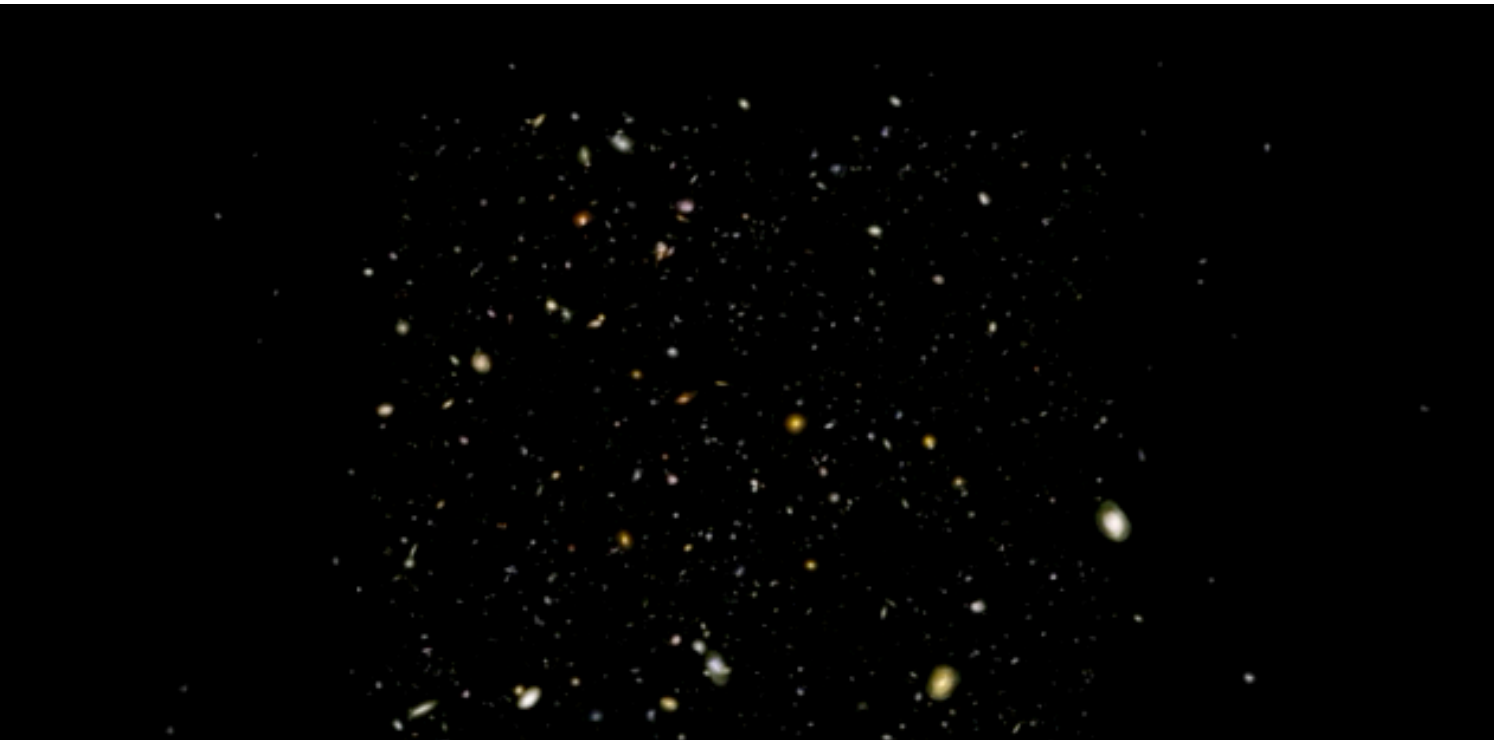
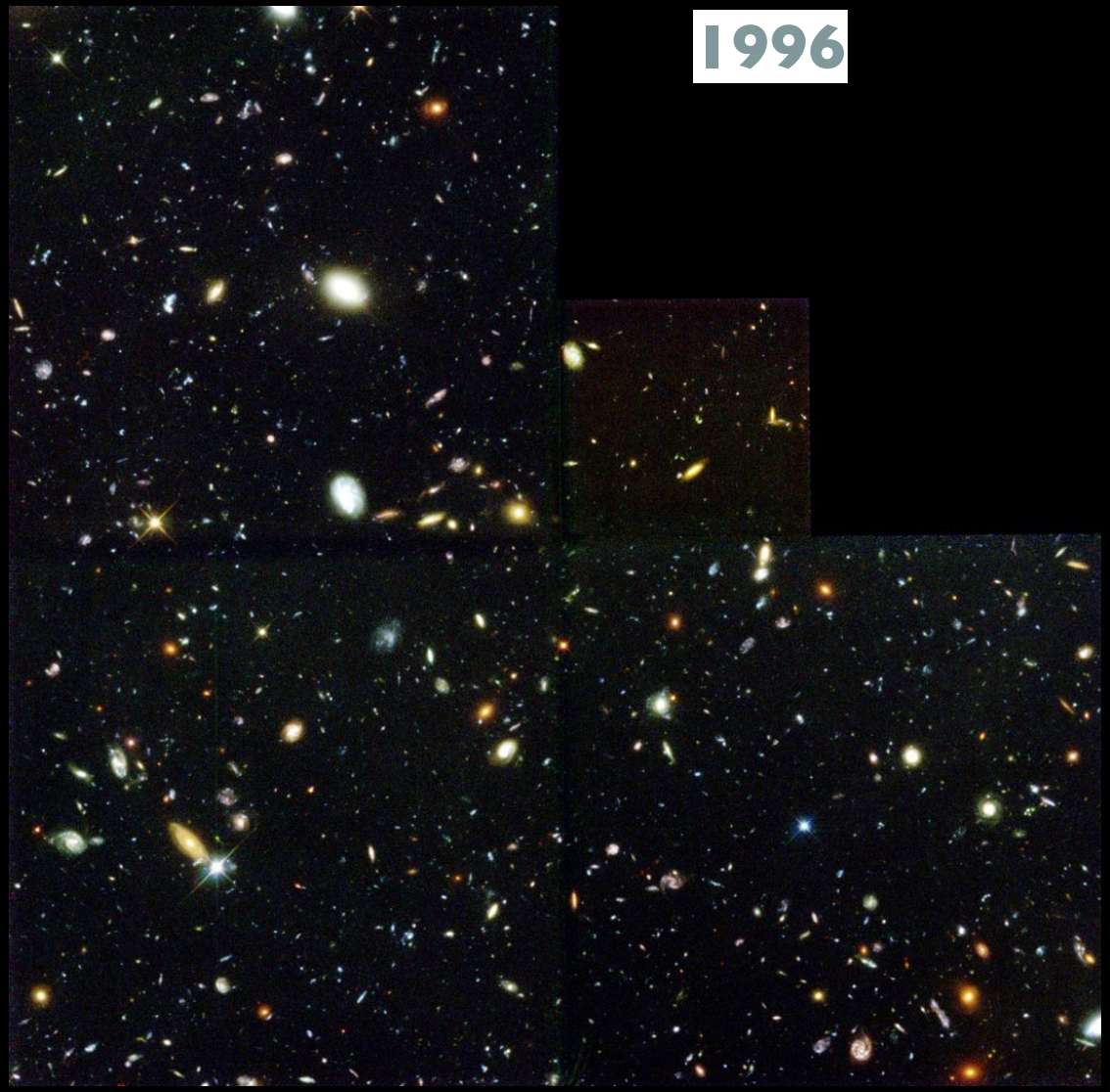


SEGMENTED MIRRORS IN SPACE ASTRONOMY

Antonella Nota (ISSI, STScI)

A Workshop to honor the legacy of Guido Horn D'Arturo

Hubble Deep Field

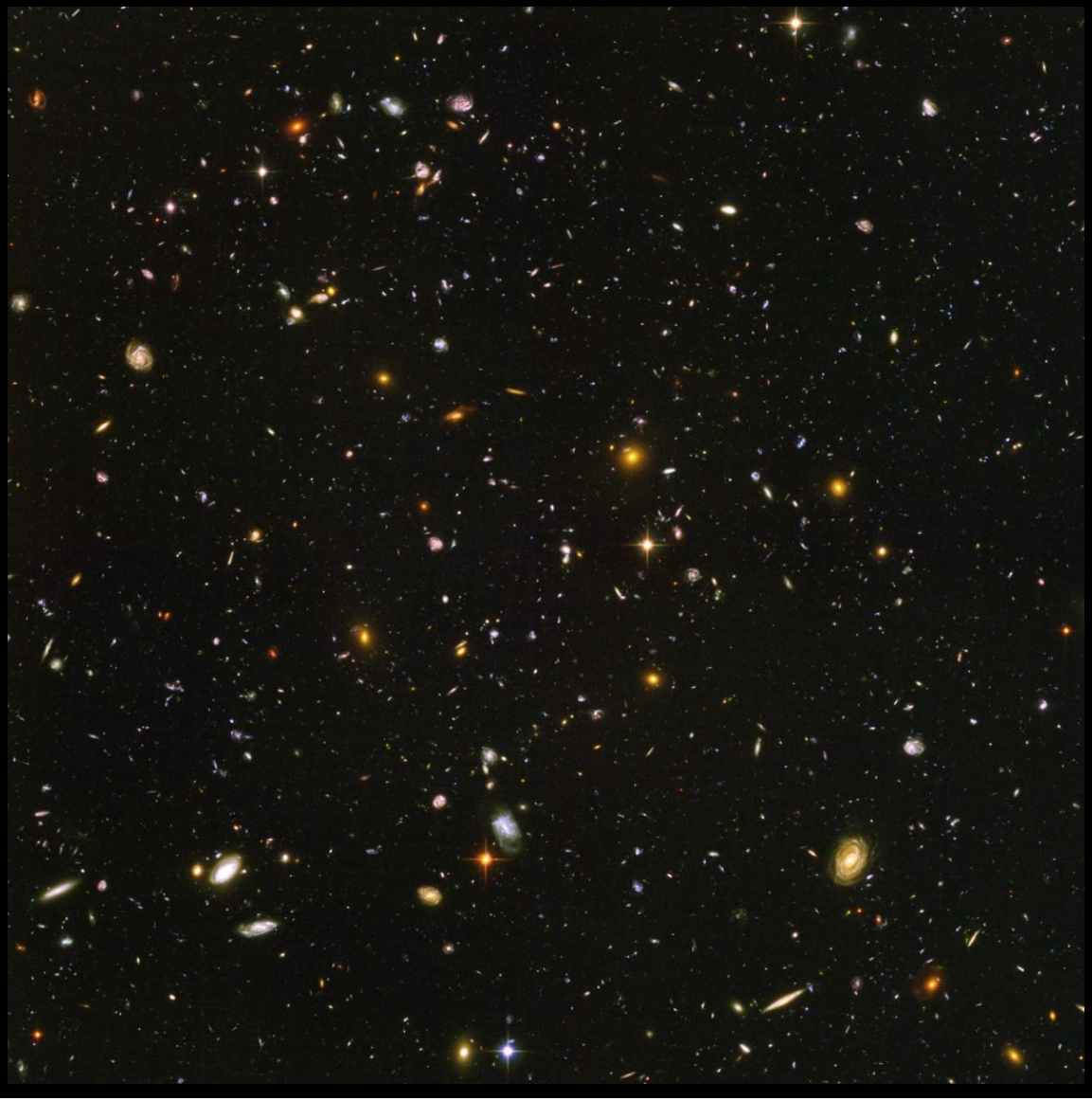


1996

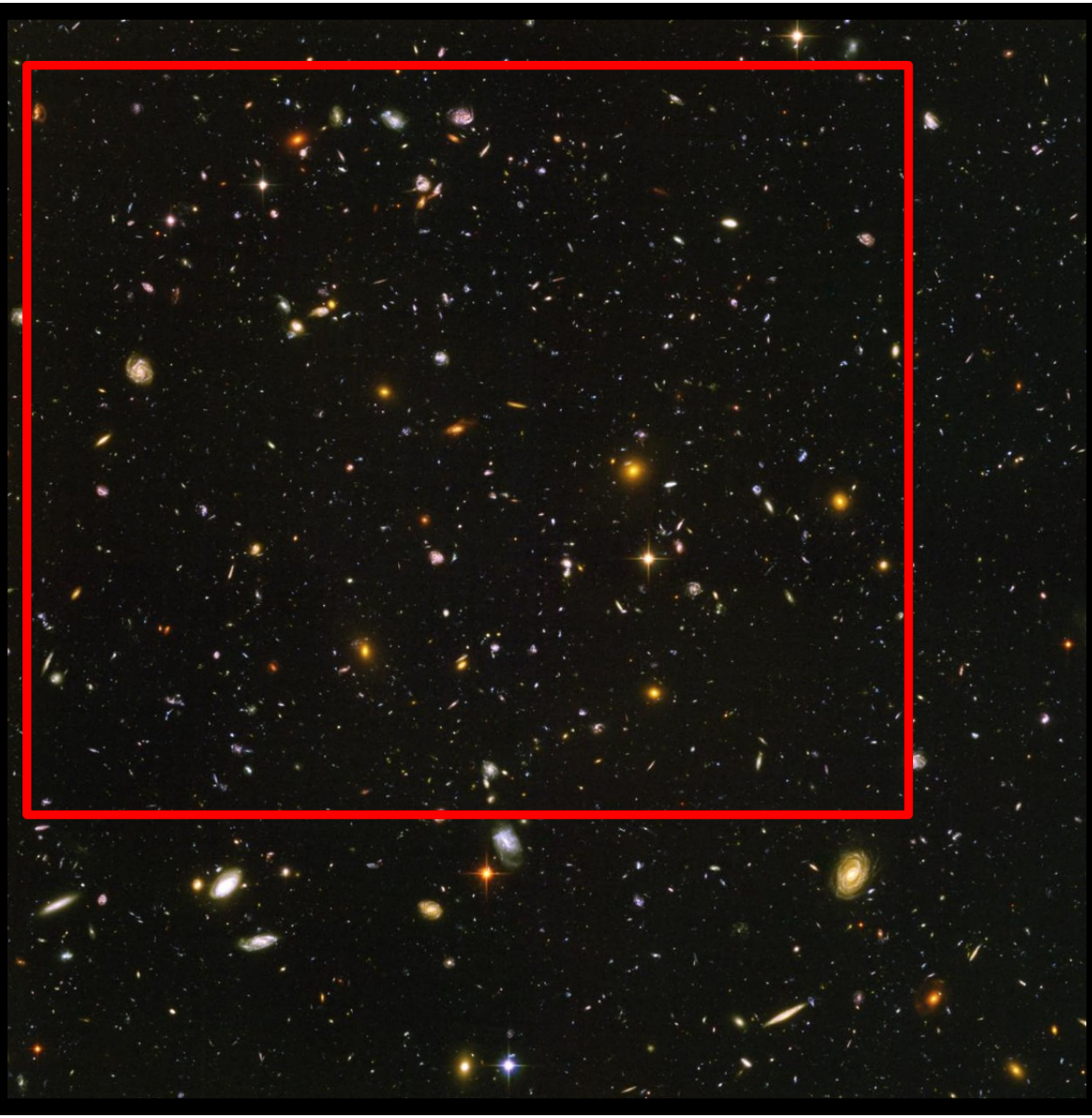
R. Williams

10 days exposure on a blank patch of sky

HDF (ACS)

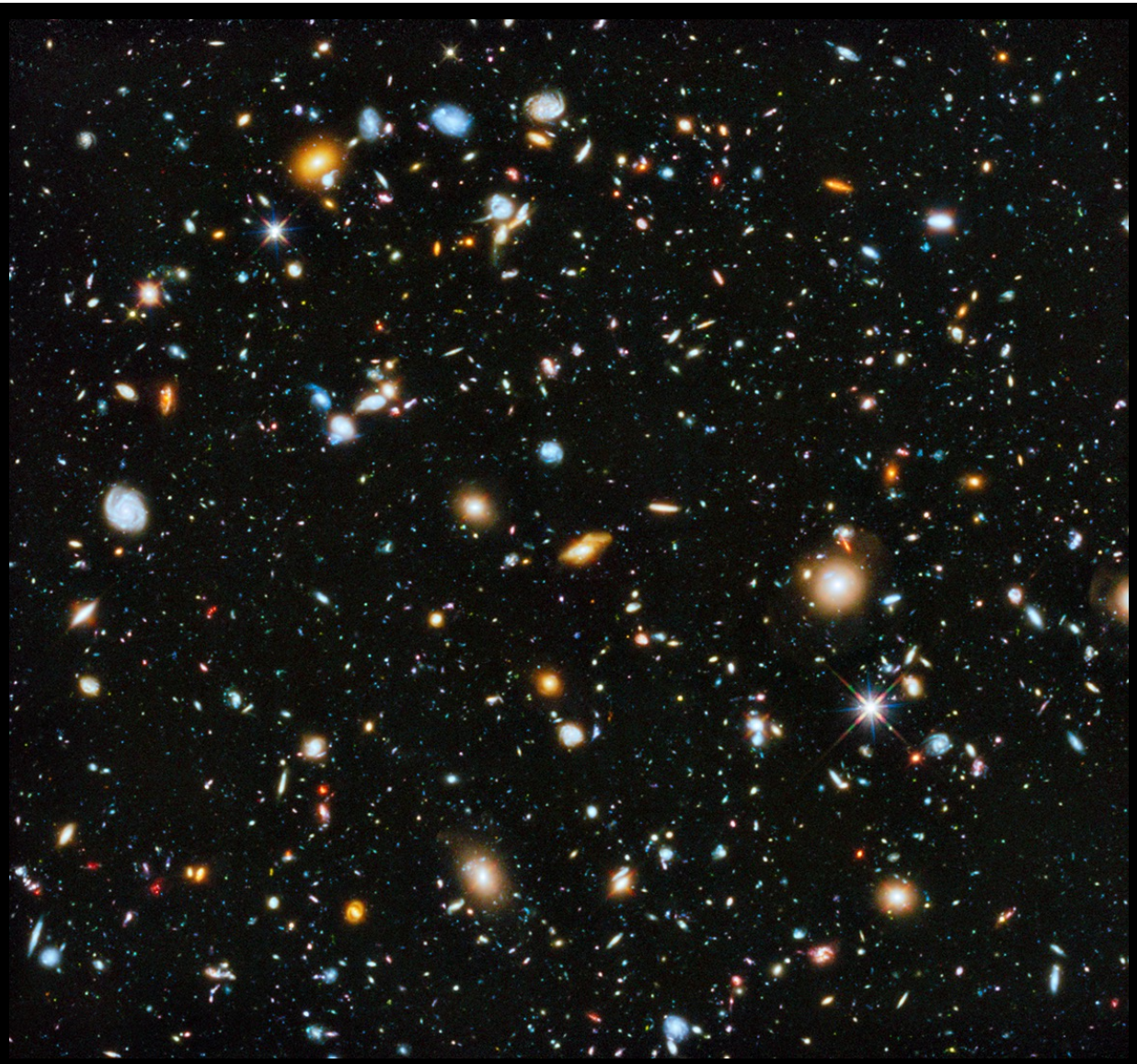


2004

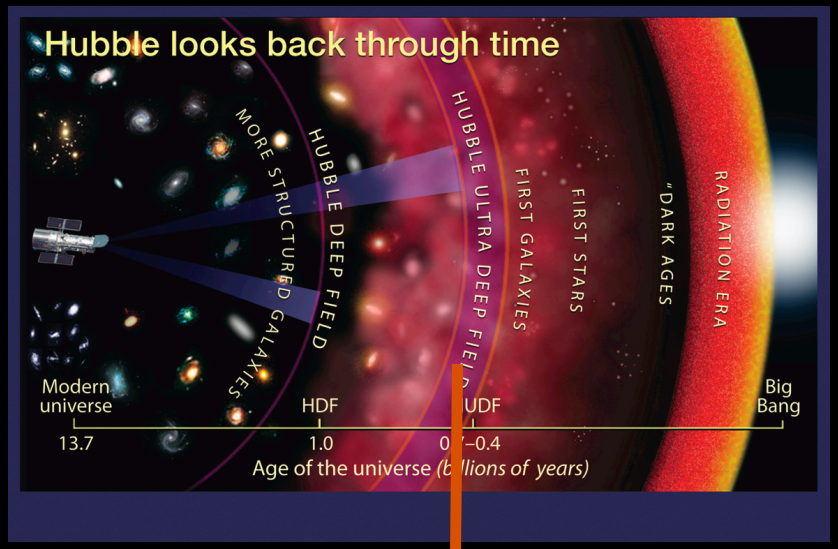


2009

+ IR



+ UV

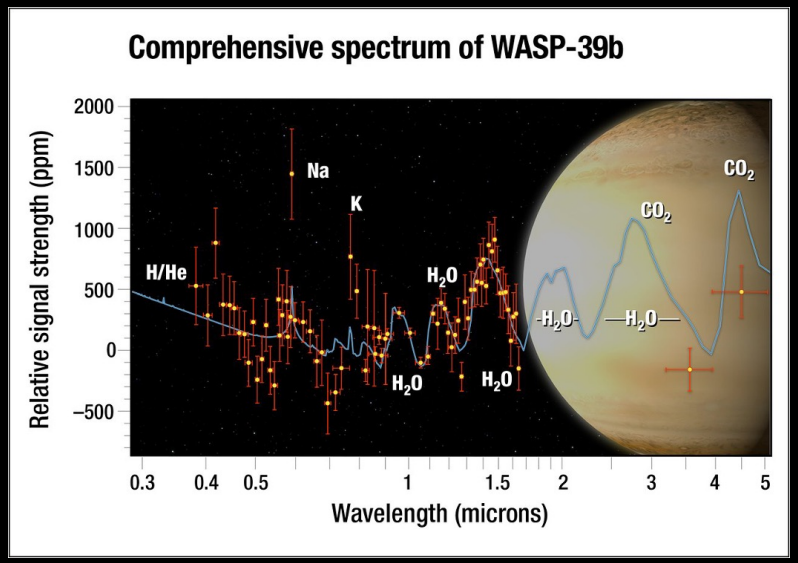


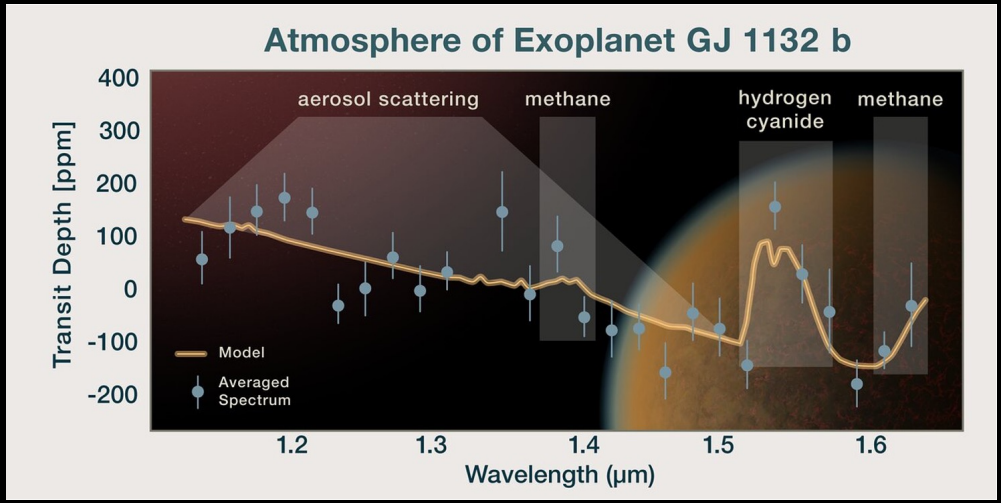
Hubble observed galaxies that existed when the universe was just a few hundred million year old

These galaxies were smaller in size and more irregular in shape than modern ones

Hubble opened the field of exoplanet atmospheres

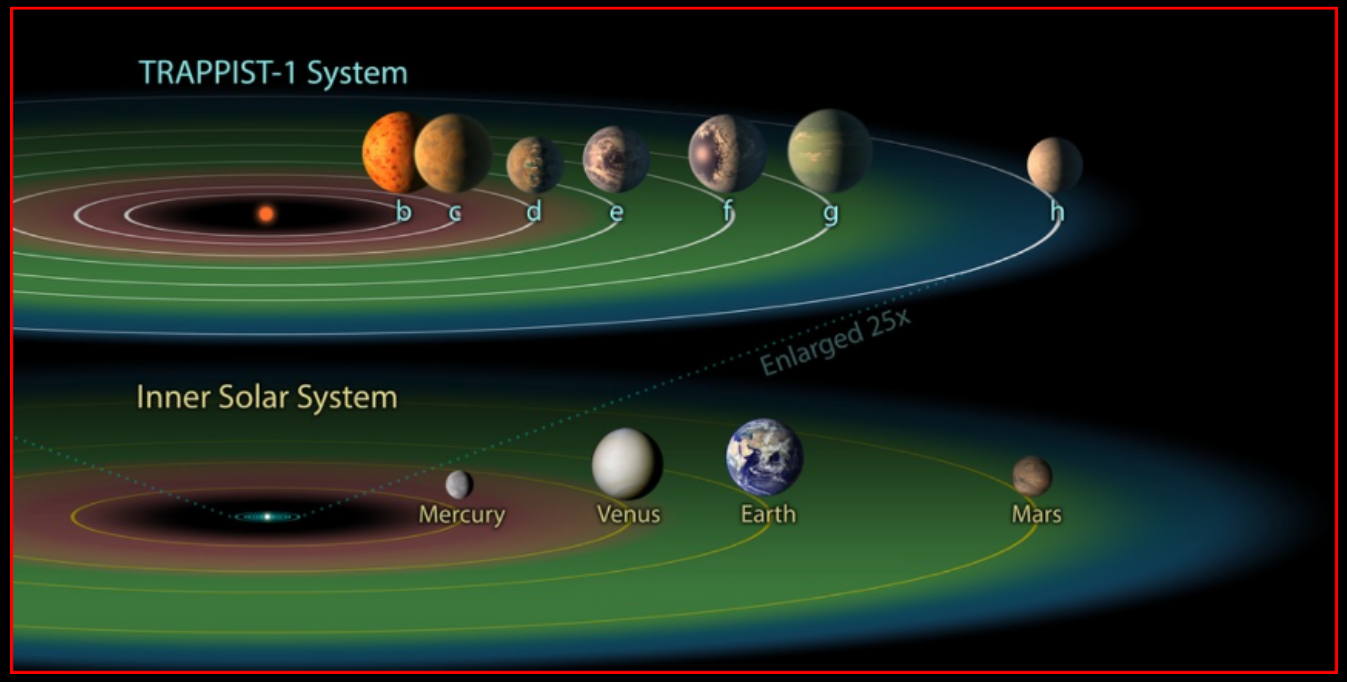
• Detection of variability in the atmosphere of Wasp 121-b
• Detection of heavy metals such as magnesium and iron escaping from the upper atmosphere of the ultra-hot Jupiter exoplanet Wasp 121-b
• Detection of water vapor in the atmosphere of K2-18b, a planet in the habitable zone
• Discovery of methane, hydrogen cyanide, aereosol scattering in the atmosphere of the earth sized rocky planet GJ 1132 b





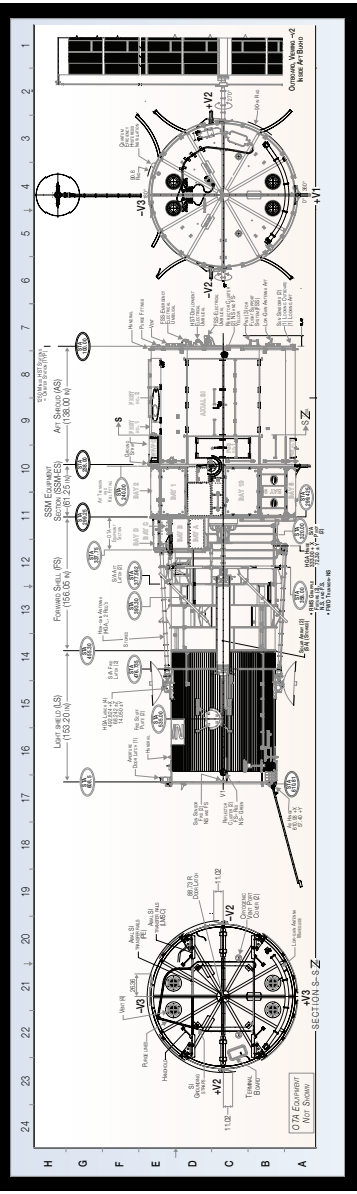
Changeat 2024, Wakeford 2018, Angelos 2019

The TRAPPIST system



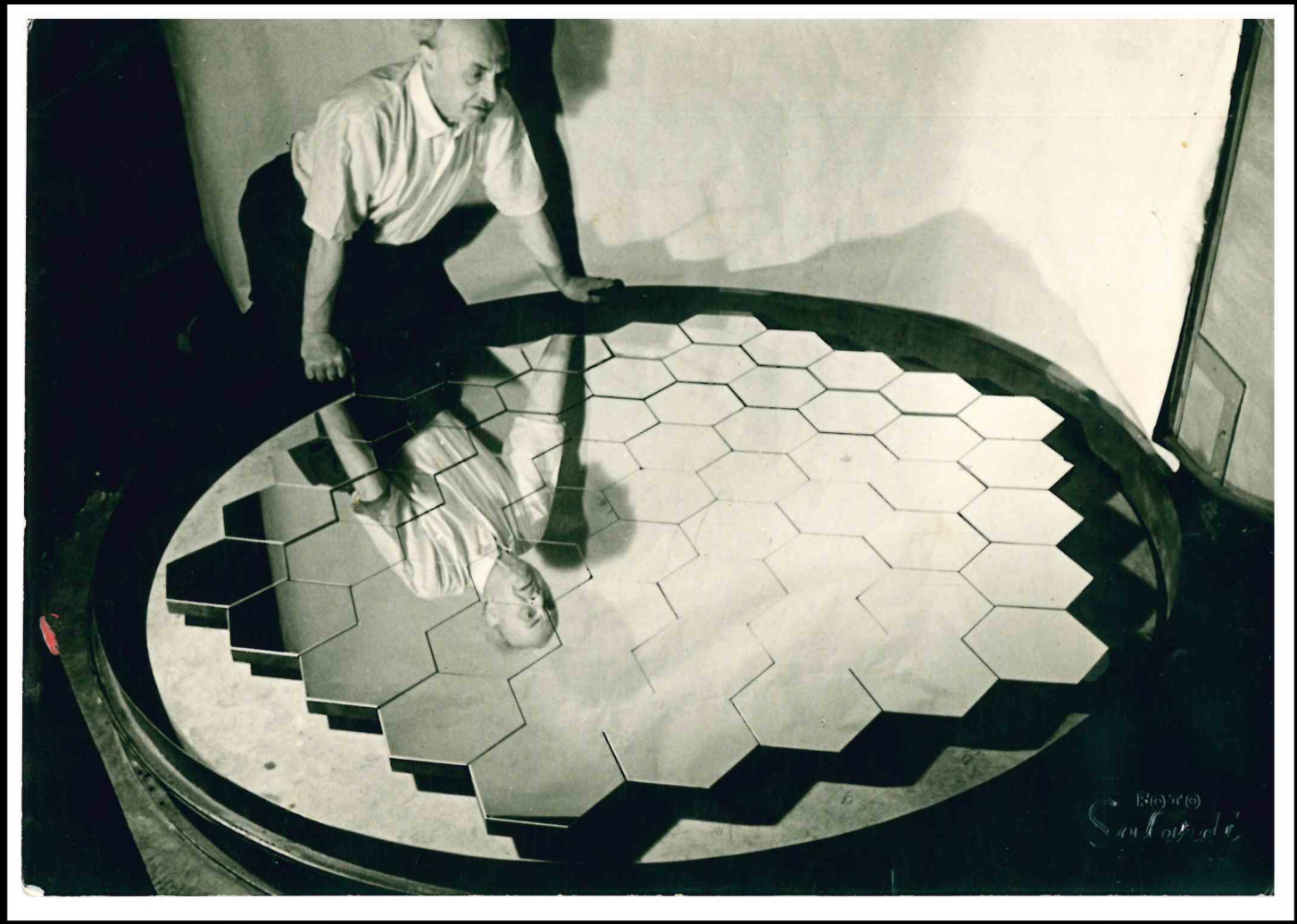
In 2018, Hubble spectroscopic surveys revealed that the inner planets, including those in the habitable zone (d, e, f), **do not have** the hydrogen-dominated atmospheres typical of mini-Neptunes.

35 yrs!!!!

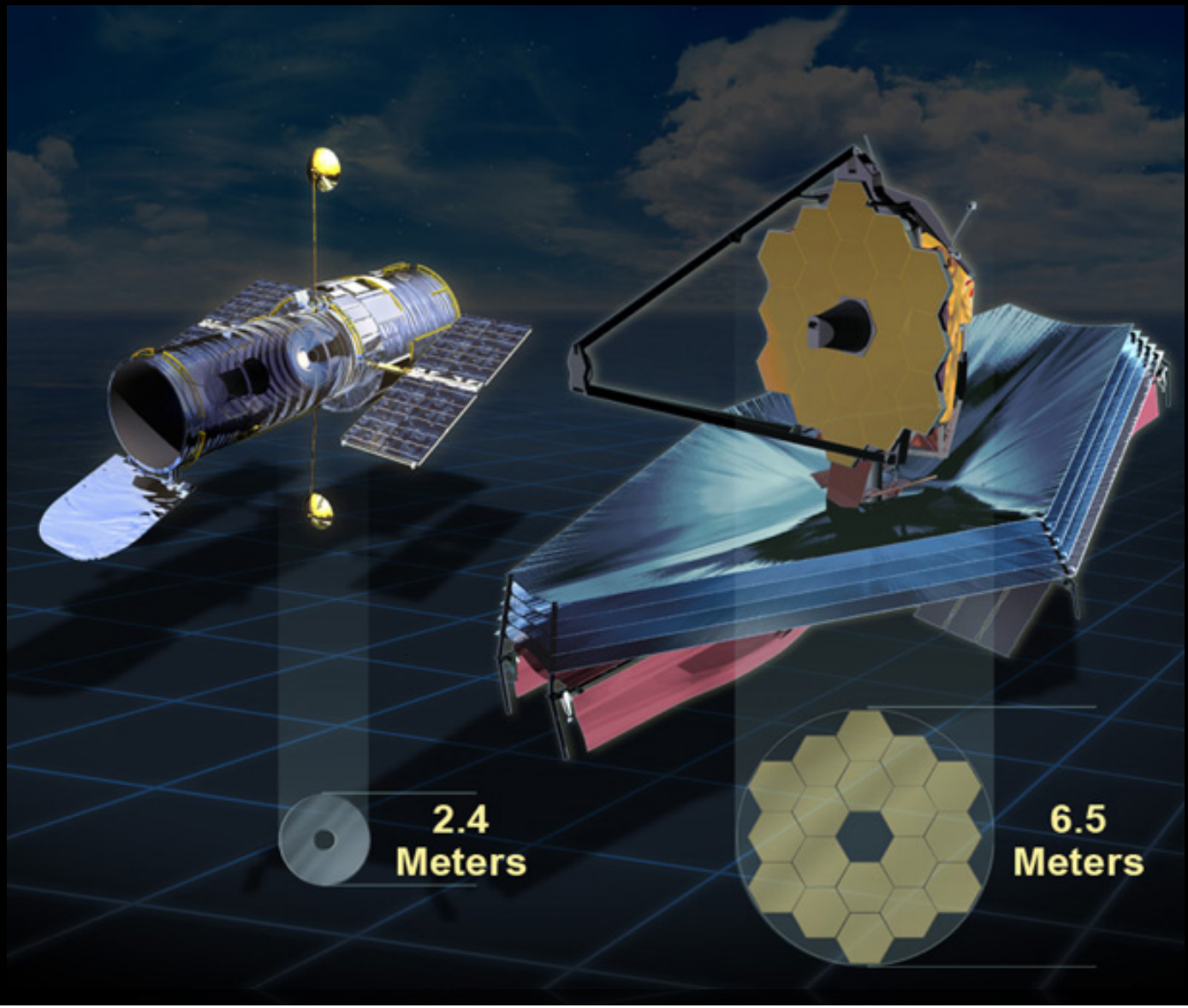


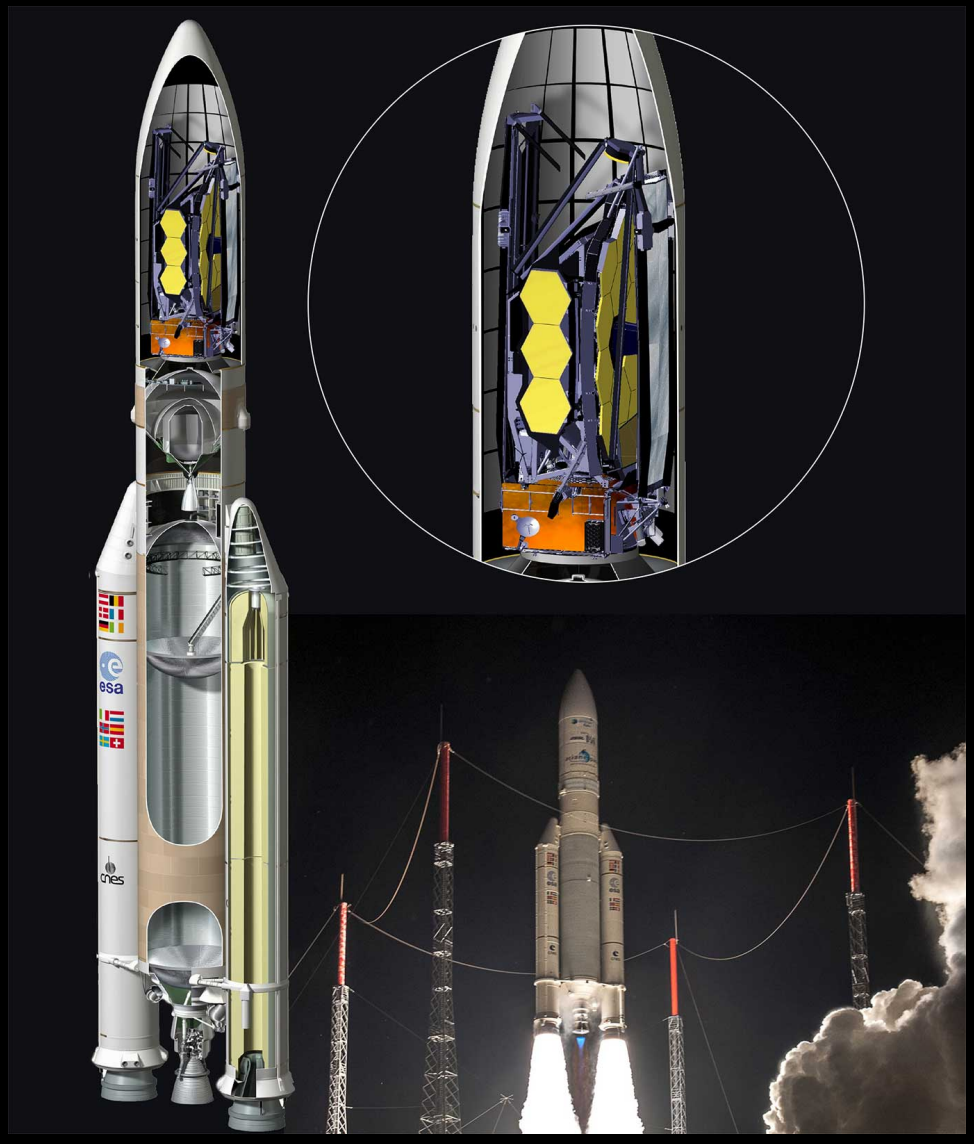
Hubble is a 2.4m telescope, optimised to observe from the UltraViolet to the Near-Infrared - launched on April 24,1990

Need larger aperture!



1952


2.4
Meters
6.5
Meters



Decision taken on
April 25, 2005

Launch
December 25, 2021

Webb mirrors

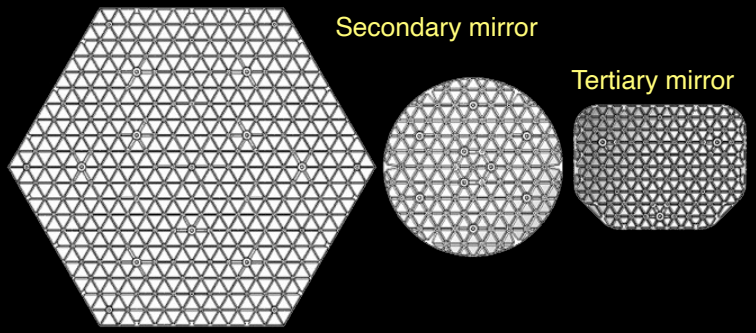
- JWST Mirrors made of beryllium
- Lightweight and stable at 40 K

Raw Be billet (two mirrors)

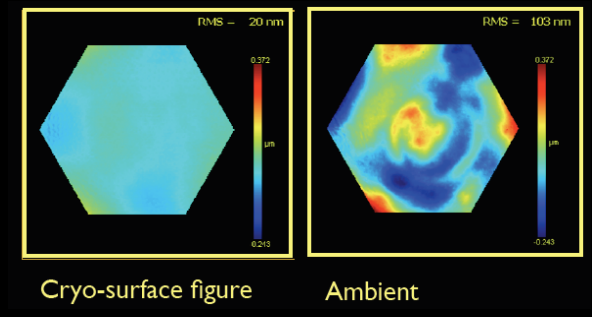
Primary mirror segment

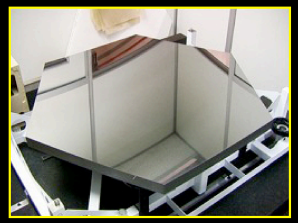
Secondary mirror

Tertiary mirror



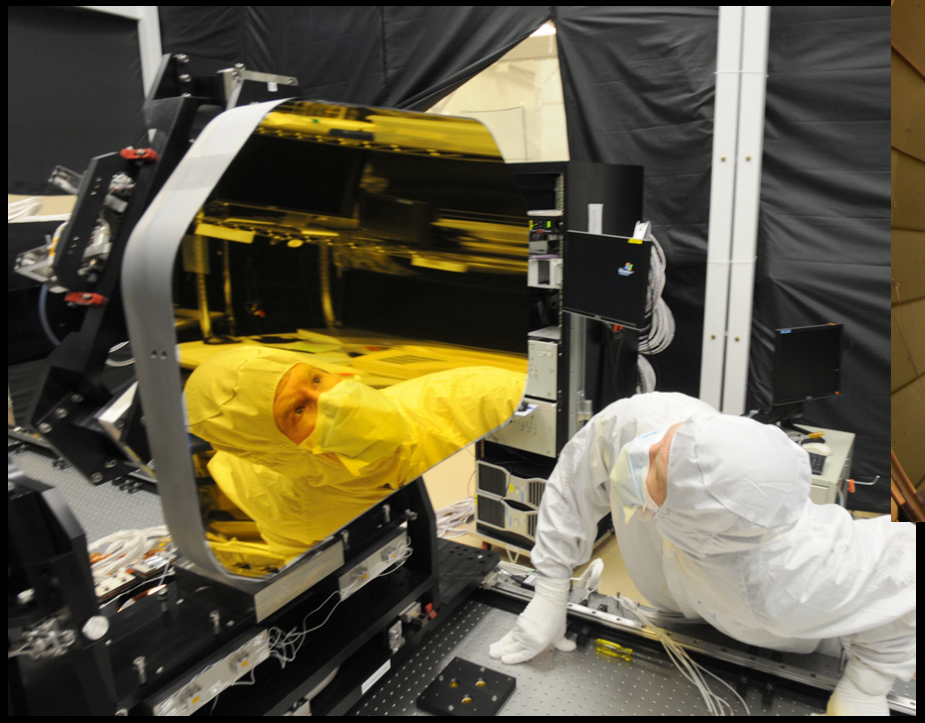
- Machined & lightweighted by Axsys
- 92% material is removed



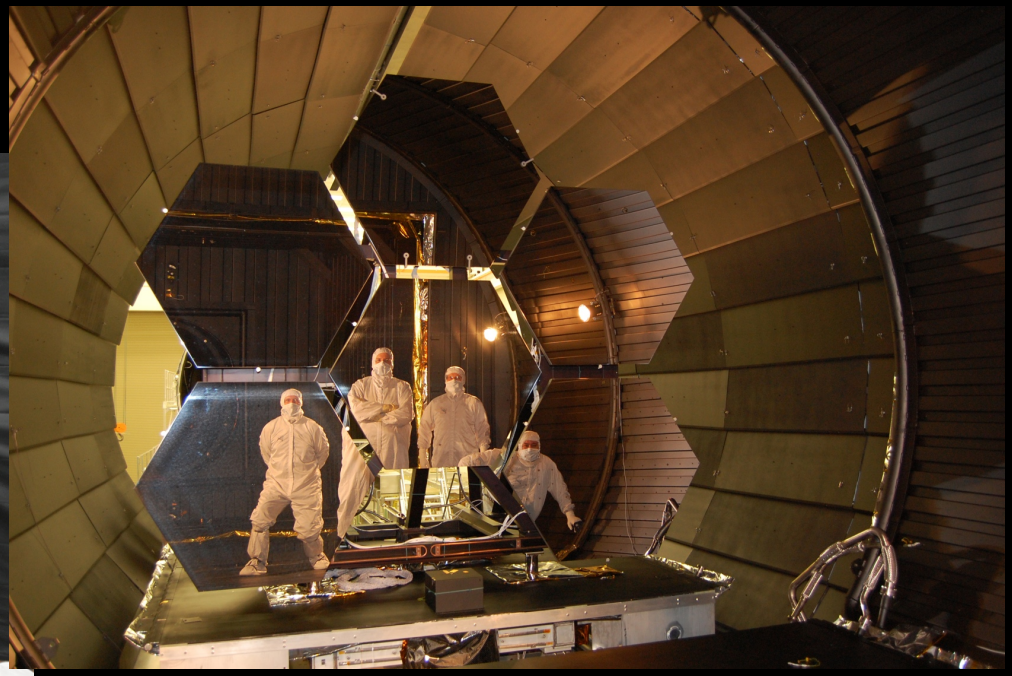


- Mirrors polished at Tinsley
- Segment cryo-figure: 20 nm

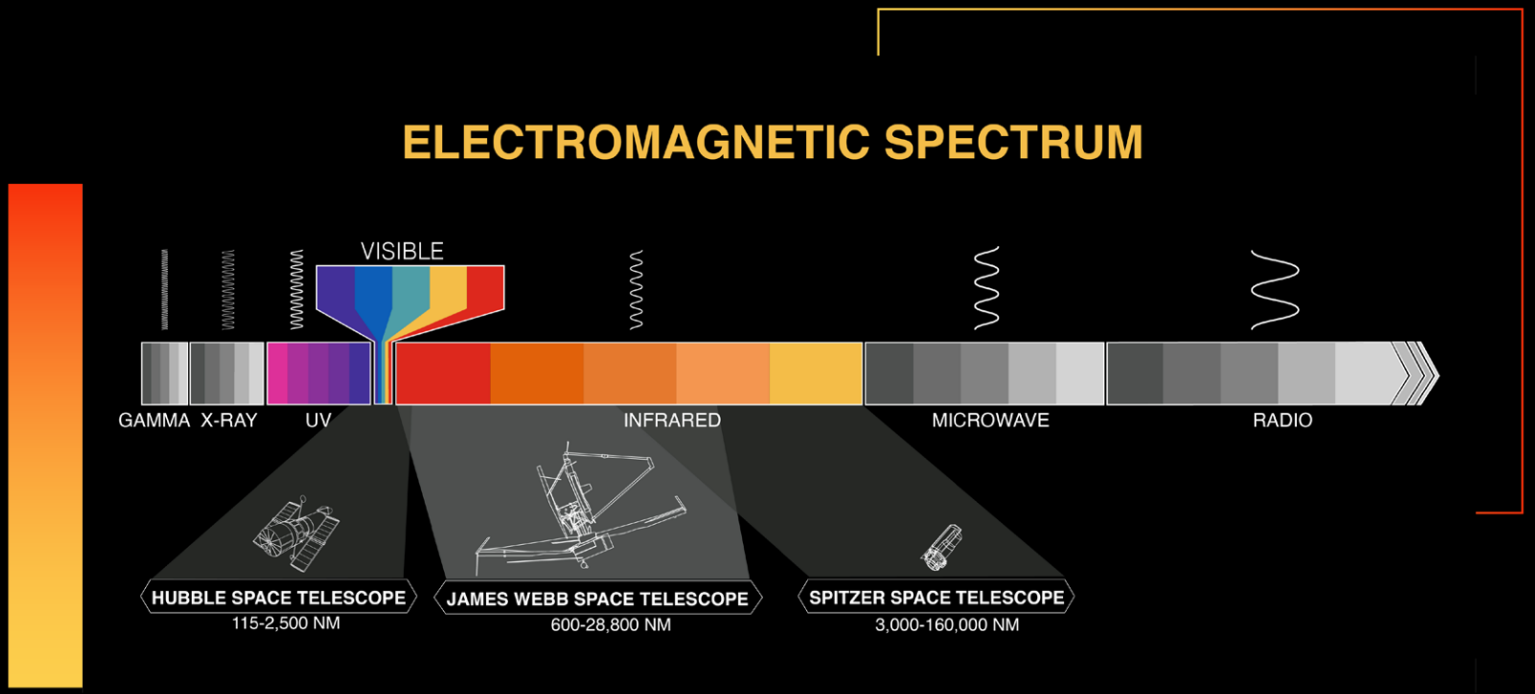
JWST golden coated tertiary



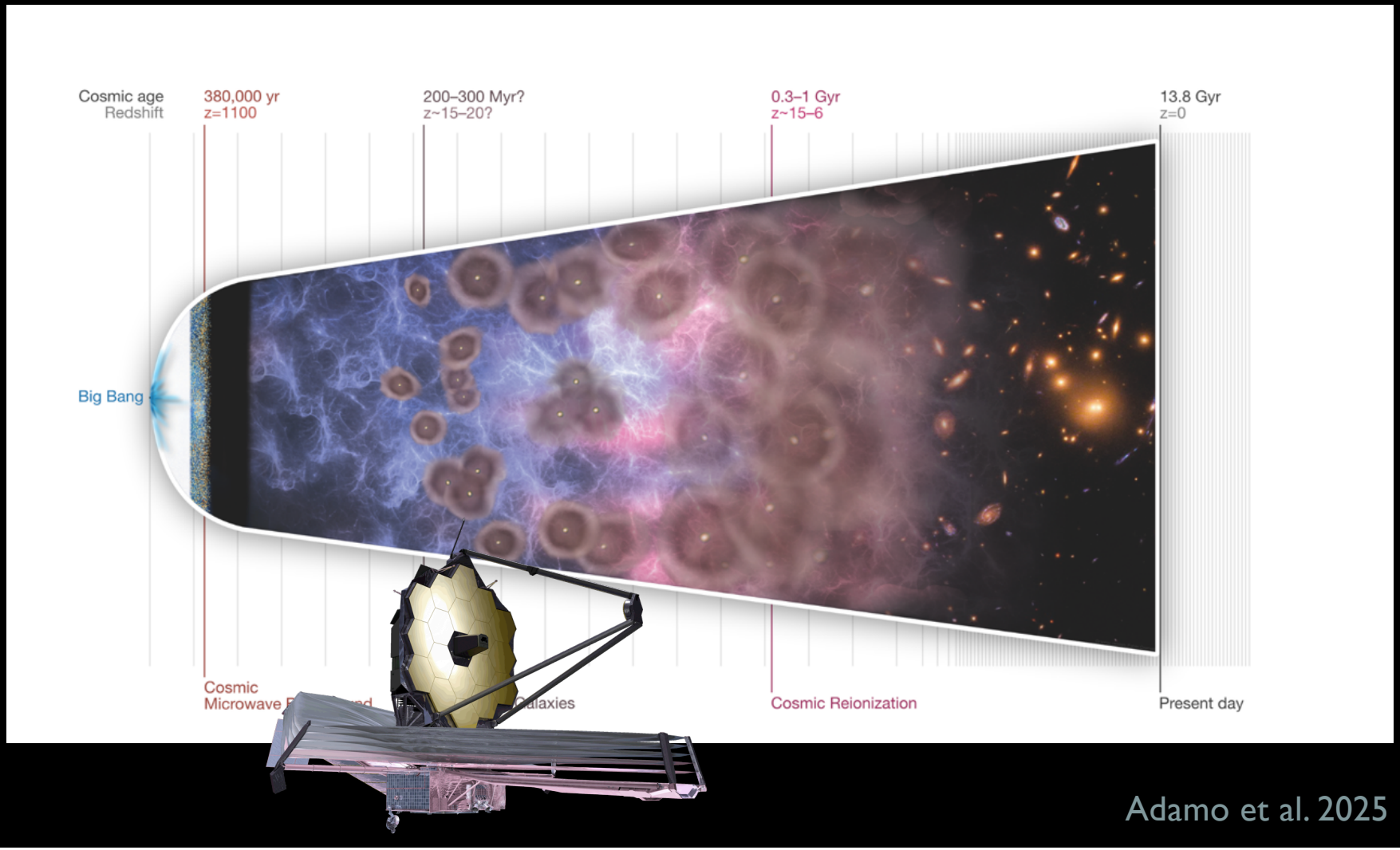
Primary mirror segments in cryo-vac chamber at Marshall



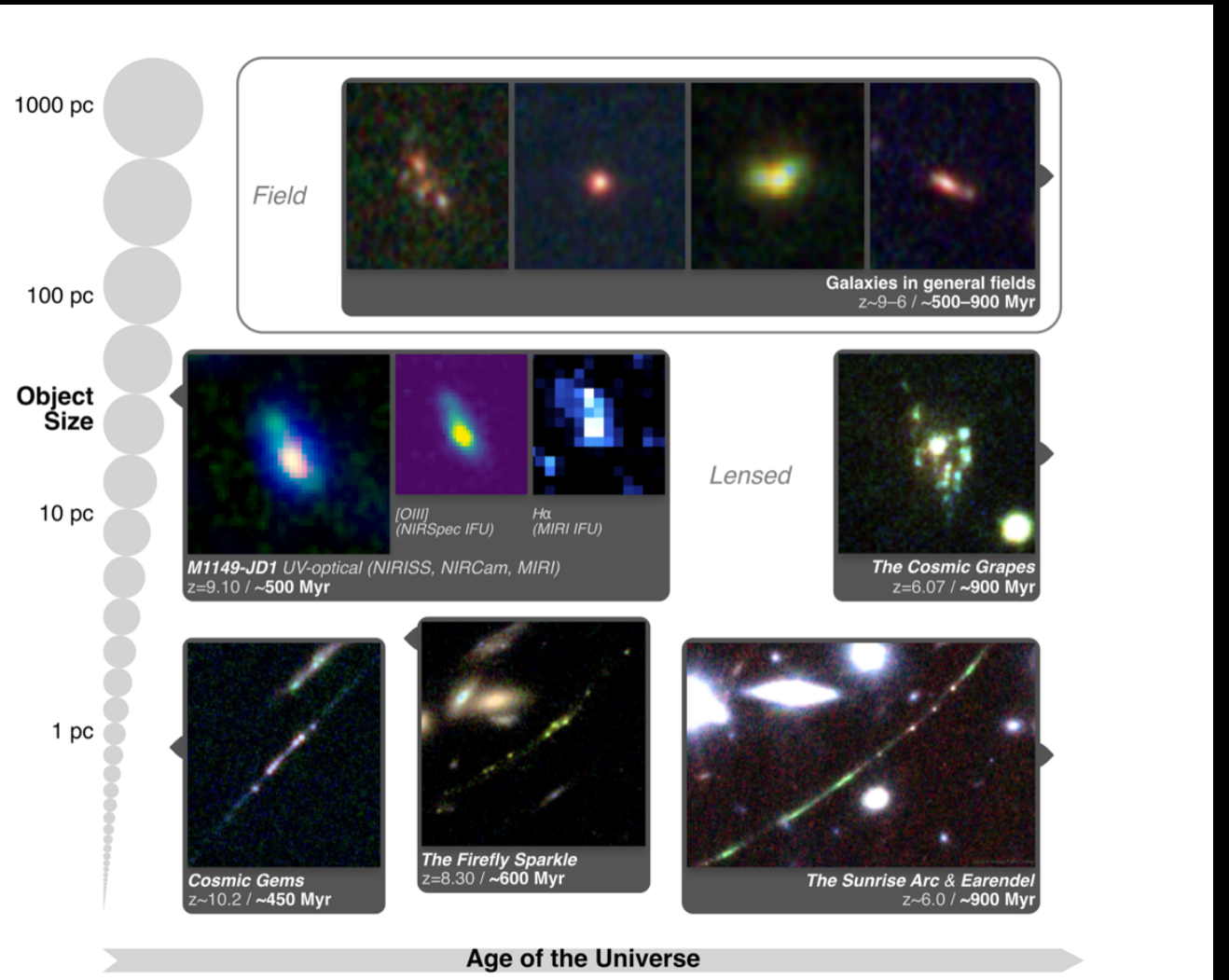
JWST observes in the Infrared



The Cosmic Timeline



Adamo et al. 2025

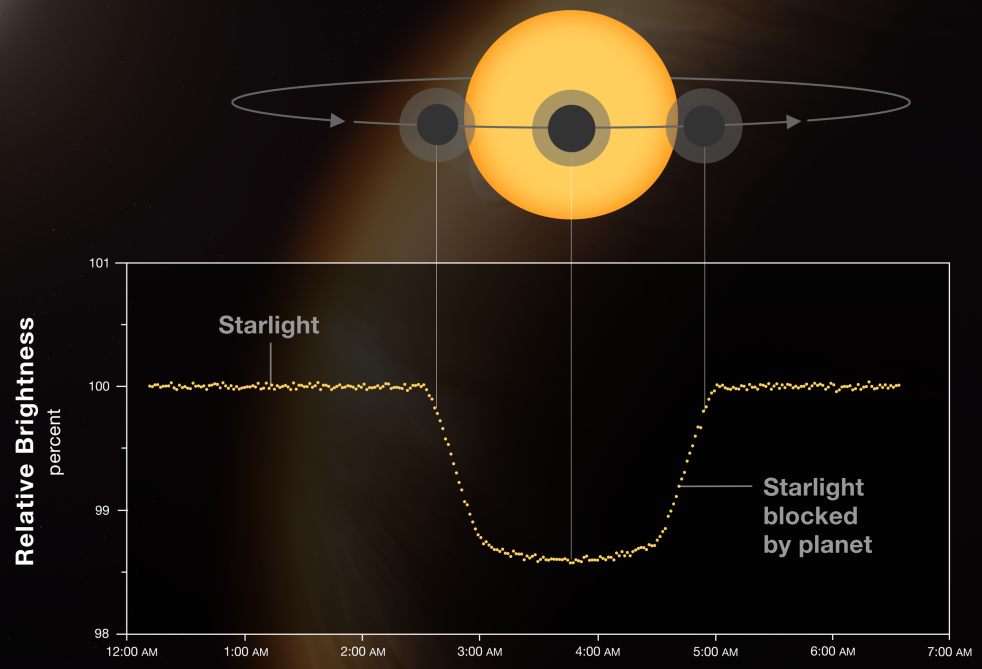


Adamo et al. 2025

HOT GAS GIANT EXOPLANET WASP-96 b

TRANSIT LIGHT CURVE

NIRISS | Single-Object Slitless Spectroscopy



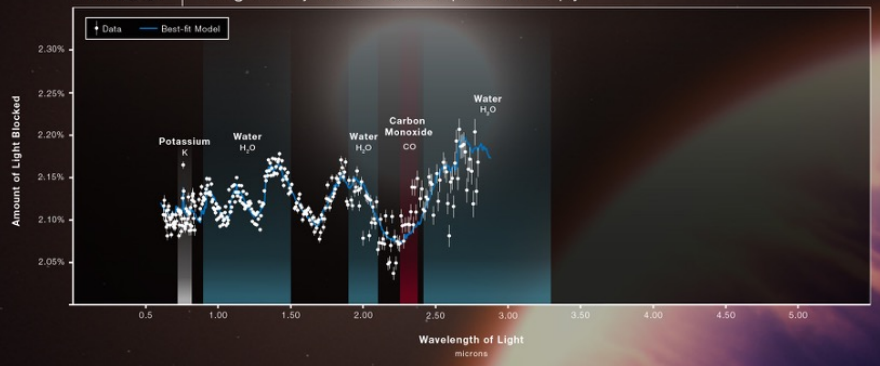
Time in Baltimore, Maryland
June 21, 2022

WEBB SPACE TELESCOPE

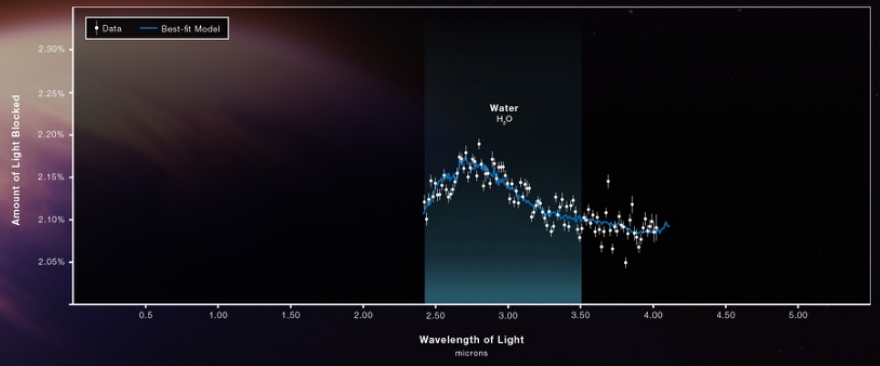
HOT GAS GIANT EXOPLANET WASP-39 b

ATMOSPHERE COMPOSITION

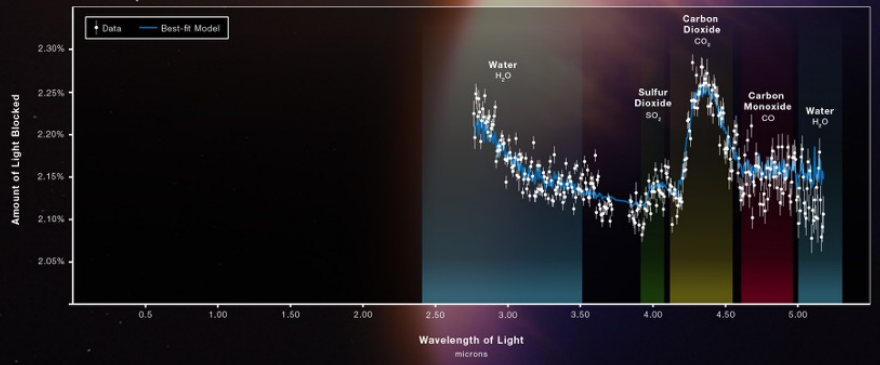
NIRISS | Single Object Slitless Spectroscopy



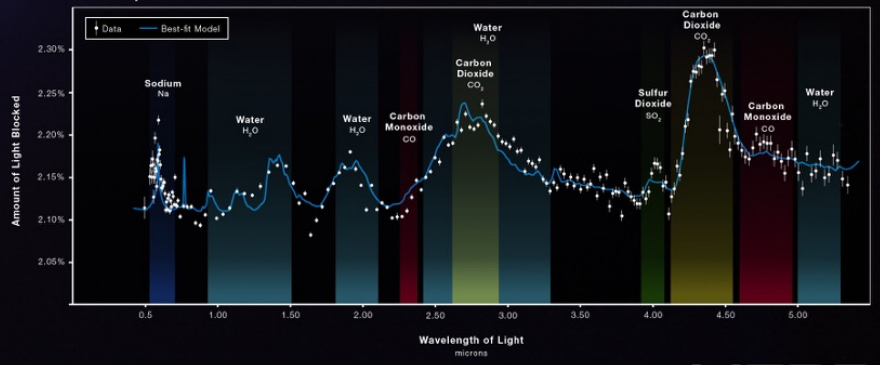
NIRCam F322W2



NIRSpec G395H



NIRSpec PRISM

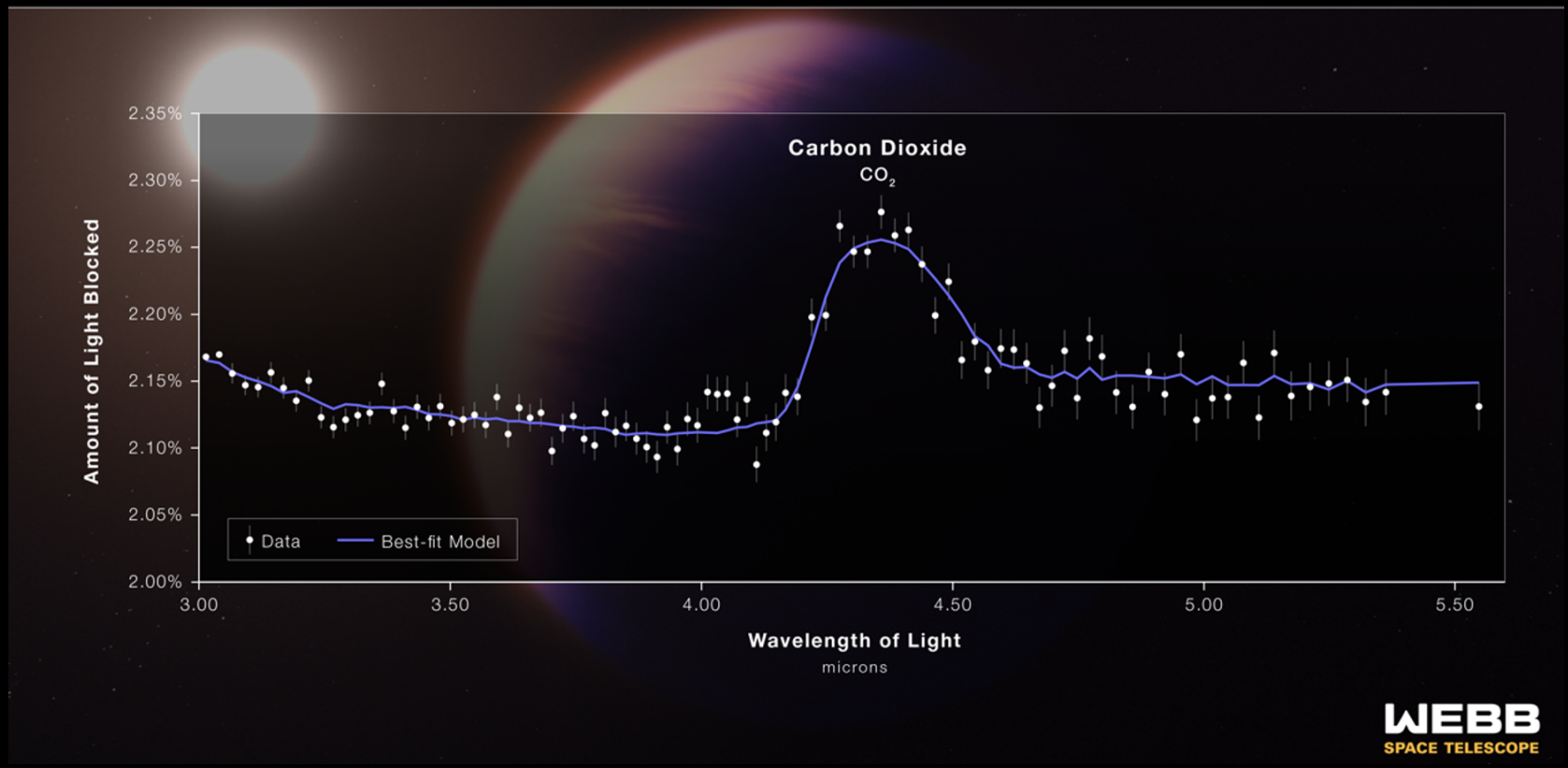


WEBB
SPACE TELESCOPE

HOT GAS GIANT EXOPLANET WASP-39 b

ATMOSPHERE COMPOSITION

NIRSpec | Bright Object Time-Series Spectroscopy

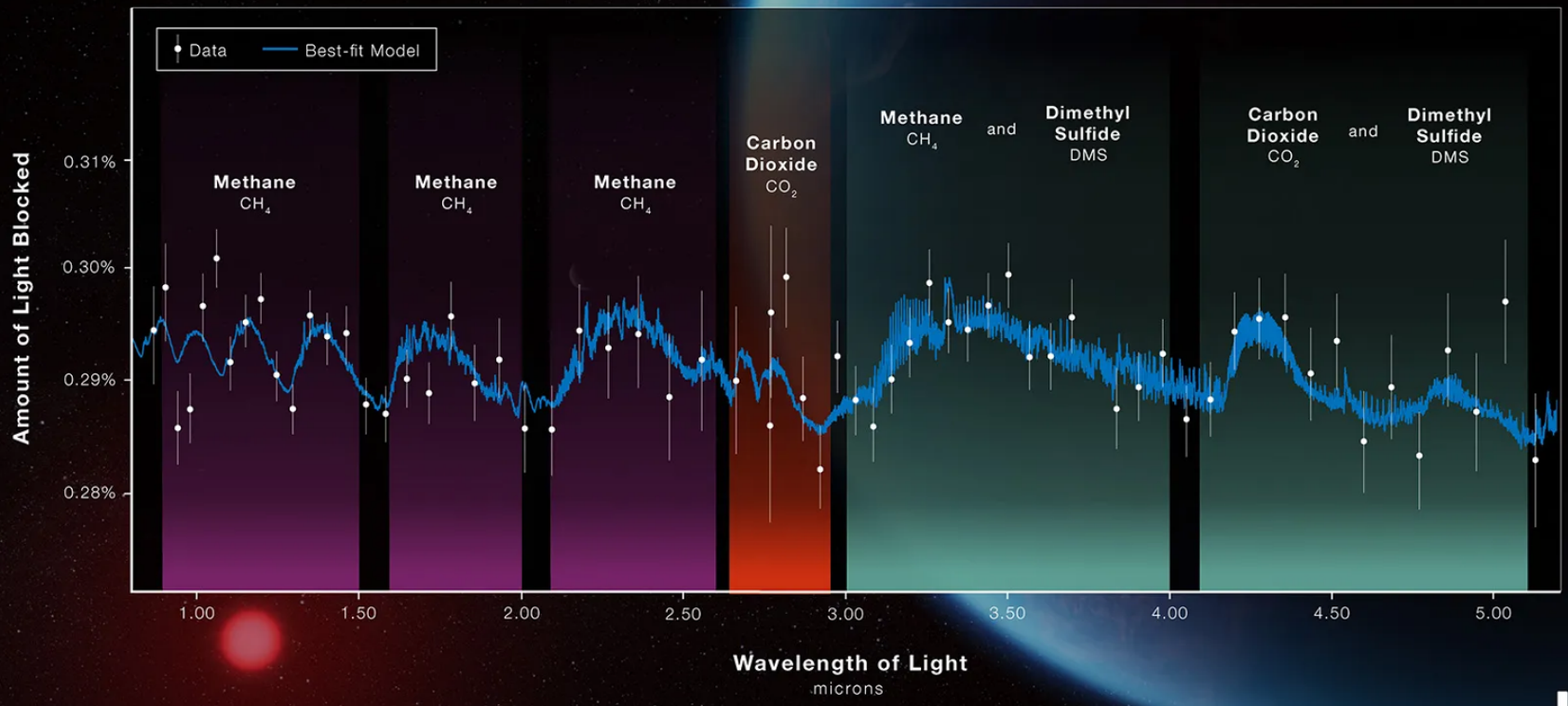


WEBB
SPACE TELESCOPE

EXOPLANET K2-18 b

ATMOSPHERE COMPOSITION

NIRISS and NIRSpec (G395H)

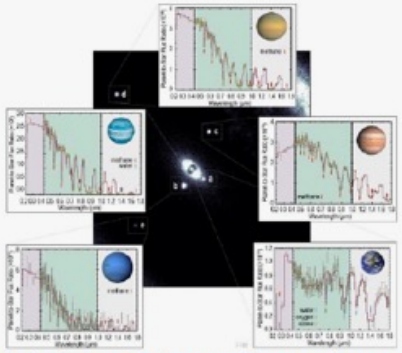


WEBB
SPACE TELESCOPE

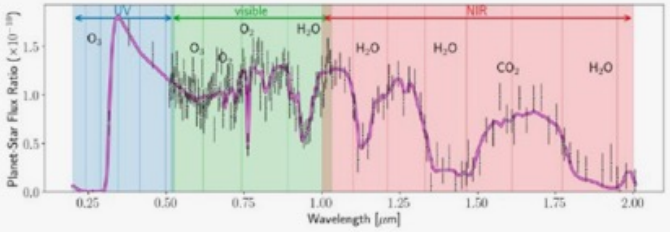
What is the next step?


HABITABLE
WORLDS
OBSERVATORY

A Future IR/Optical/UV Telescope Optimized for Observing Habitable Exoplanets and General Astrophysics

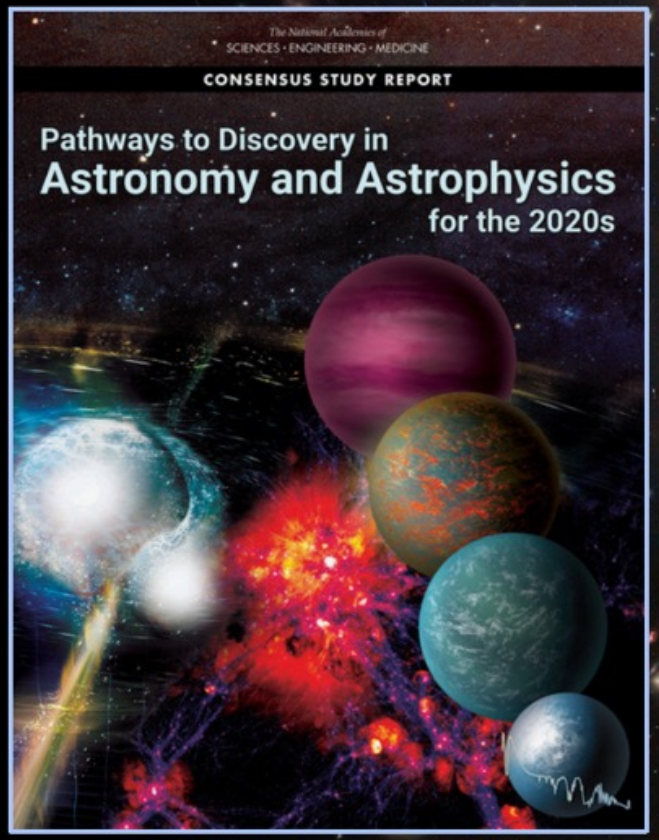


Simulated space-telescope image of a complete planetary system including a life-bearing Earth-like planet



Simulated spectrum of an Earth-twin planet observed from the UV to near-IR by a space coronagraph

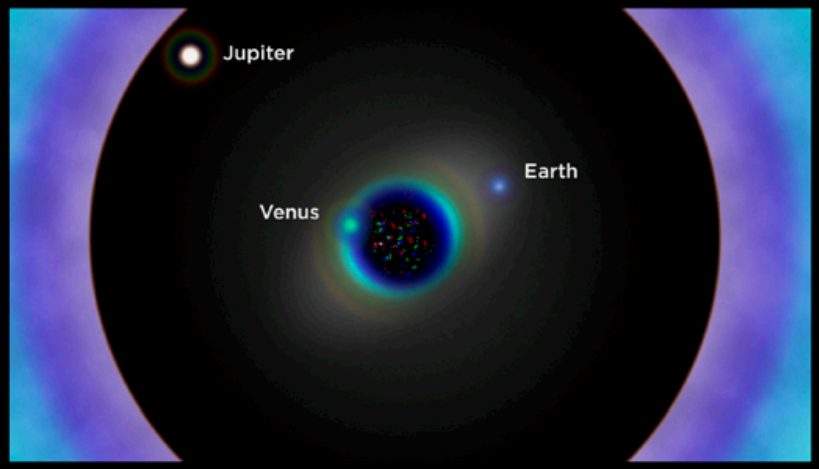
Recommendation: After a successful mission and technology maturation program, NASA should embark on a program to realize a mission to search for biosignatures from a robust number of about ~25 habitable zone planets and to be a transformative facility for general astrophysics. If mission and technology maturation are successful, as determined by an independent review, implementation should start in the latter part of the decade, with a target launch in the first half of the 2040's

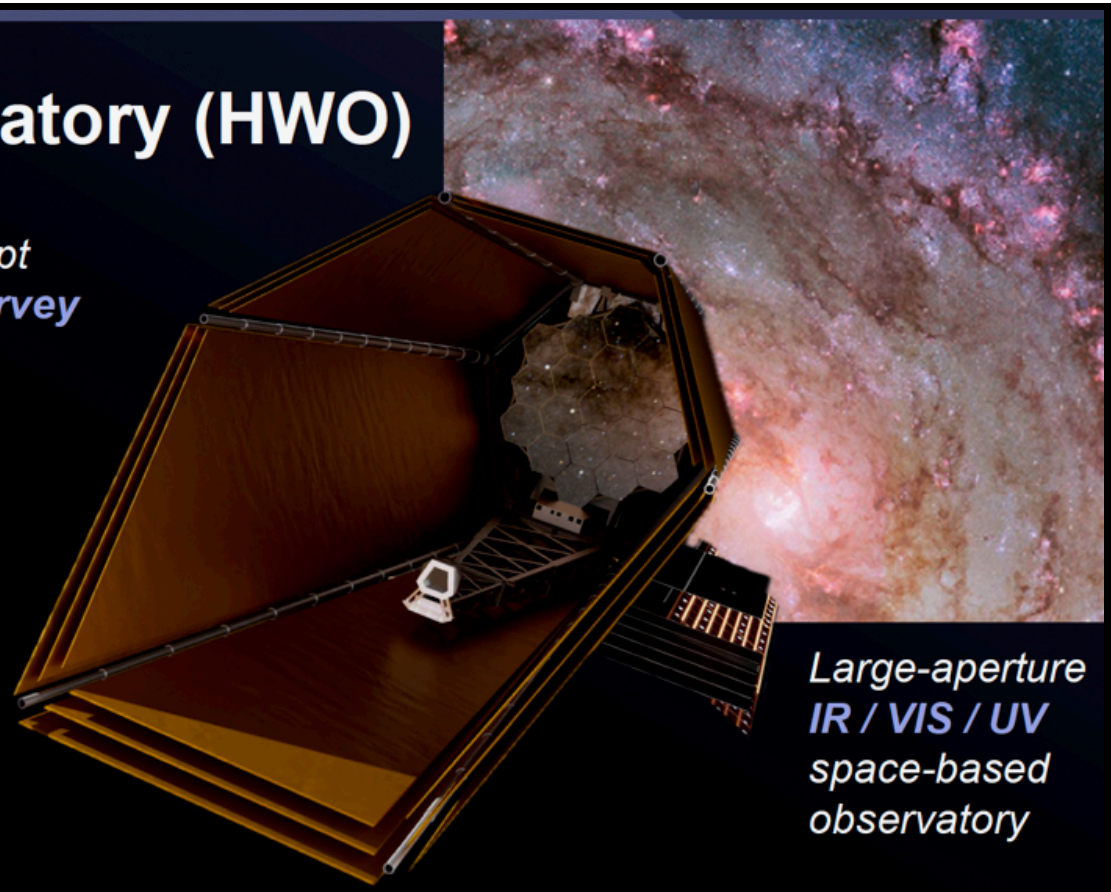


Credit M.Clampin

Habitable Worlds Observatory (HWO)

*NASA **astrophysics flagship** mission concept recommended by the Astro2020 **Decadal Survey***





*Large-aperture **IR / VIS / UV** space-based observatory*

First space telescope** designed to **search for signs of life** on planets outside our solar system & will perform **transformative astrophysics

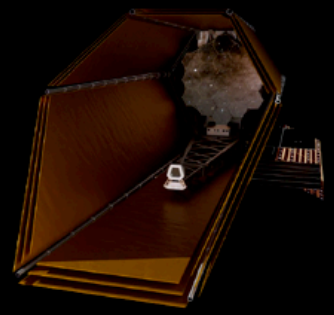
Pepper et al. 2025

Arney et al. 2025

HWO Preliminary Specs and Candidate Instruments

Telescope

Diameter	~6.0 m (inner)
Bandpass	~100–2500 nm



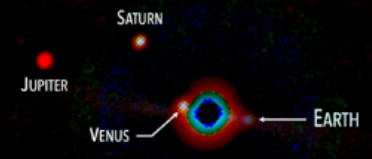
Fourth Instrument

to be defined

Coronagraph

High-contrast imaging and imaging spectroscopy

Bandpass	~200–1800 nm
Contrast	$\lesssim 1 \times 10^{-10}$
	Vis: ~140 NIR: ~70,200



High-Resolution Imager

UV/Vis and NIR imaging

Bandpass	~200–2500 nm
Field-of-View	~3' x 2'

60+ science filters & grism

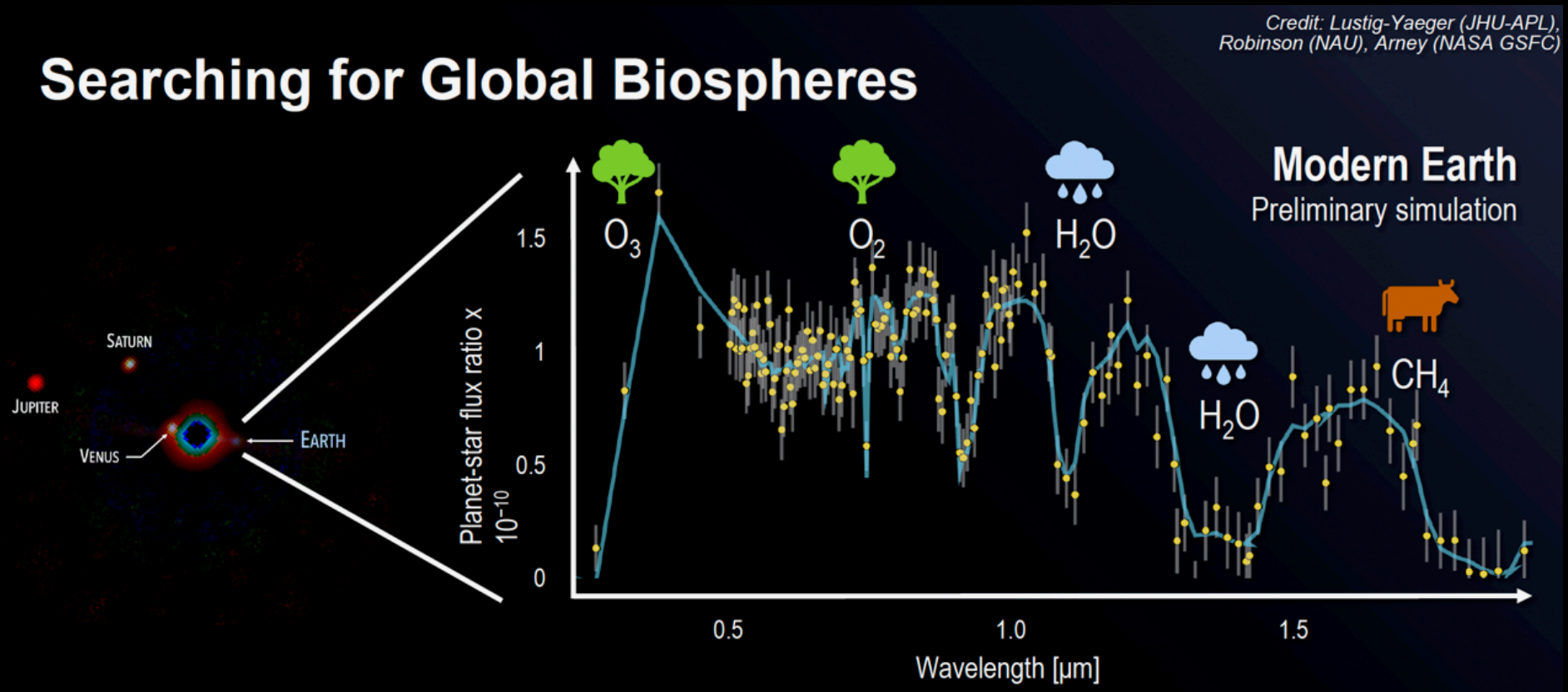
High-precision astrometry?

UV Multi-Object Spectrograph

UV/Vis multi-object spectroscopy and FUV imaging

Bandpass	~100–1000 nm
Field-of-View	~2' x 2'
Apertures	~840 x 420
	~500–60,000

Searching for Global Biospheres



HWO will directly image ~25+ Earth-sized exoplanets in the Habitable Zones around Sun-like stars, suppressing starlight by factors of ~10 billion to obtain exoplanet atmosphere spectra covering multiple potential biosignatures

HWO Science

- Mapping the Baryon cycle in emission and absorption
- Deep Fields 8x faster than HST and 4x JWST
- UV spectroscopy of millions of sources
- Viewing the Solar System in high resolution & cadence
- Seeing all the building blocks of galaxies
- Resolved stellar populations beyond the Milky Way

Implementing Lessons Learned for Large Missions

Independent Research Papers

Challenges and Potential Solutions to Develop and Fund NASA Flagship Missions

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Abstract—Large, strategic "Flagship" missions have unique characteristics that lead to challenging developmental difficulties for the National Aeronautics and Space Administration (NASA). Missions such as the Hubble Space Telescope (HST), Chandra X-ray Observatory (CXO), and the Mars Science Laboratory (MSL) had technical and programmatic challenges that led to significant schedule delays and subsequent cost growth. Although NASA has instituted policies that have reduced cost growth for many "typical" NASA missions, Flagship missions continue to present unique challenge due to their requirement to provide unprecedented science or tackle bold exploration goals, typically while concurrently developing new technologies. The unique challenges presented by Flagship missions make it extremely difficult to fit within traditional cost and schedule caps. New technical and programmatic advances needed to meet performance requirements are unprecedented. This paper addresses why Flagship missions are unique and proposes a new programmatic approach to develop and fund Flagship missions.

TABLE OF CONTENTS

1. DEFINITION OF FLAGSHIP MISSIONS

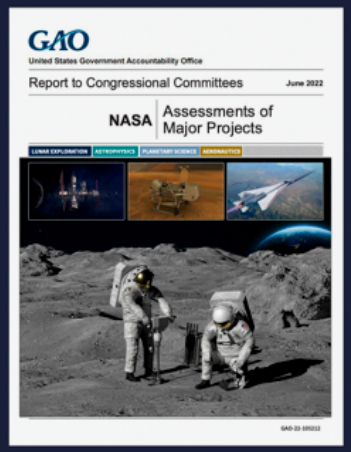
According to Merriam-Webster's Dictionary, a Flagship is: 1) the ship that carries the commander of a fleet or subdivision of a fleet and flies the commander's flag, or 2) the finest, largest, or most important one of a group of things. [1] In many ways, National Aeronautics and Space Administration (NASA) Flagship missions incorporate both of these definitions as they are the most visible because of their potential for scientific discovery and expense and are also the finest, largest, and most important of NASA's science missions. NASA Flagship missions are unprecedented in the science that they enable as they provide exquisite measurements that cannot be done otherwise and typically require new technology or advanced engineering developments to acquire the measurements.

Figure 1 shows typical examples of NASA Flagship missions such as Viking, Galileo, the Hubble Space Telescope (HST), and others relative to their launch date and development cost. As shown in Figure 1, Flagship missions are typically developed on the order of every 10 years and have a cost greater than $2B fiscal year 2017. The development cost is from the start of preliminary development at the beginning of Phase B through launch and is taken from NASA historical budget documents and normalized to fiscal year 2017 using equivalent dollars (FY17$). [2, 3] The relatively high cost of Flagship missions is due to their significant complexity with examples such as HST, as it was the largest pointable space telescope of its time, and the James Webb Space Telescope (JWST), which is larger than HST and operates at significantly colder temperatures while still meeting unprecedented stability requirements.

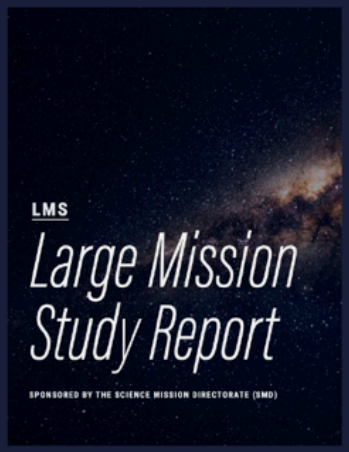
Figure 1. NASA Flagship Mission Cost vs. Launch Date

Mission Concept Reports

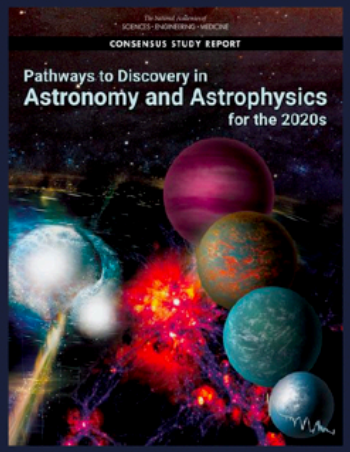
GAO Report on Major Projects



NASA SMD Internal Studies



National Academy Reports



Want to learn more about HWO?

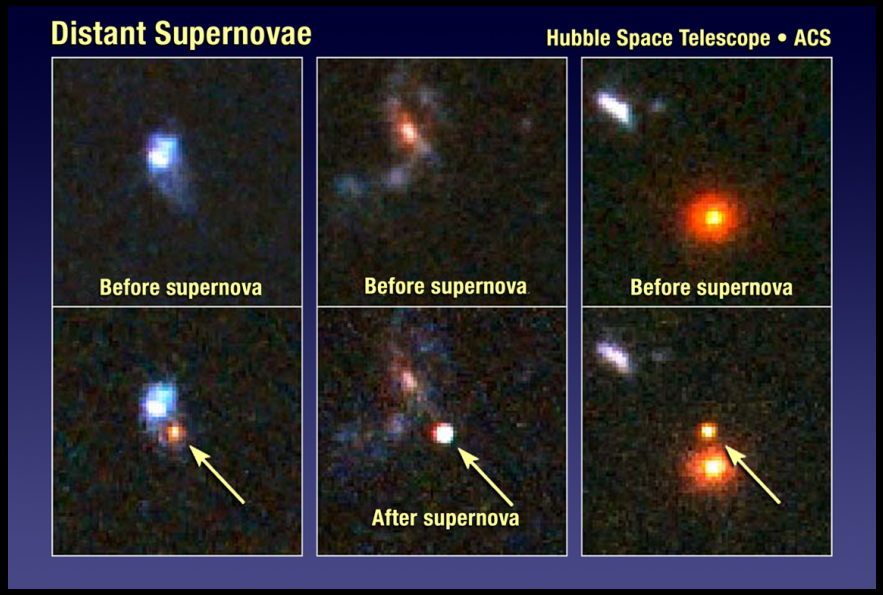
Info and updates on NASA HWO Website

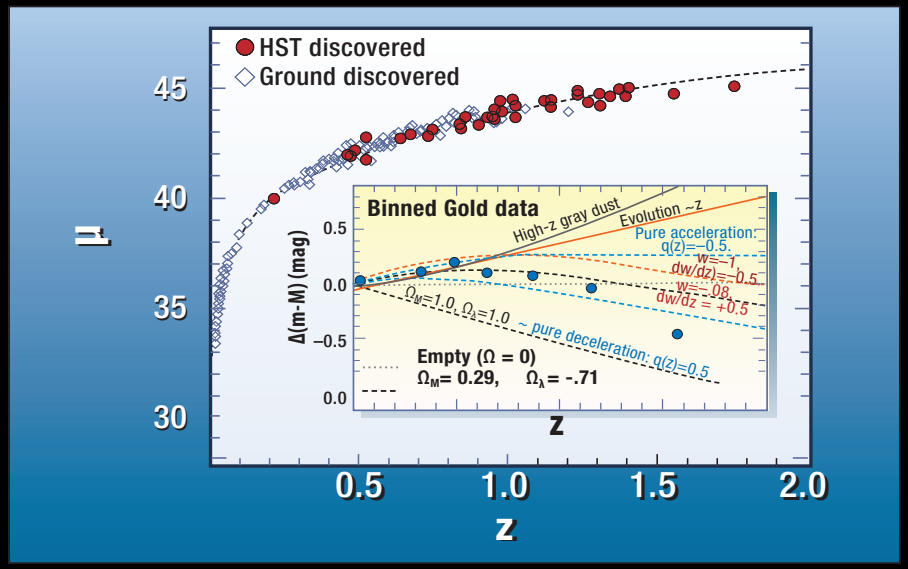
Subscribe to HWO-News email list

NASA HWO

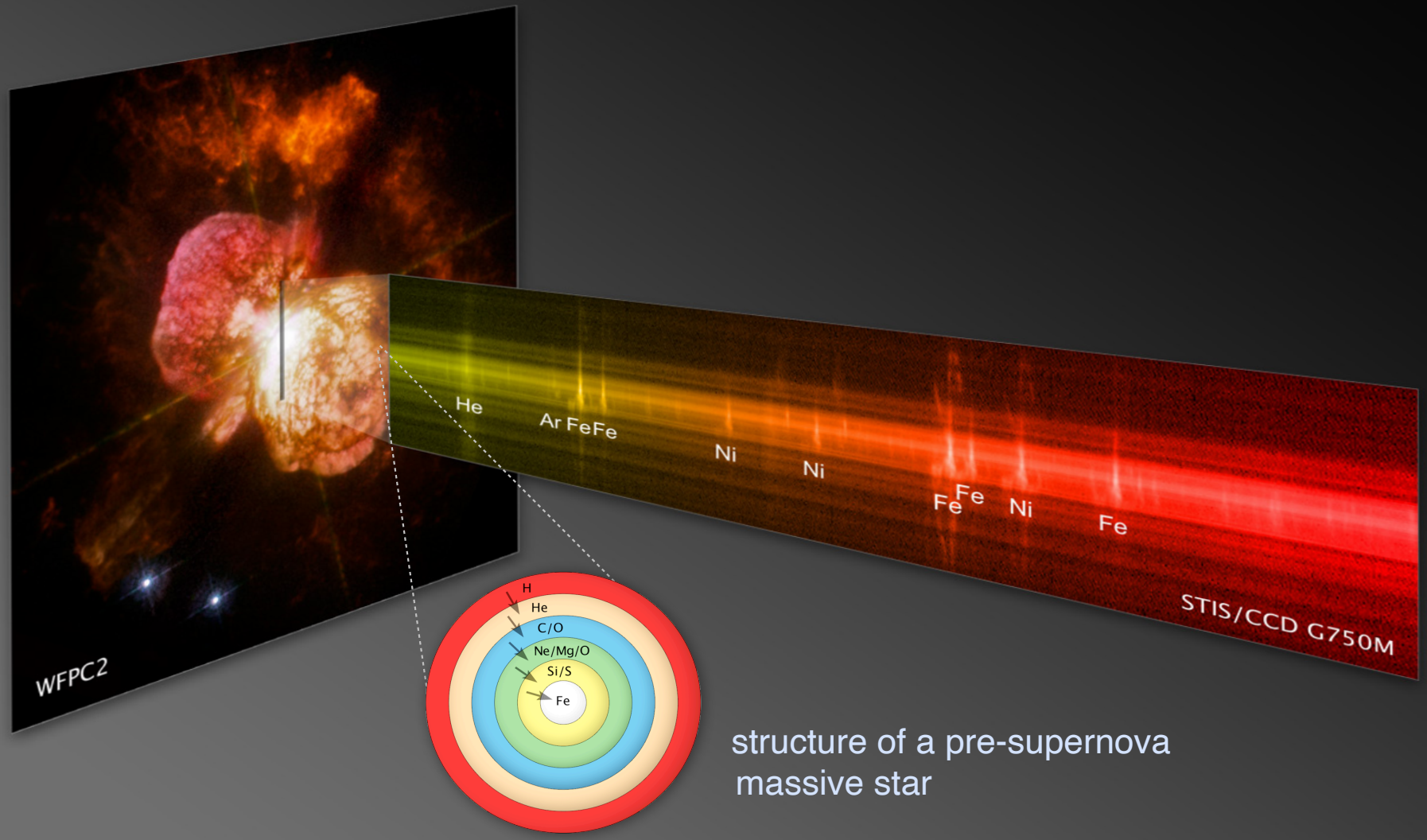
Thank you! !

“The discovery of Dark Energy has greatly changed how we think about the laws of Nature.”
Ed Witten, 2008





Massive Star Eta Carinae ▪ STIS



structure of a pre-supernova massive star

The James Webb Space Telescope

- International collaboration ESA-NASA-CSA
- Deployable infrared telescope with 6.5 meter diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
- Launch June 2014 on an ESA-supplied Ariane 5 rocket to Sun-Earth L2
- 5-year science mission