Space Telescopes:
Seeing the edge of time and searching for life

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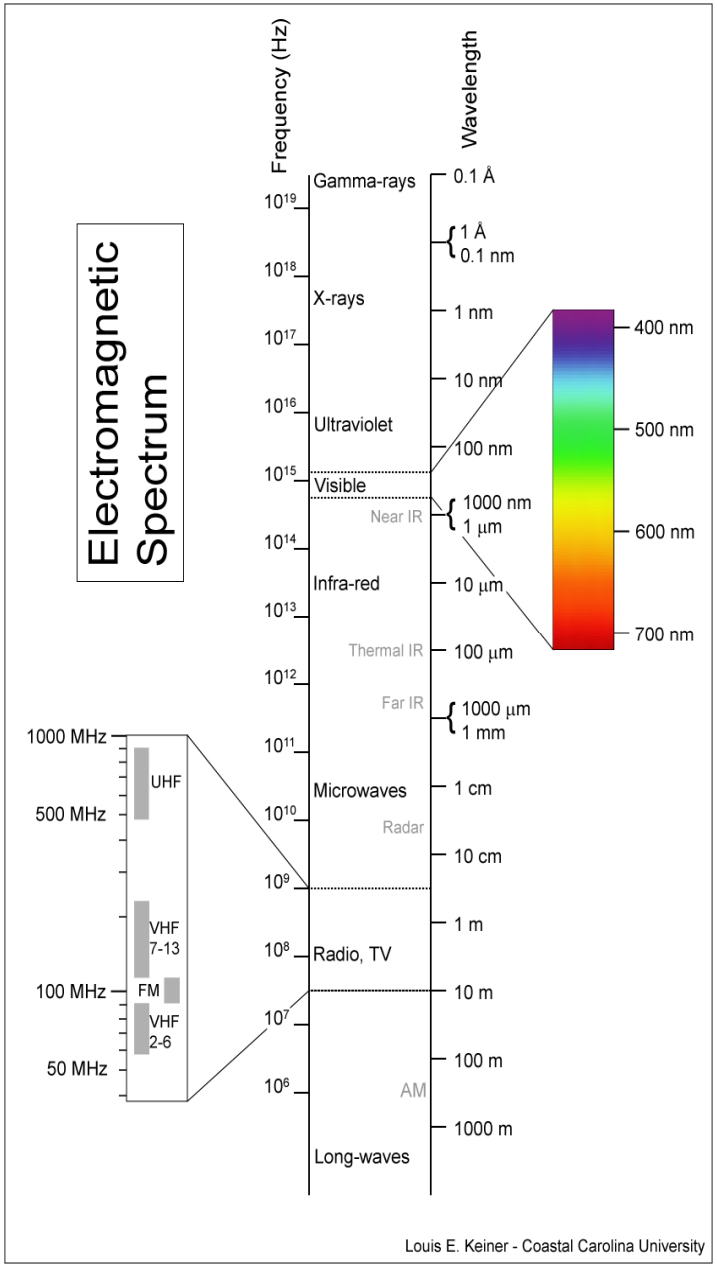
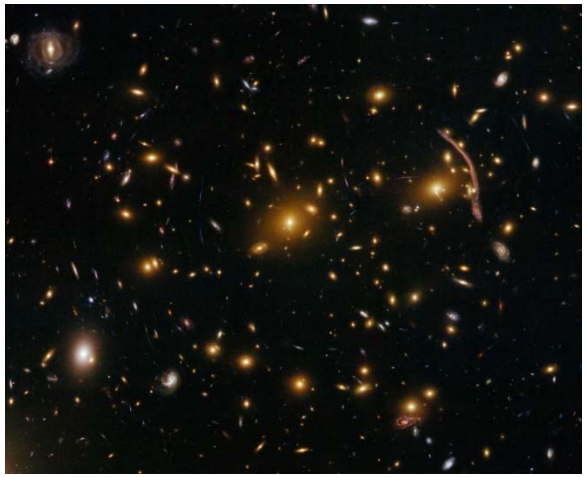
Topics

- Why Fly a Telescope in Space?
- Hubble Space Telescope
- James Webb Space Telescope: First Light Machine
  - Seeing the first stars and galaxies…
- High Definition Space Telescope
  - Searching for life
  - Cosmic Birth

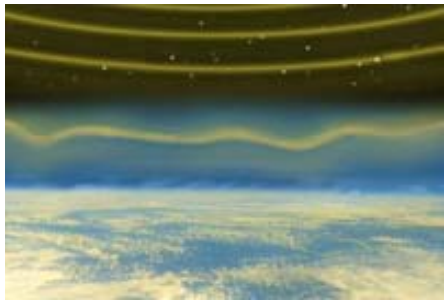
A “Light Refresher”:

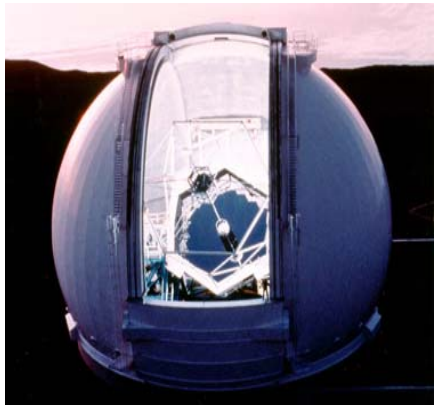
- “Light “ can be thought of 2 ways
  - Particles: Lights travels in particles called photons
    - Photons are discrete bundles of energy
  - Waves: Light also travels as waves
    - Electro-magnetic waves whose wavelength (or wave size) depends on the wavelength of light
  - The amount of energy depends on the wavelength
- Visible light is only a small portion of the spectrum
- Heat can be transferred as invisible infrared light
  - Even room temperature telescope mirrors can give off heat in the form of invisible infrared light



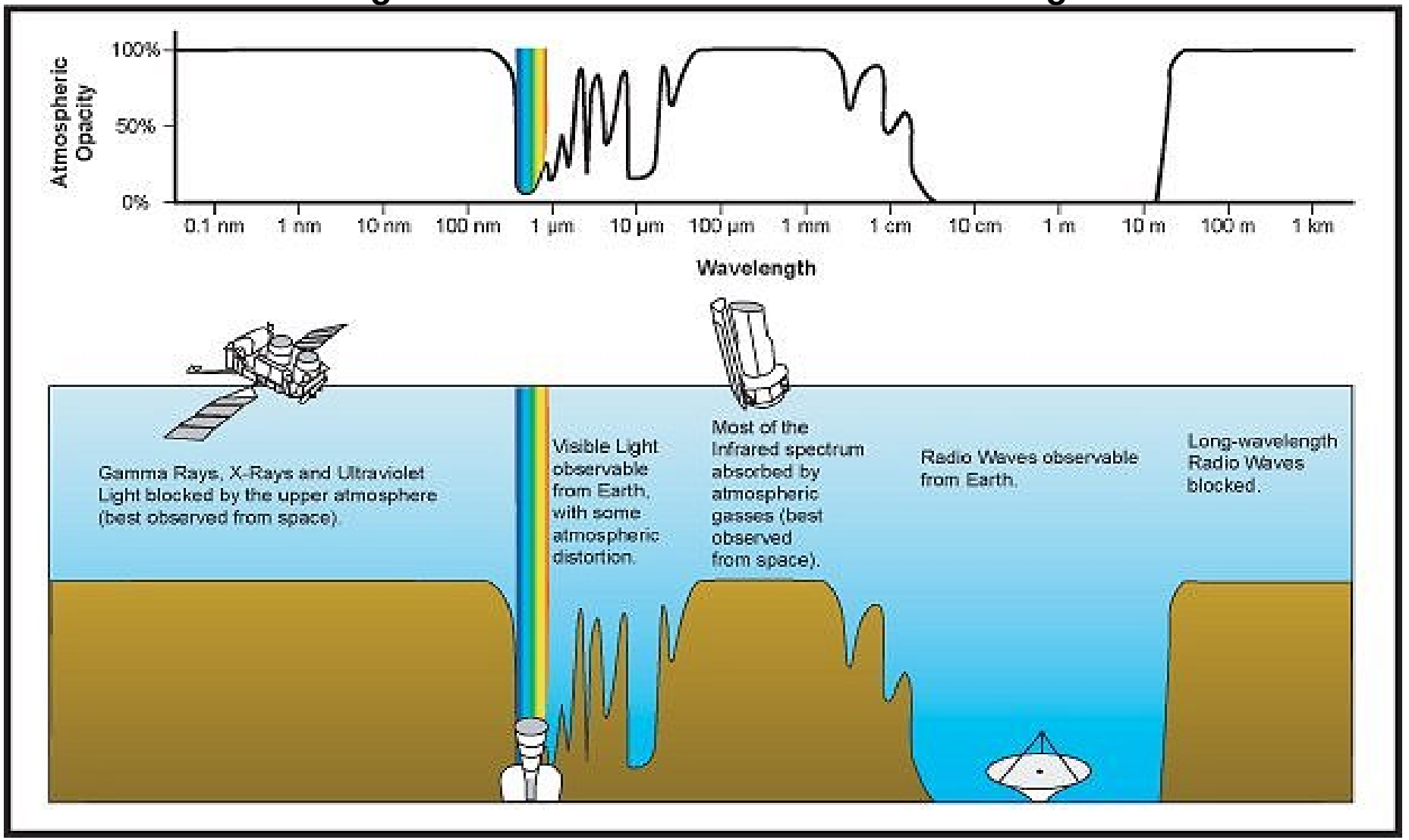


Why a Telescope in Space?

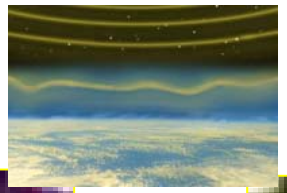


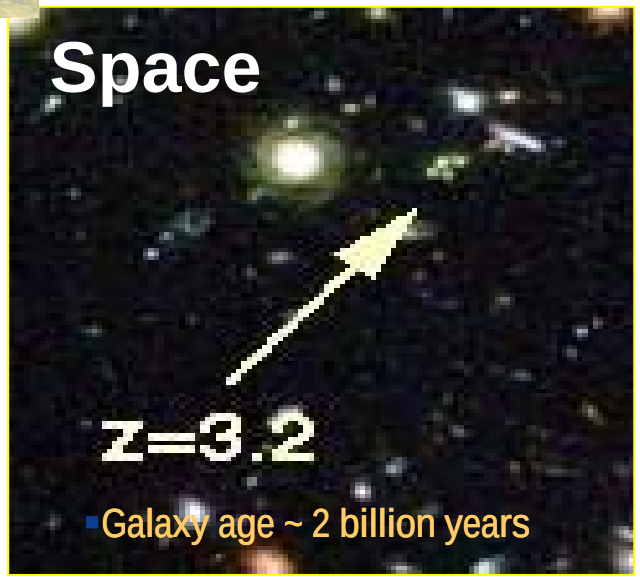


Access to Wavelengths:
The Earths Atmosphere Blocks Gamma, X-Rays, UV and IR and it generates heat in the form of infrared light



Atmospheric Blurring

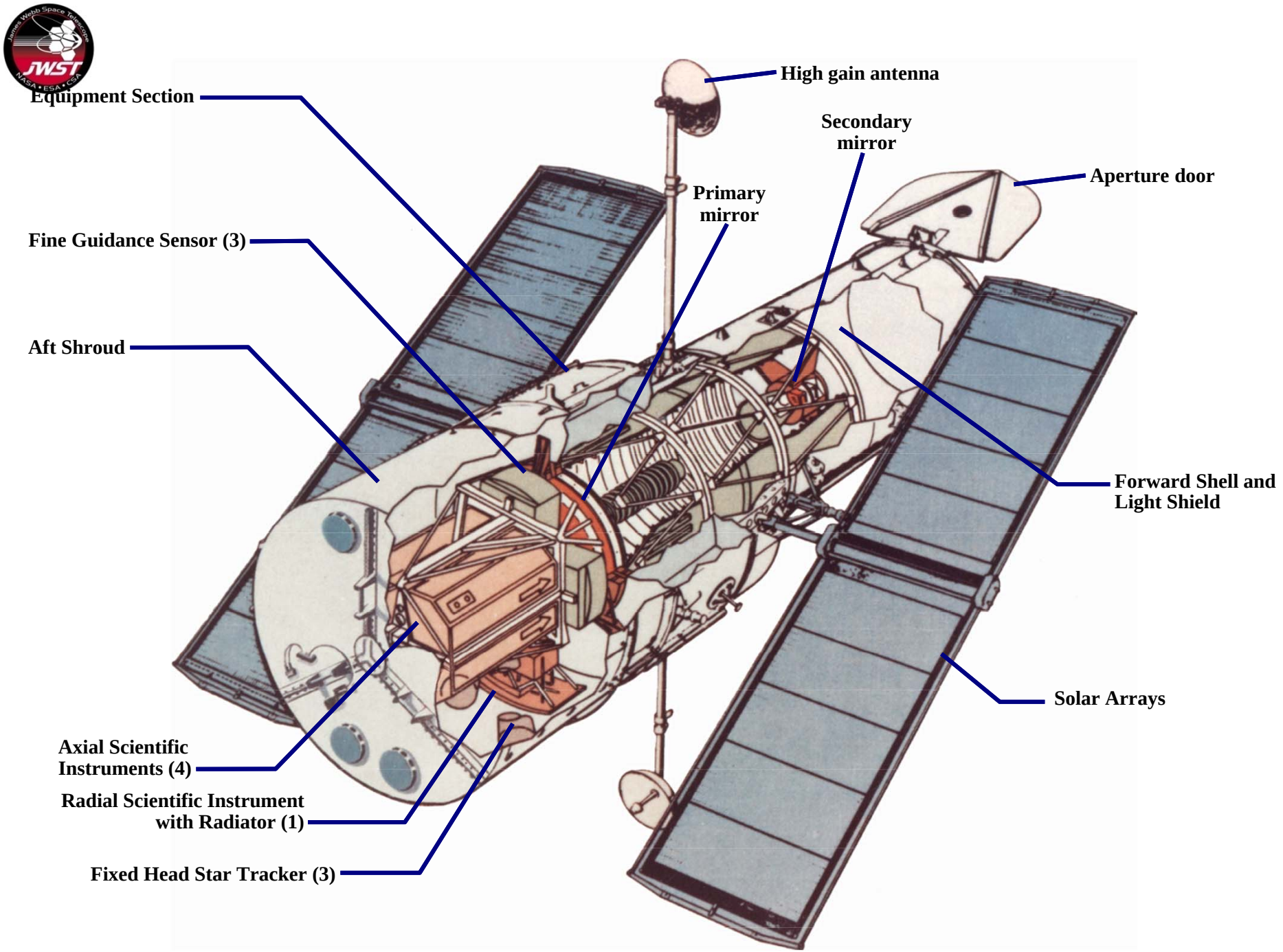


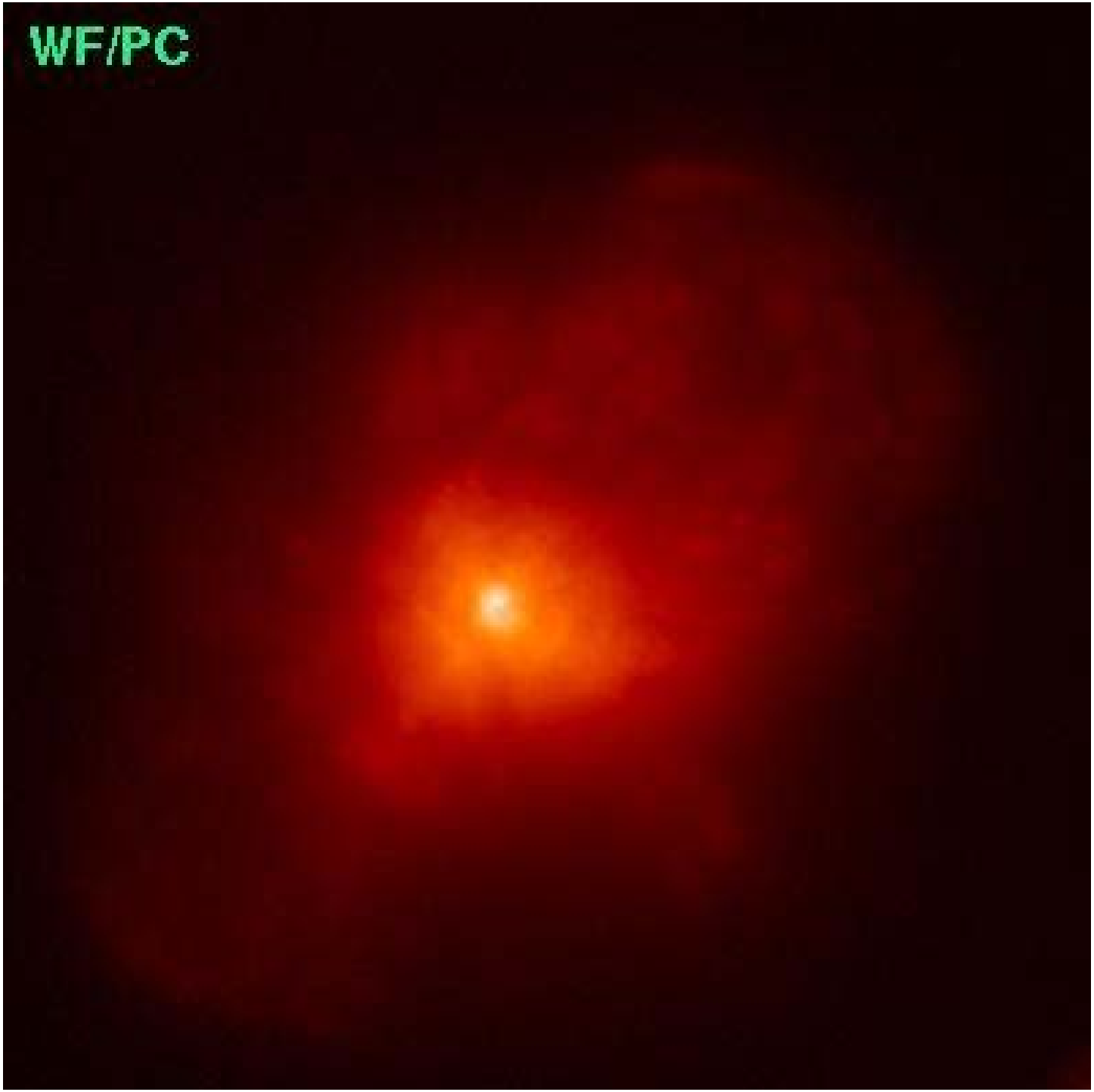


- Astronomers use special mirrors that deform real time to correct the turbulence of the atmosphere
  - Still can't see wavelengths that are absorbed
  - Works over a somewhat limited picture size (field of view)
- Telescopes in space can be very stable when put in a thermally stable orbit (more on this later)

The Hubble Space Telescope

“Expect the Unexpected”

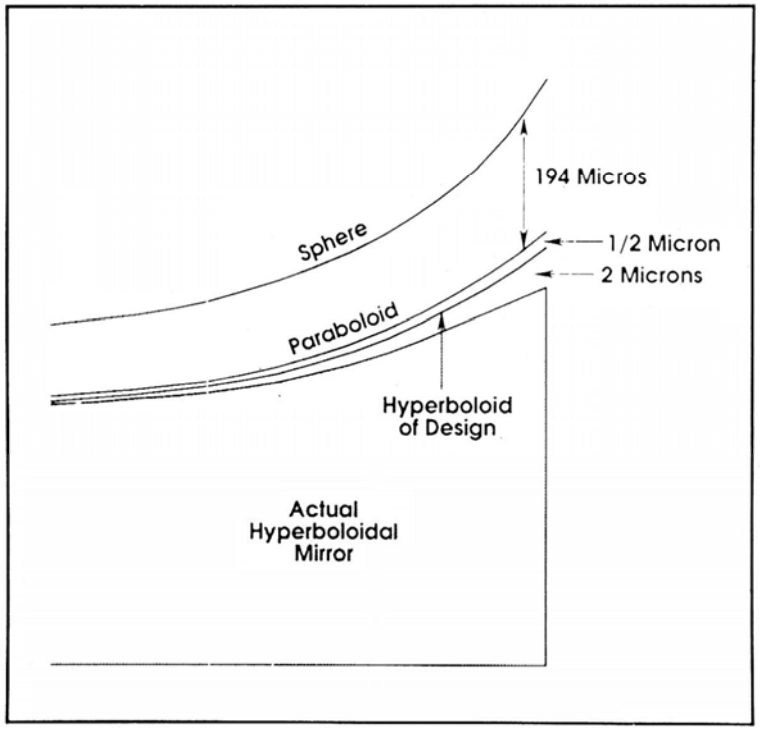

High gain antenna
Equipment Section
Secondary mirror
Aperture door
Primary mirror
Fine Guidance Sensor (3)
Aft Shroud
Forward Shell and Light Shield
Solar Arrays
Axial Scientific Instruments (4)
Radial Scientific Instrument with Radiator (1)
Fixed Head Star Tracker (3)

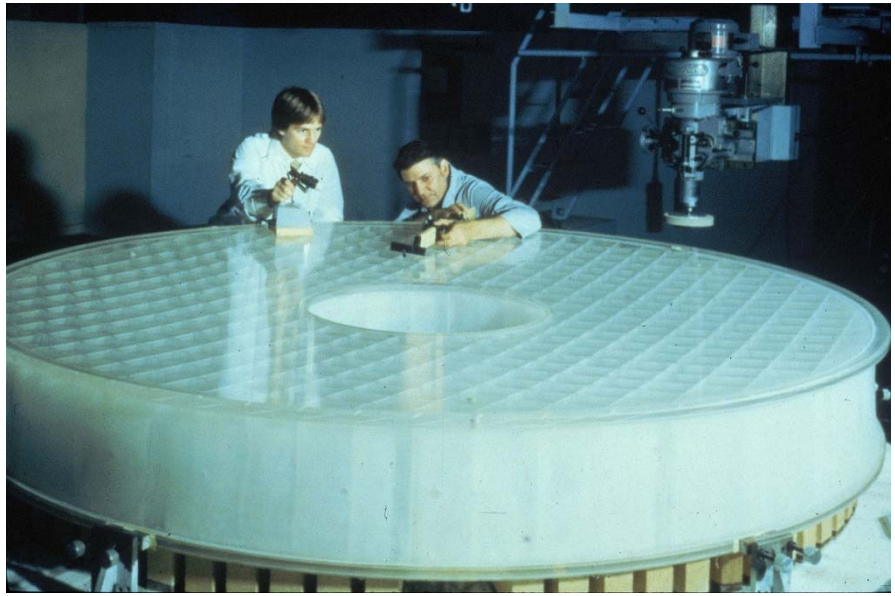

WF/PC

Hubble Primary Mirror:
Polished nearly perfectly but to the wrong prescription

“The Trouble with Hubble”

PRIMARY MIRROR FIGURING ERROR





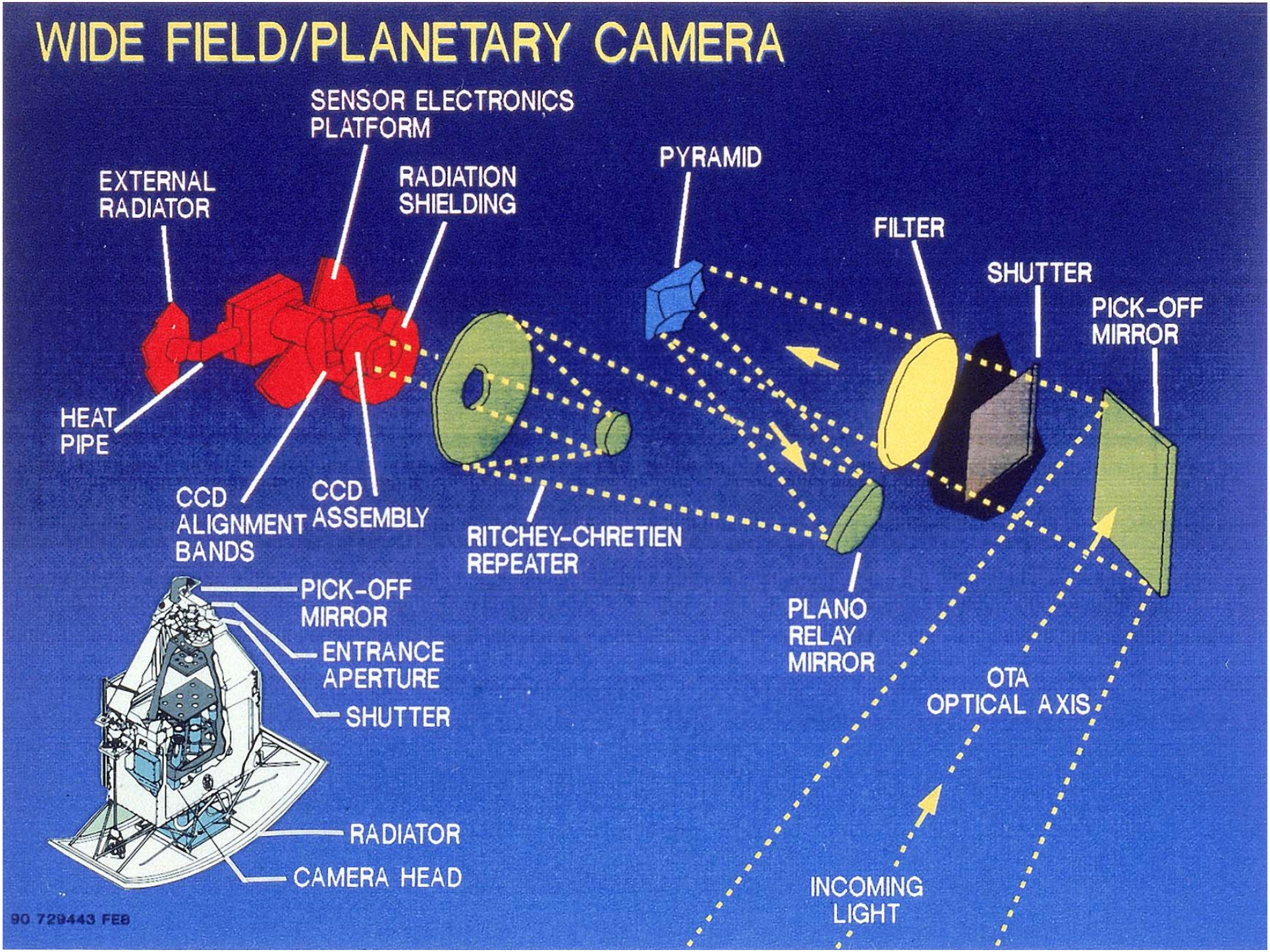
Optical Test Device (Called a Null Lens) used to test the primary mirror was made wrong.

Too much material was removed from the edge of the mirror.

Fixing Hubble: "Contact Lenses in Space"

- Hubble was built to be serviced periodically by astronauts aboard the Space Shuttle
  - Second generation instruments were already in development including the Wide Field Camera-2 being built by JPL in nearby Pasadena
- Late in 1990, NASA decided to fix Hubble on it's first servicing mission
- The Servicing Mission occurred in December 1993
  - Wide Field Planetary Camera-2 was retrofitted with a special corrective optic (mirror)
  - Corrective Optics Axial Replacement (COSTAR) was developed to correct the 3 axial instruments. It included a pair of mirrors for each instrument channel, one which corrected the Hubble error

WIDE FIELD/PLANETARY CAMERA



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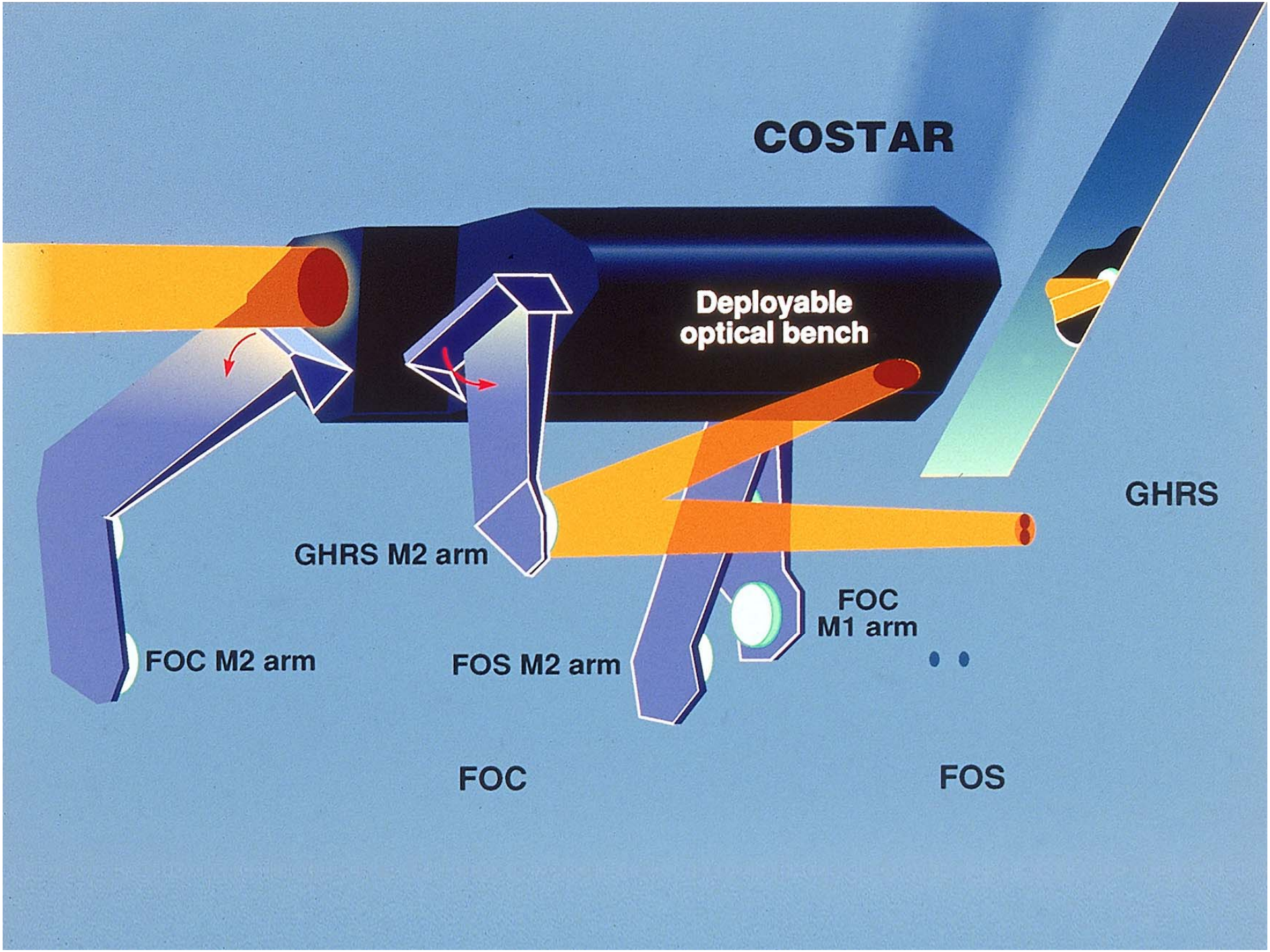
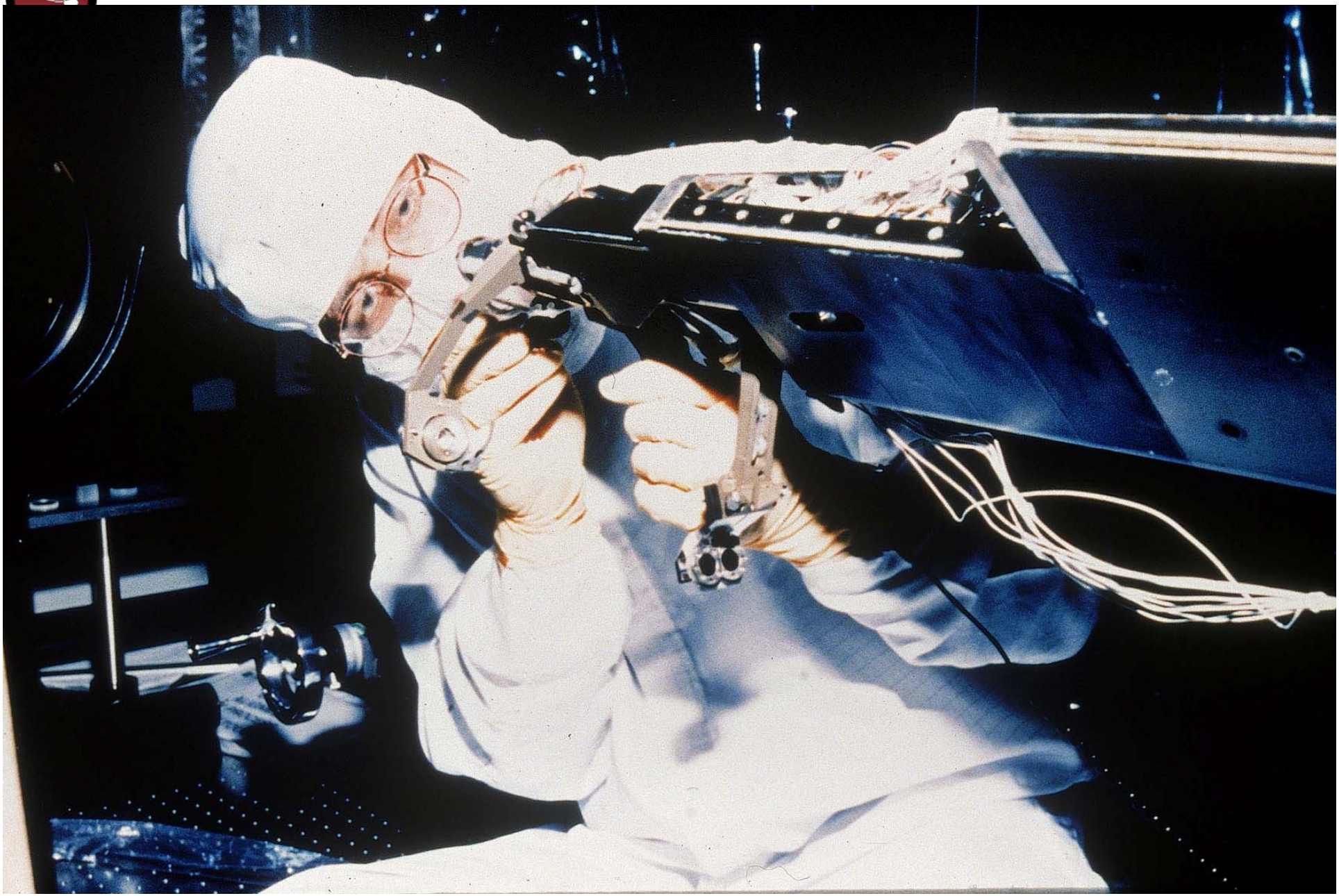
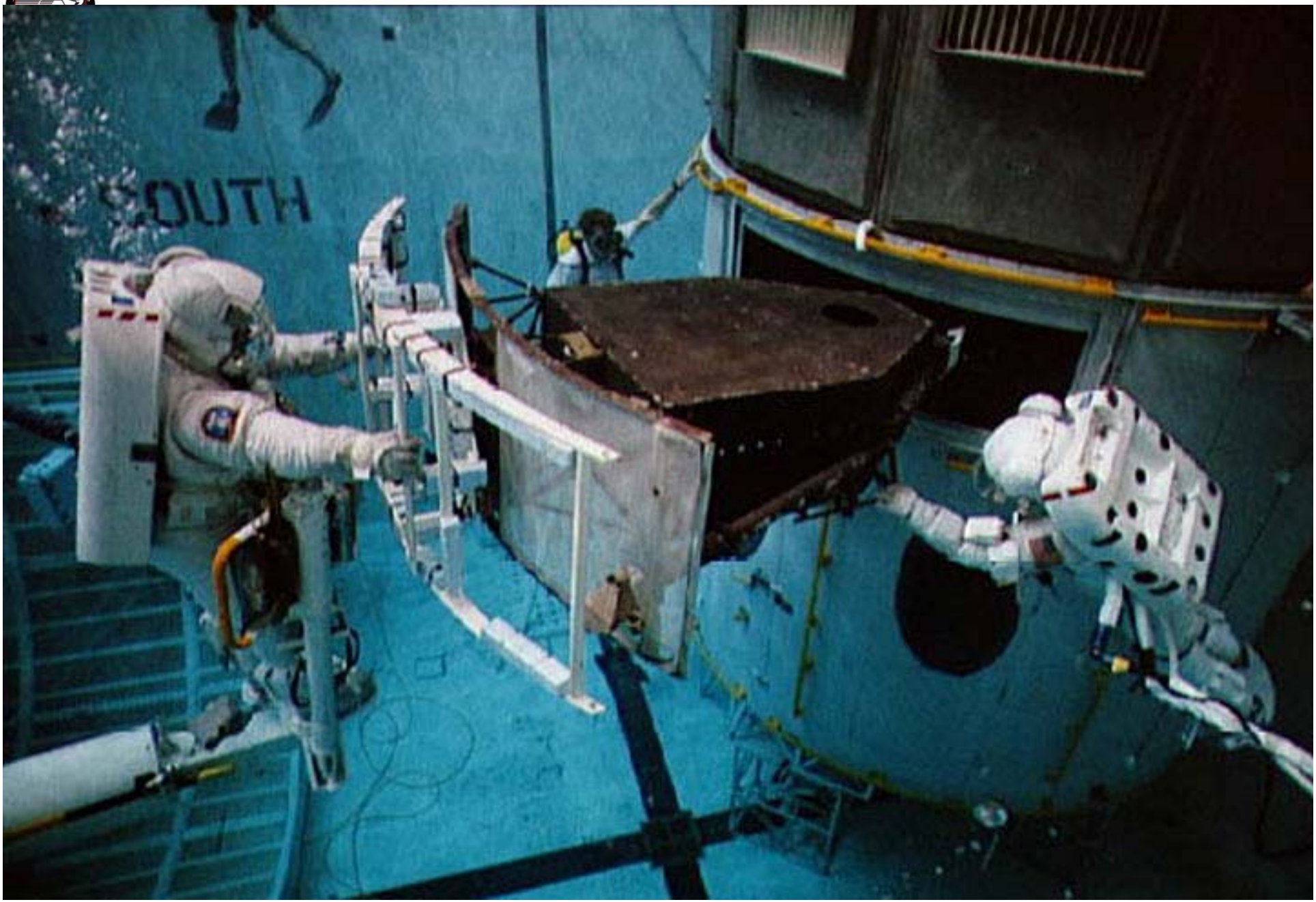
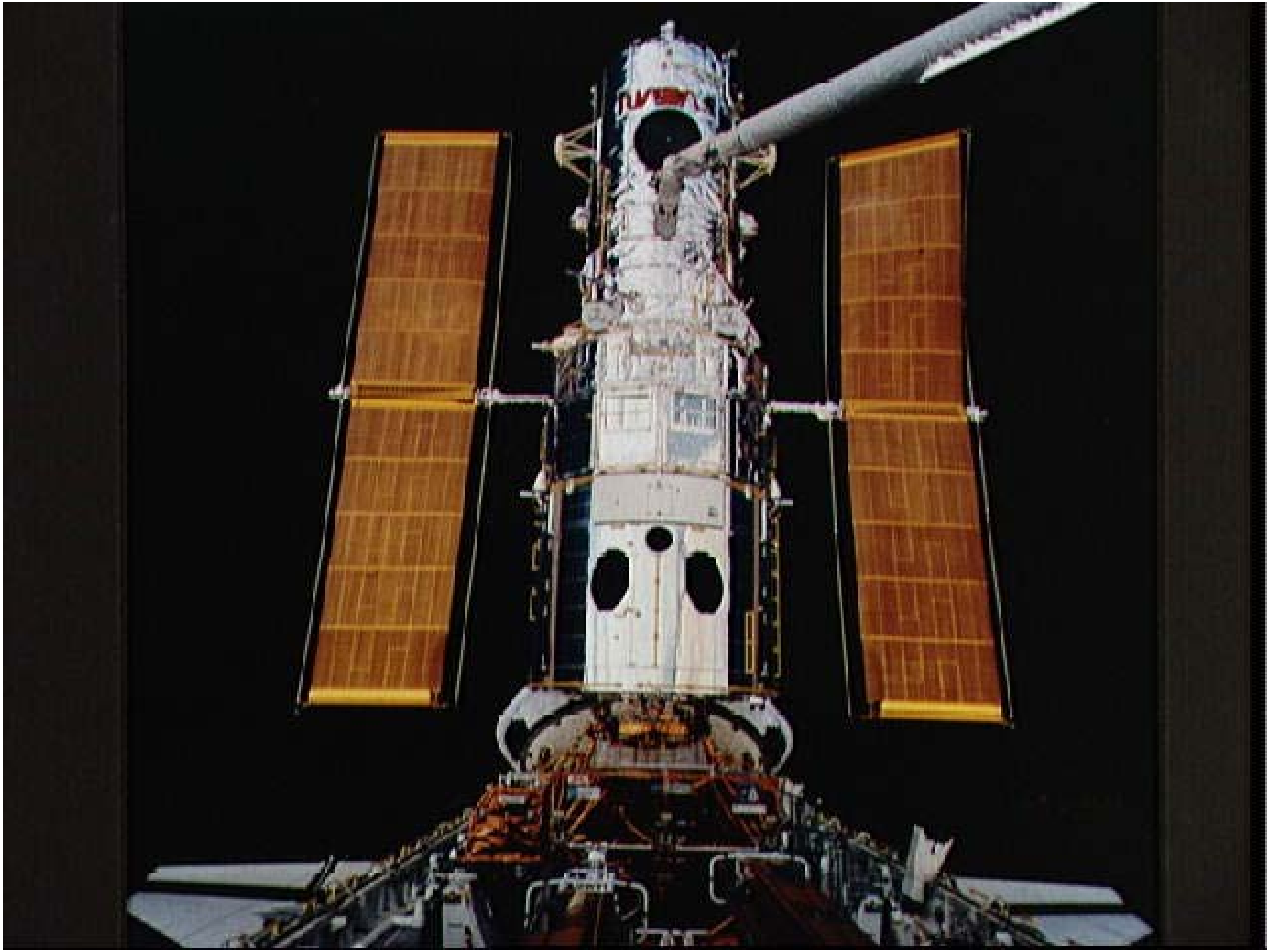
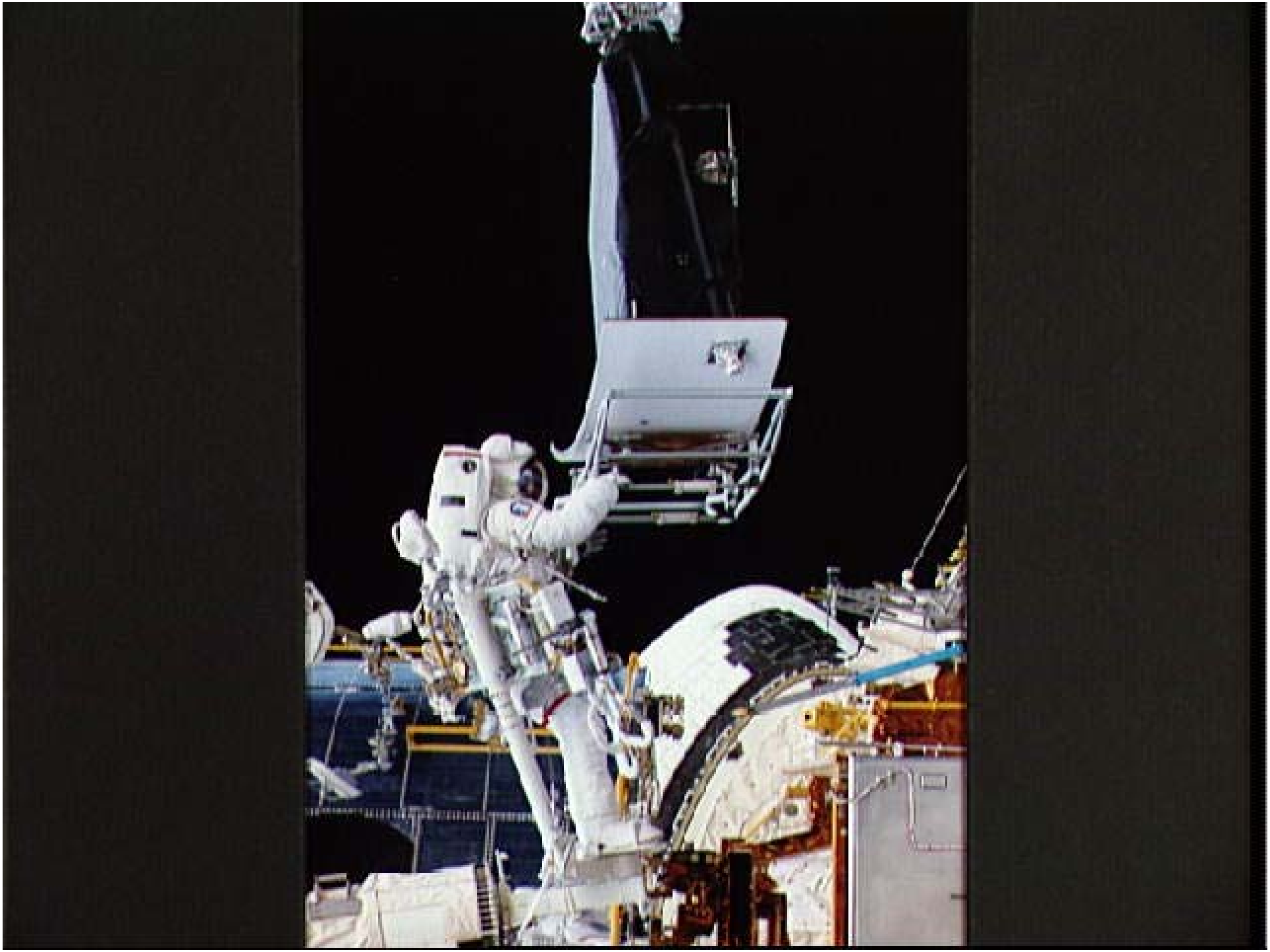
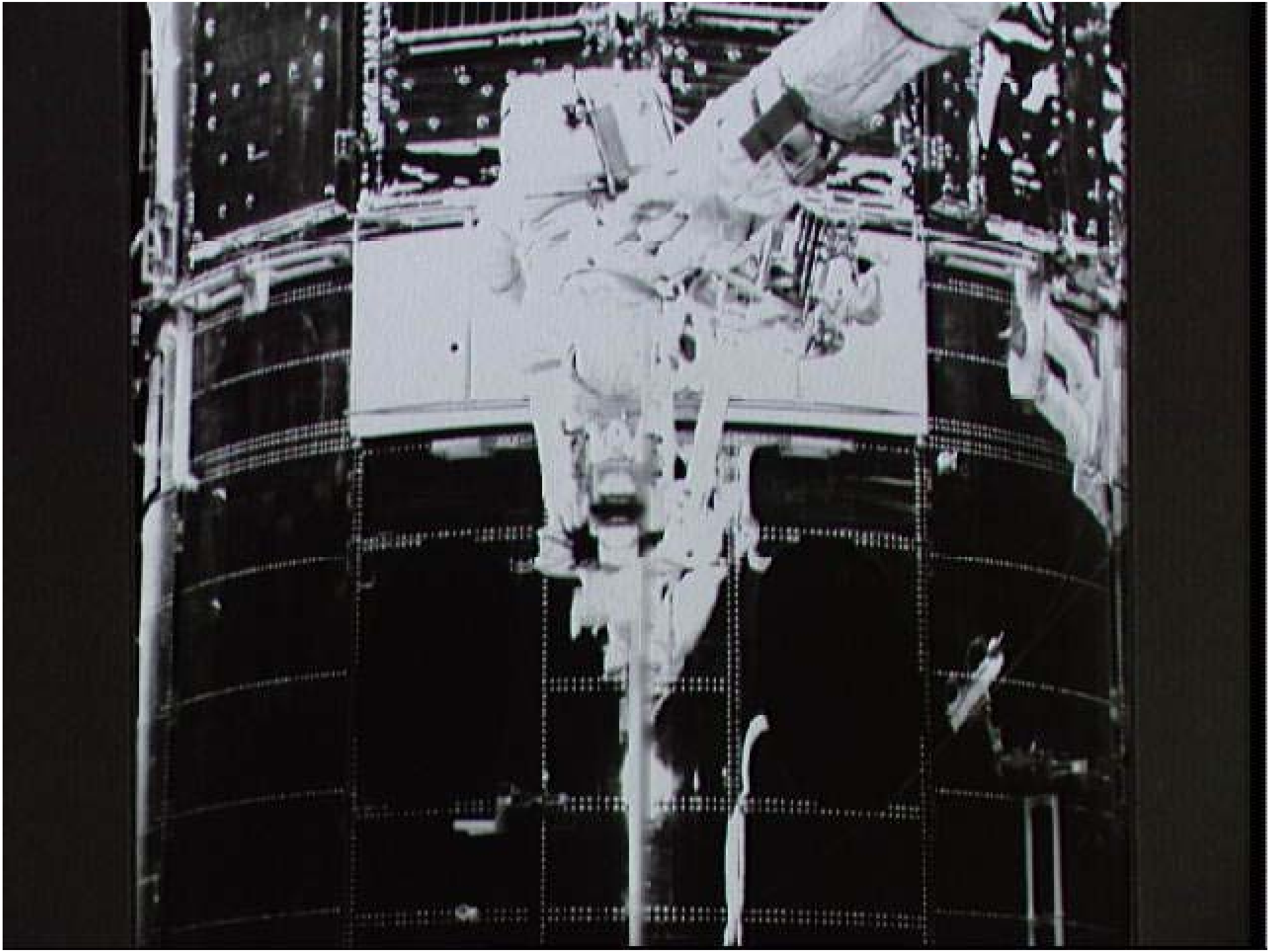

COSTAR
Deployable optical bench
GHRS
GHRS M2 arm
FOC M1 arm
FOC M2 arm
FOS M2 arm
FOC
FOS




OUTH



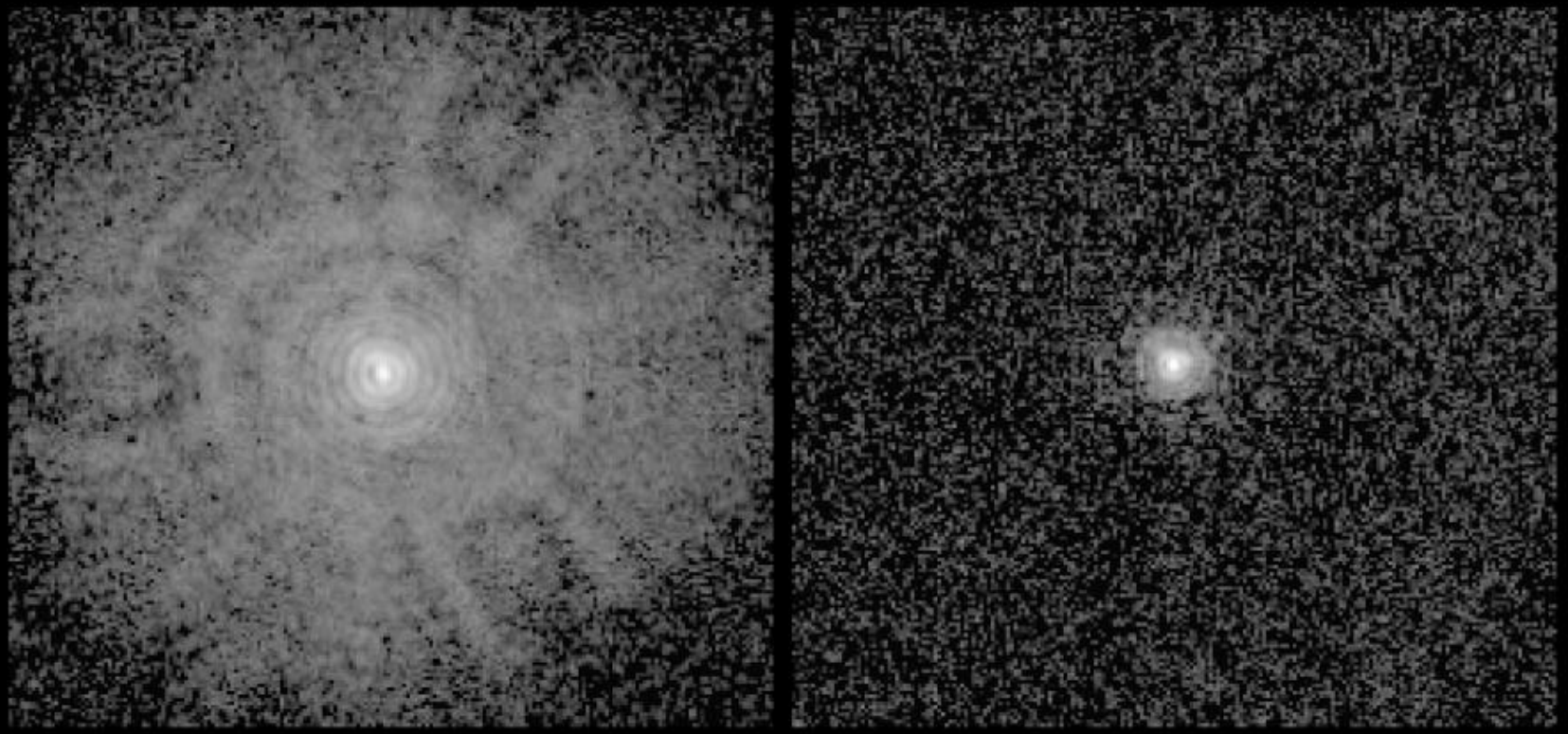




HUBBLE SPACE TELESCOPE

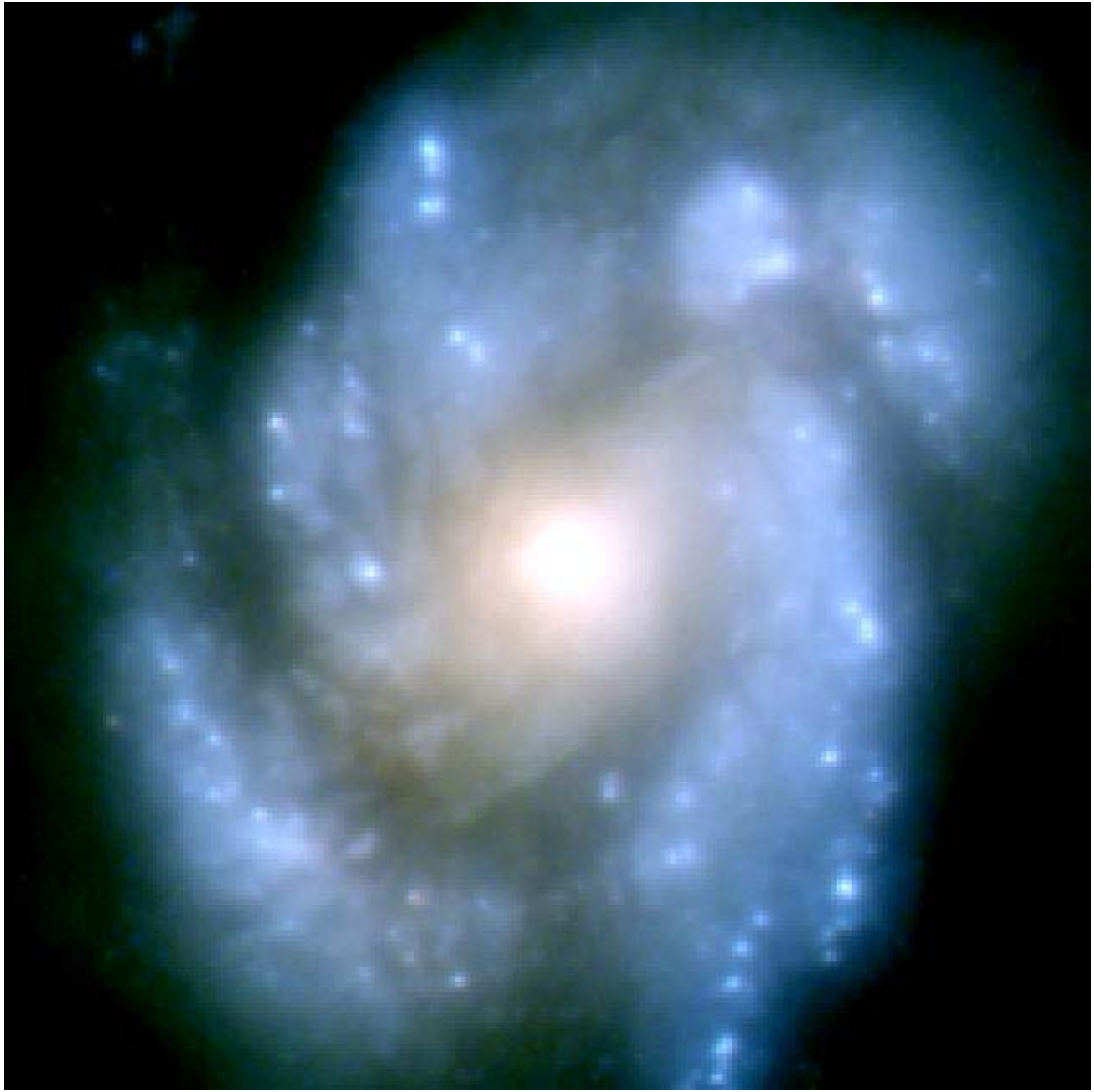
FAINT OBJECT CAMERA

COMPARATIVE VIEWS OF A STAR

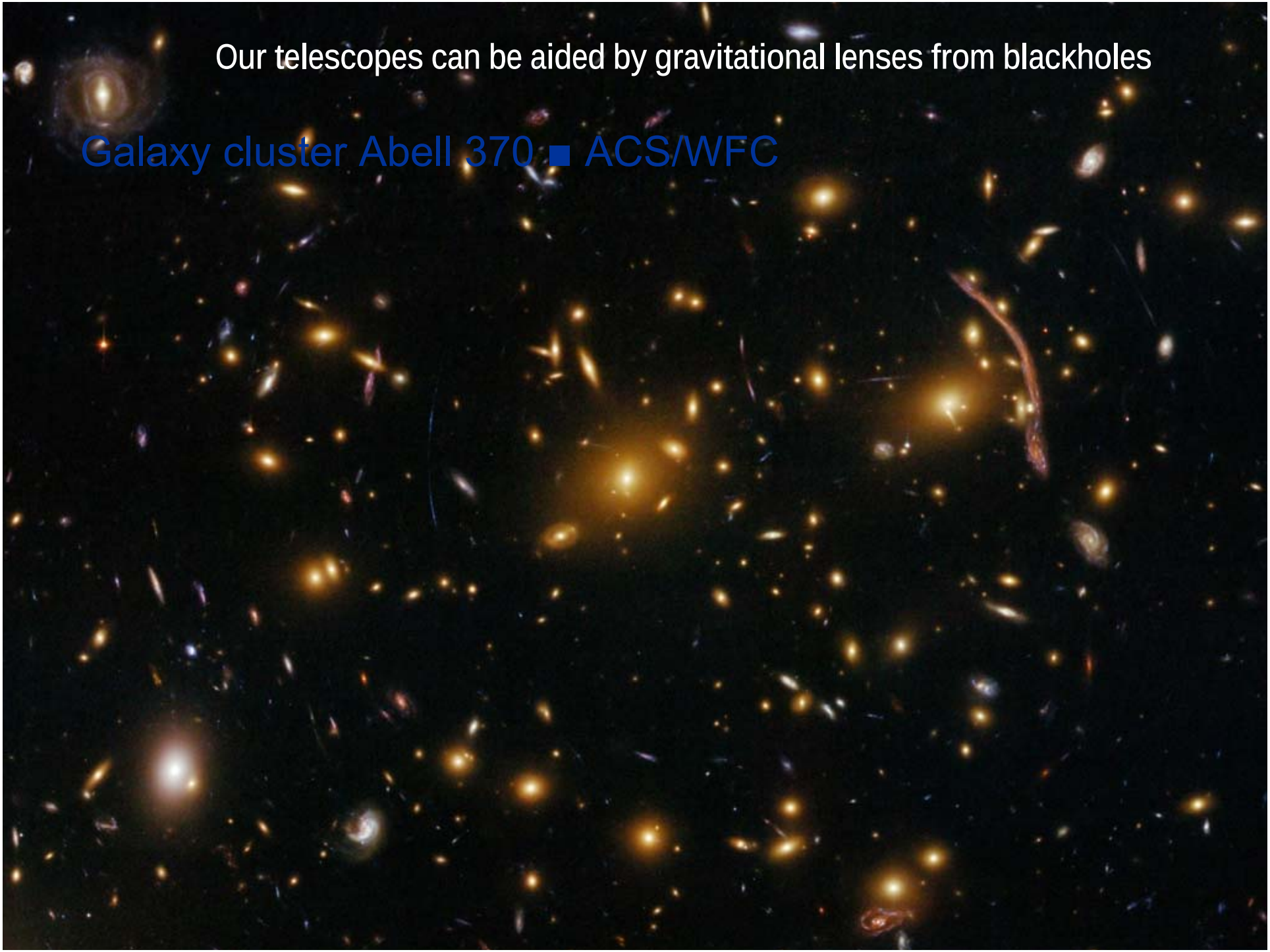


BEFORE COSTAR

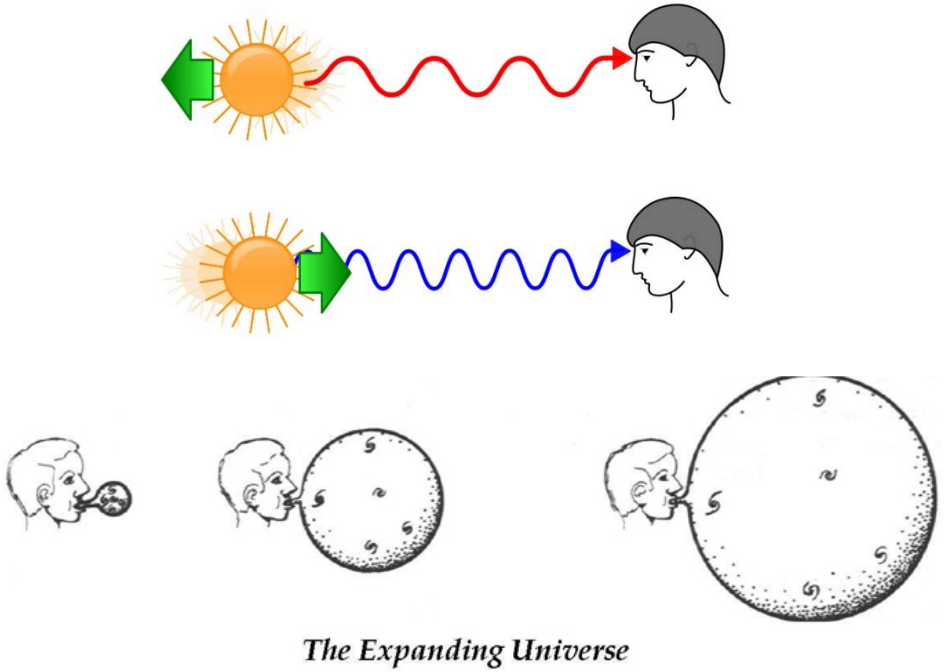
AFTER COSTAR

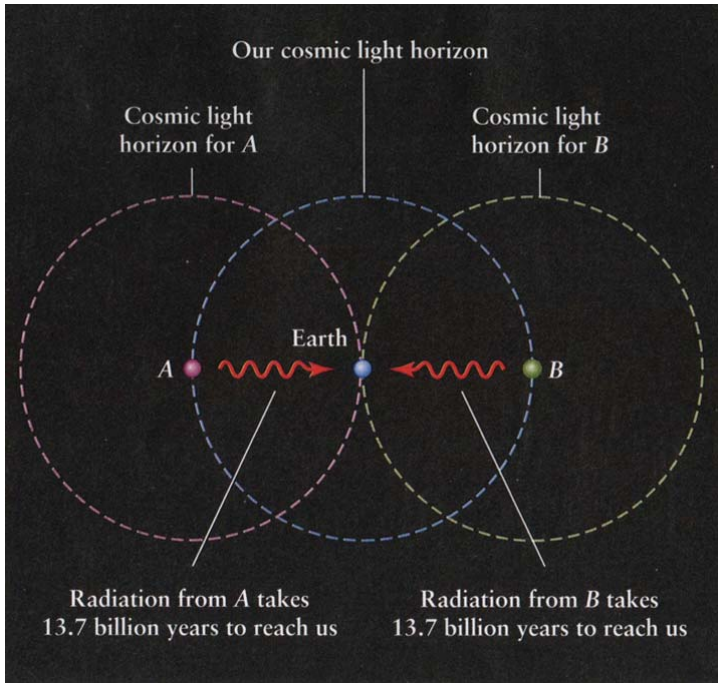


Our telescopes can be aided by gravitational lenses from blackholes



Seeing the Edge of Time





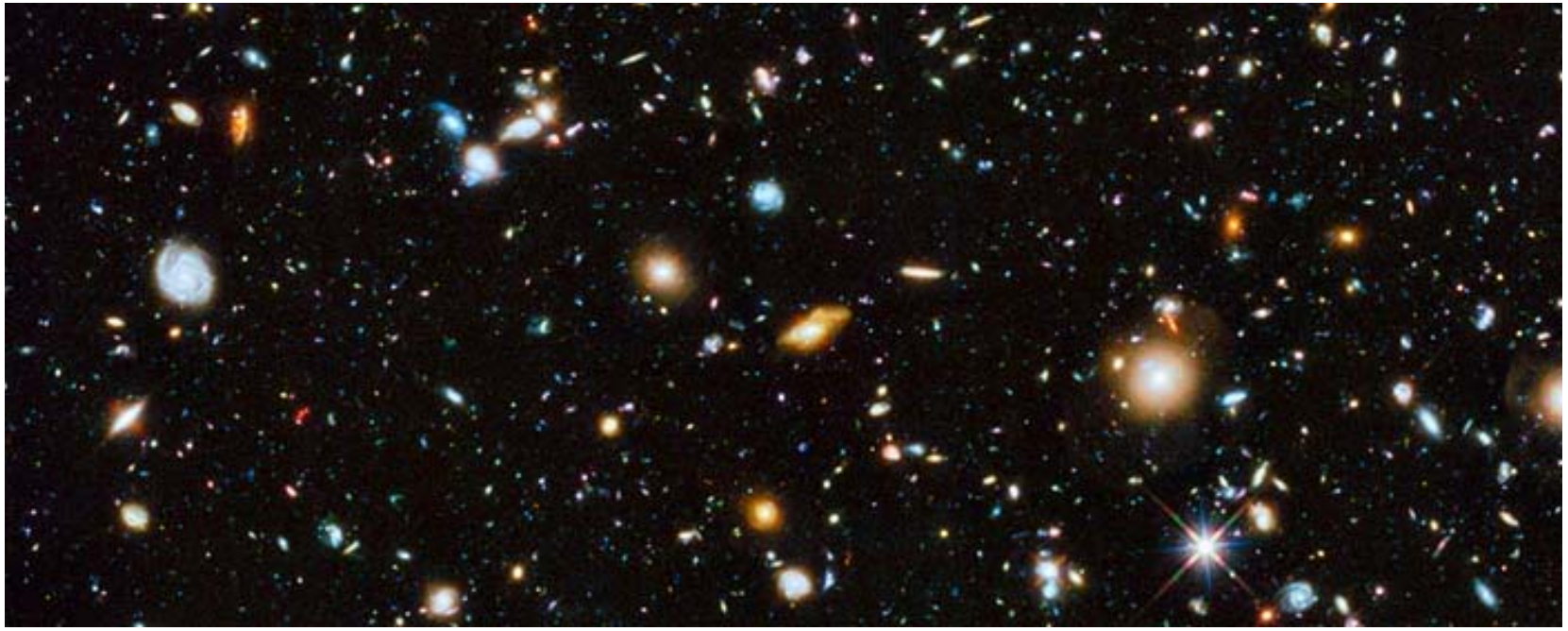
Theory of inflation:
after Big Bang, rapid expansion in a fraction of a second to the huge universe we have now, universe continued to expand since then another 20x

These photons could not have communicated with each other unless inflation took place during the very early Universe (data from WMAP shows universe is almost identical in temperature)

From: http://www.ctc.cam.ac.uk/outreach/origins/inflation_zero.php

Hubble Deep Field:

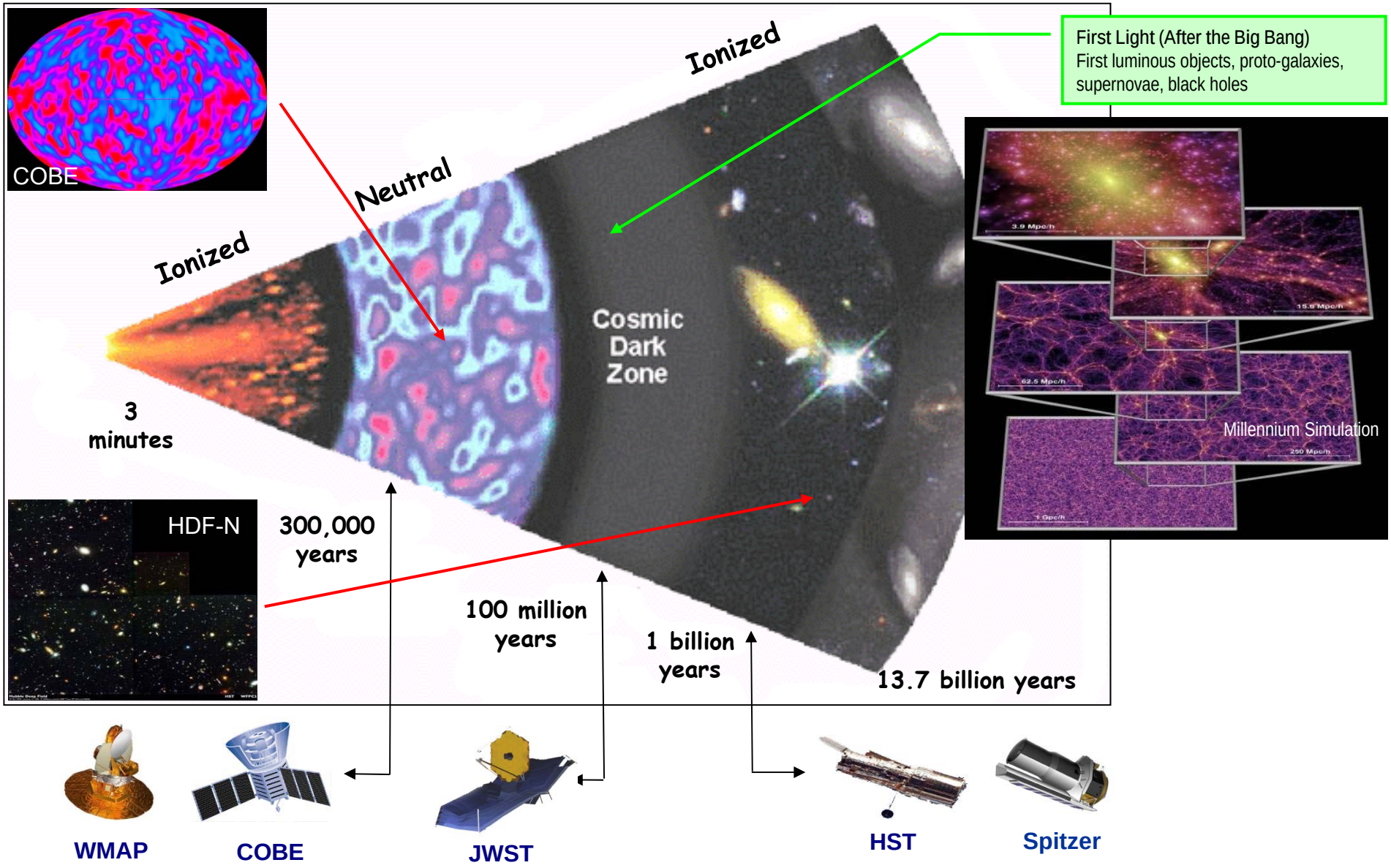
Earliest galaxies are red-shifted to infrared



The James Webb Space Telescope (JWST)

“The next big thing”

JWST is designed to observe formation of the first galaxies



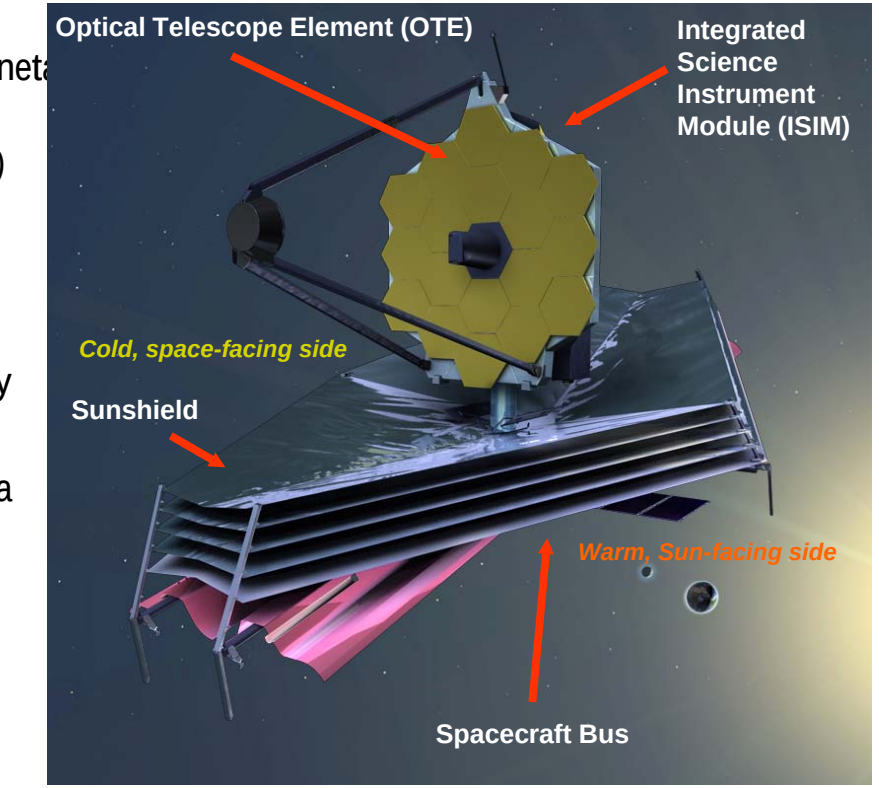
James Webb Space Telescope (JWST)

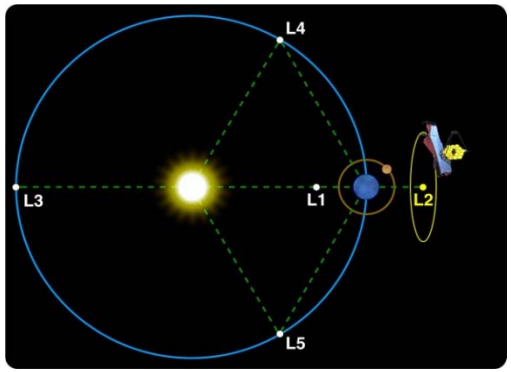
Mission Objective

- Study the origin and evolution of galaxies, stars and planetary systems
  - *Optimized for infrared observations (0.6 – 28 μm)*

Organization

- Mission Lead: Goddard Space Flight Center
- International collaboration with ESA & CSA
- Prime Contractor: Northrop Grumman Space Technology
- Instruments:
  - Near Infrared Camera (NIRCam) – Univ. of Arizona
  - Near Infrared Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA
  - Fine Guidance Sensor (FGS) – CSA
- Operations: Space Telescope Science Institute (STScI)





Description

- Deployable telescope w/ 6.5m diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
  - 50K, -370F
- Launch NET June 2014 on an ESA-supplied Ariane 5 rocket to Sun-Earth L2
- 5-year science mission (10-year goal)

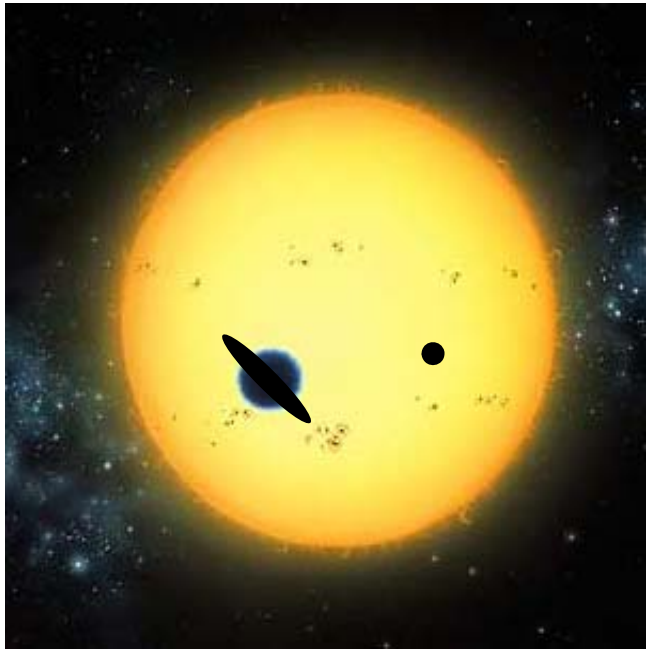
www.JWST.nasa.gov

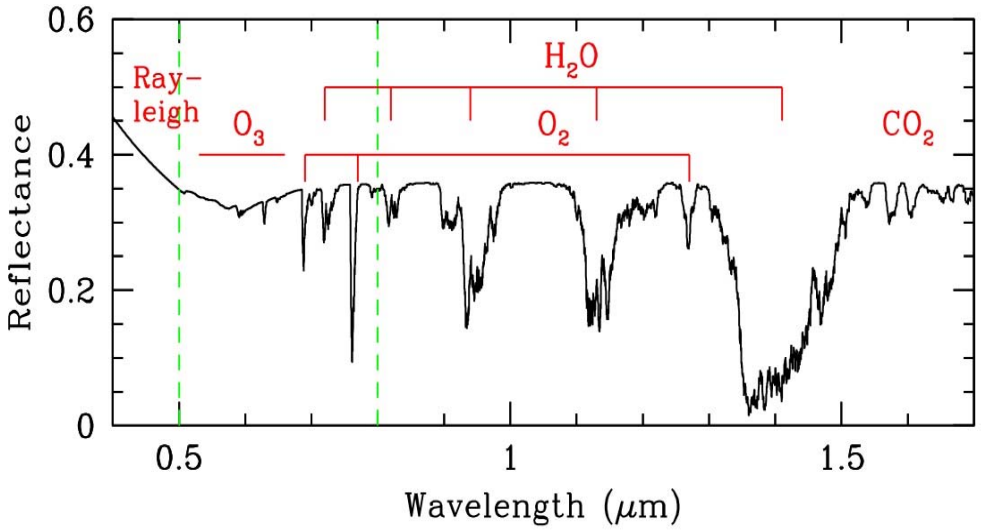
JWST requires a segmented deployable primary mirror

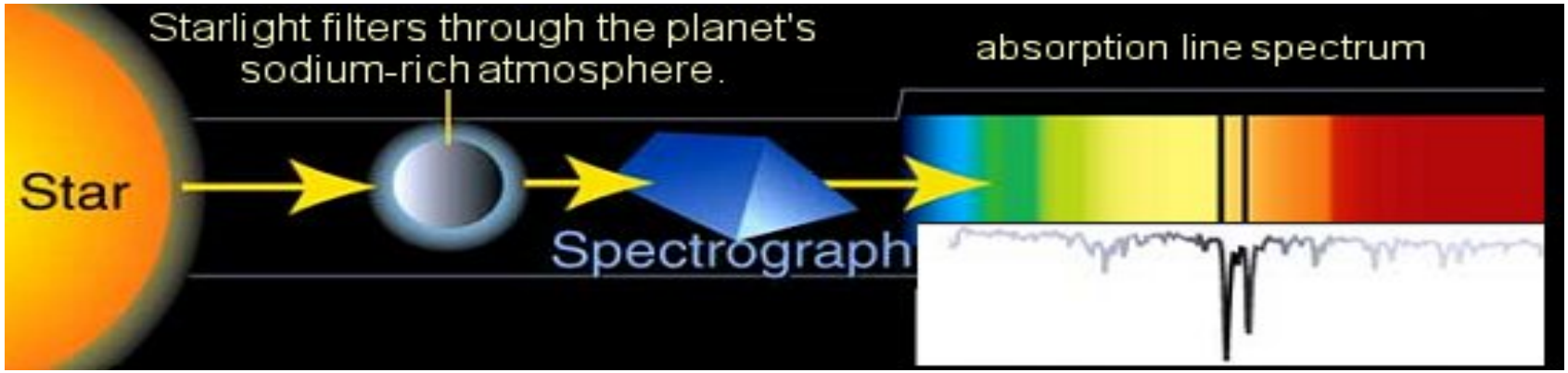
Ariane 5 ECA

- JWST is designed to integrate with an Ariane V launch vehicle and 5 m diameter fairing
- Launch from Kourou Launch Center (French Guiana) with direct transfer to L2 point.
- Payload launched at ambient temperature with on orbit cooling to 50 K via passive thermal radiators
- JWST payload: 6330 kg

After JWST was started, astronomers detected exoplanets, and recently used Kepler to show they are common
Webb can study the atmospheres of exoplanets of Jupiter and “super earths” using transits







What might come next: A new report this past month

Co-Chairs:

Julianne Dalcanton
(Washington)

Sara Seager (MIT)

Develop a shared vision for UVOIR astronomy in the 2020s and after. . .

. . . based on common ground between "exoplanet" and "cosmic origins" communities. . .

. . . and a conviction that large scale requirements for transformative science in both areas are compatible.

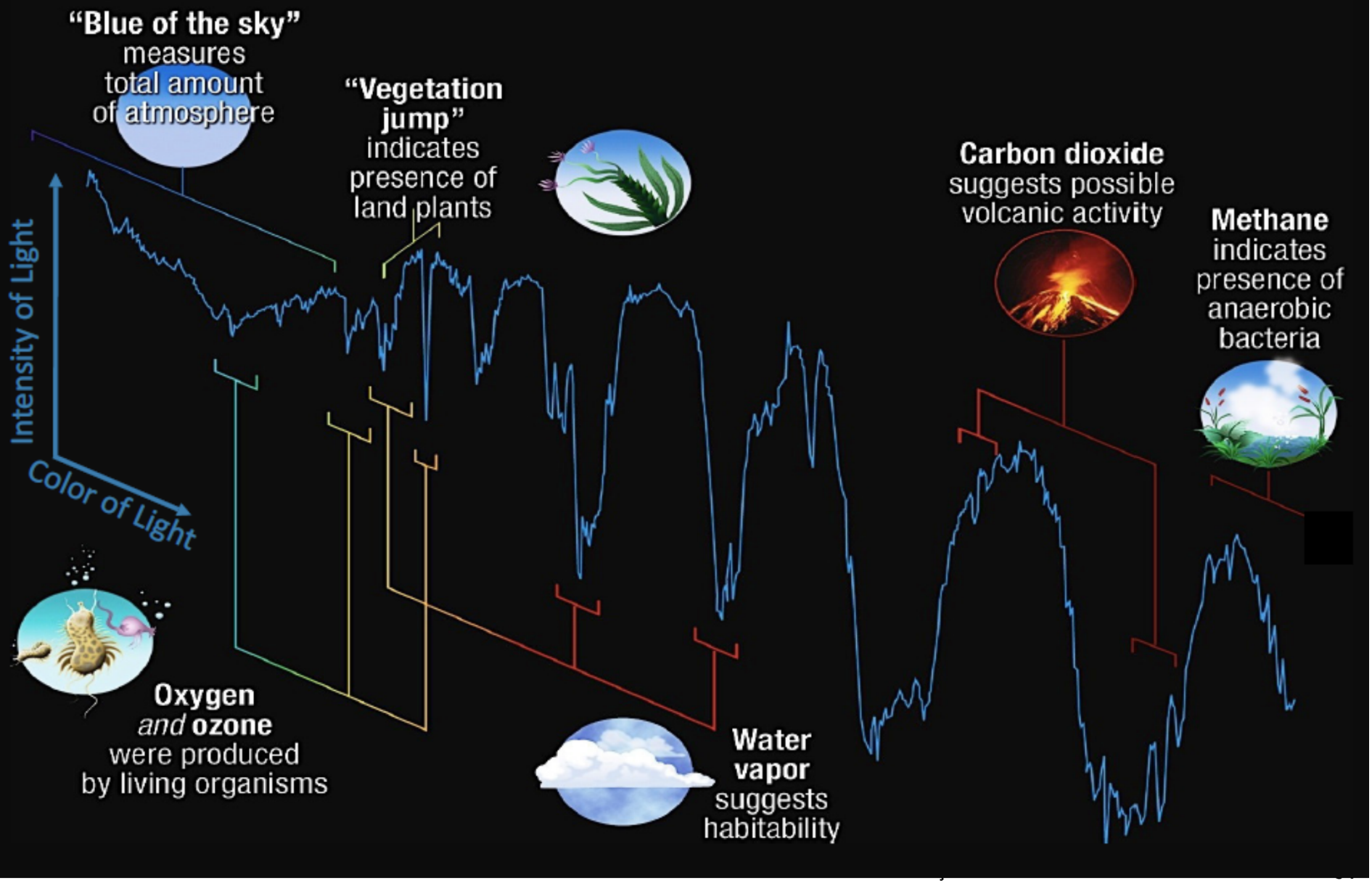
Suzanne Aigrain
Steve Battel
Niel Brandt
Charlie Conroy
Lee Feinberg
Suvi Gezari
Olivier Guyon
Walt Harris

Chris Hirata
John Mather
Marc Postman
David Redding
David Schiminovich
Phil Stahl
Jason Tumlinson
Heidi Hammel
(AURA ex officio)

Technologists Instrument Builders

What We Ultimately Need to Search for Life:

We need to look at reflected light off the earth like planets around sun-like stars



The challenge of seeing an earth-like planet

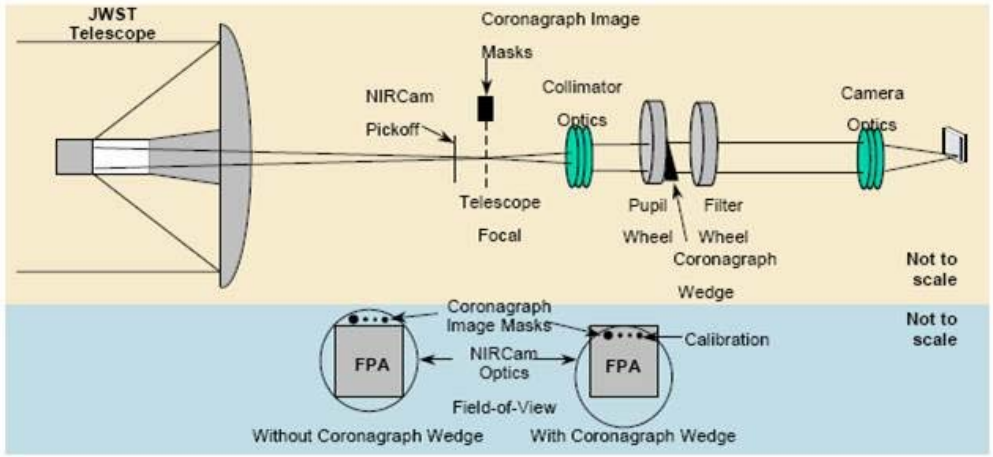
Looking at our solar system from far away, the sun is 10 billion times brighter than the earth

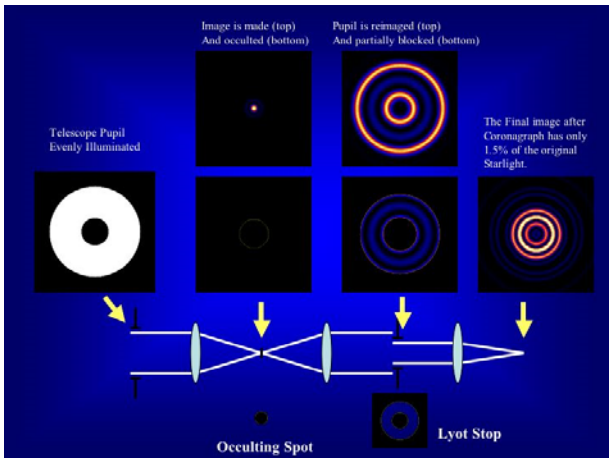
To image the earth and perform spectroscopy to determine if the signatures of life exist, one needs to block the earth with a special device called a coronagraph capable of reducing the startlight by 10^10

Ideally want to use an internal coronagraph instrument to survery many stars efficiently

- JWST has several internal coronagraphs, but only works to 10^6

An external starshade is possible that would ease the stability requirement on the telescope but takes a long time to move so you can't survey many stars to give you a good chance of finding life

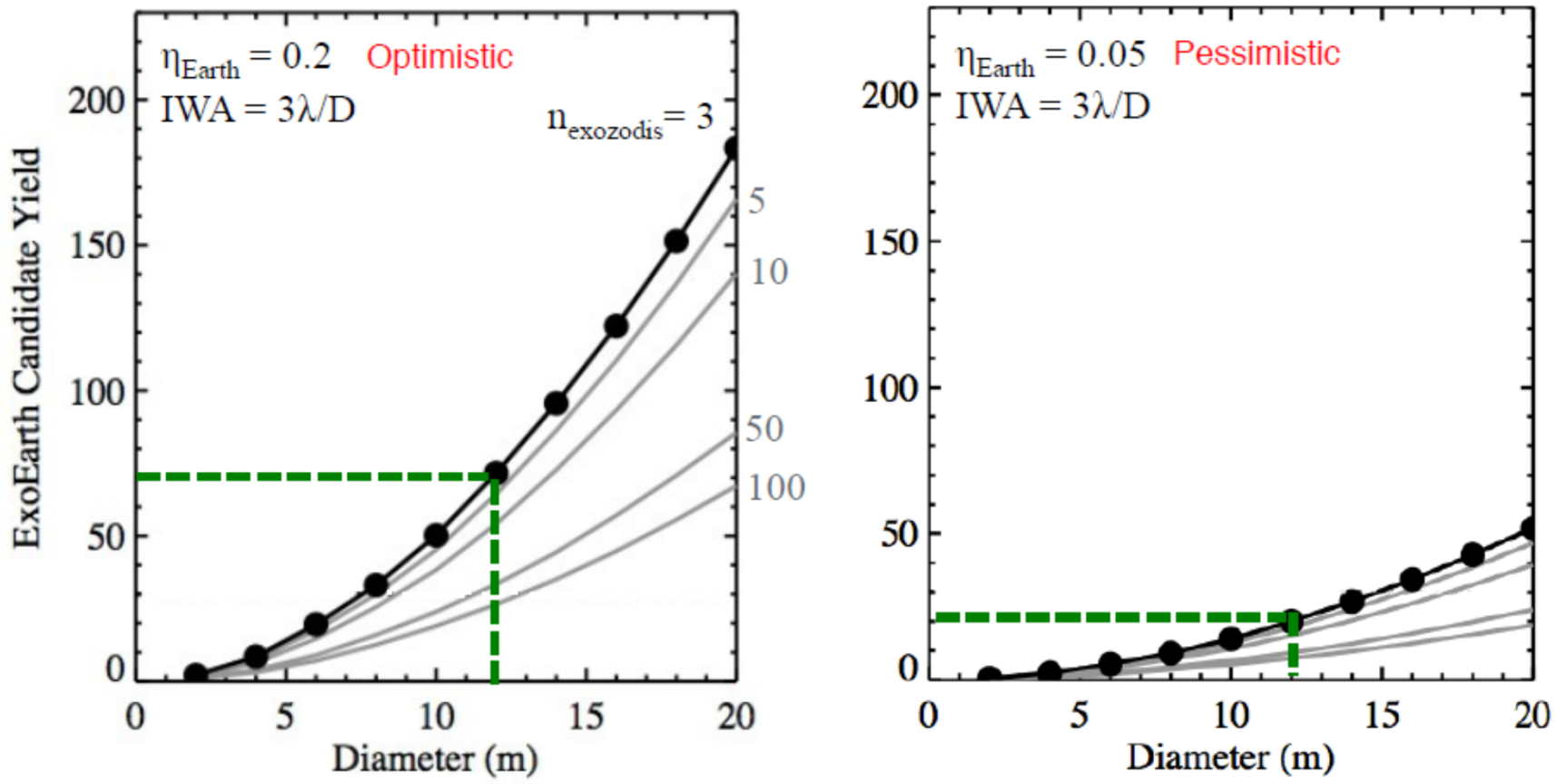




http://lyot.org/background/coronagraphy.html

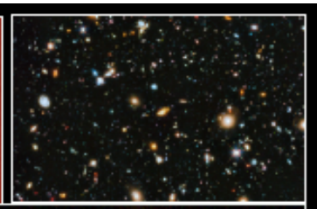
ExoEarth Yield Results

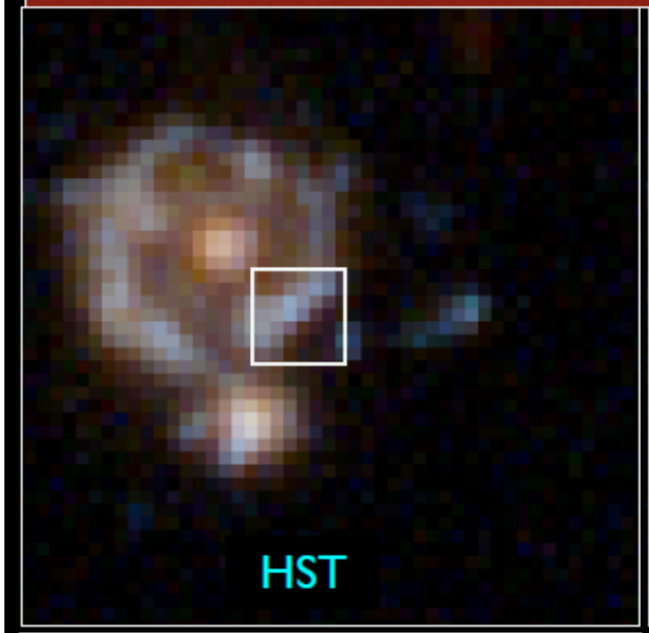
(see Stark et al. 2014; 2015)

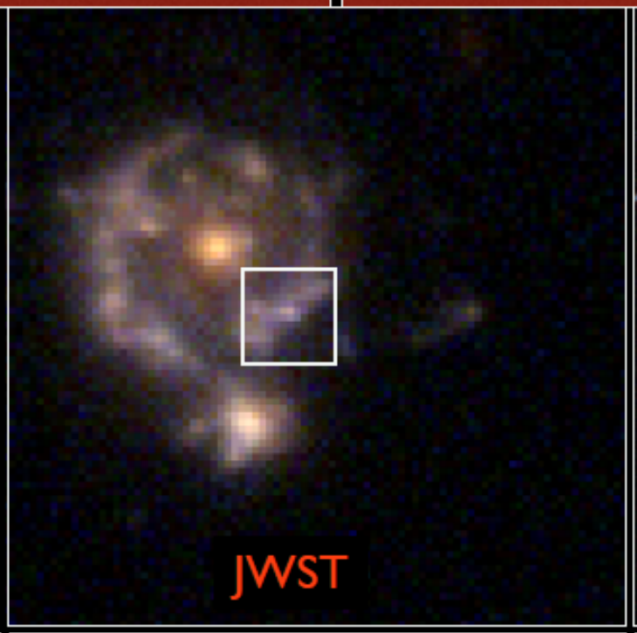


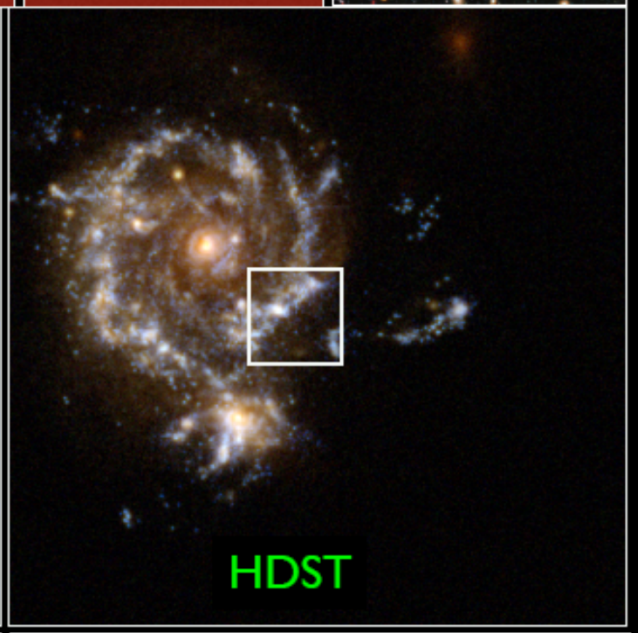
$$N \propto \eta_{Earth} (Zodis)^{-0.23} (D_{Tel})^{1.88} (IWA)^{-0.64} (ExpTime)^{0.36} (QE)^{0.39} (Contrast)^{-0.09}$$

A 12-meter telescope can reach 20 - 70 Earth-like planets: this is enough to detect or significantly constrain the incidence of biomarker molecules.

How Did the Milky Way Form from its Earliest Seeds?	Epoch z = 1 - 4	Resolution 30-100 pc	



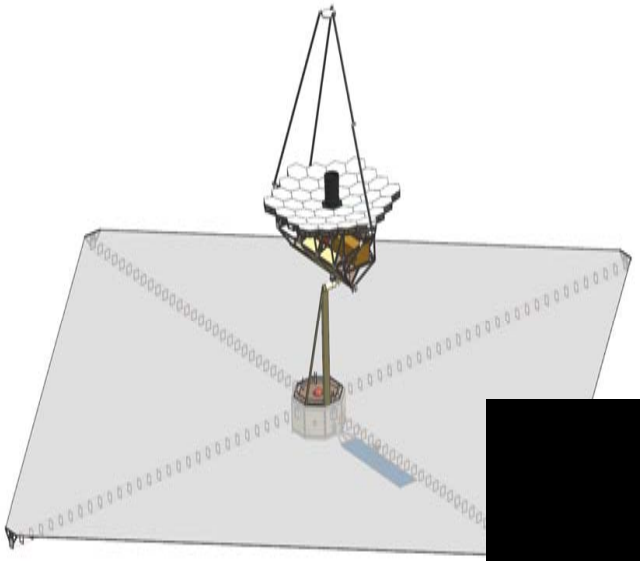




With unique 100 parsec resolution in the optical at all redshifts, HDST can resolve ALL the building blocks of galaxies: individual star forming regions and dwarf satellites, including progenitors of the present-day dwarf spheroidals.

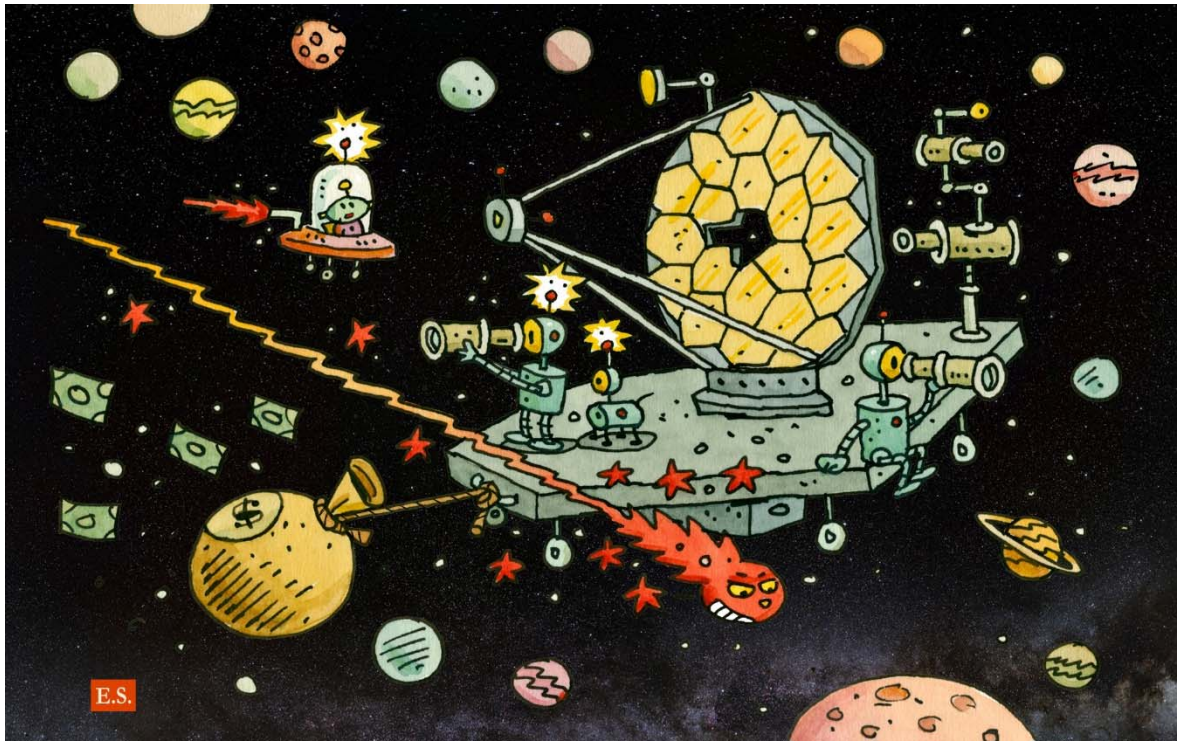
These high-resolution images will complement spectroscopy from 30m class ground-based telescopes and ALMA of the galaxies and their molecular gas.

A potential architecture for an HDST like telescope:
Similar to JWST but room temperature and
A gimbal is used to keep the sunshield is kept normal to the sun



Beyond HST and JWST: High Definition Space Telescope

Picture from 7/13 NYTimes



"But if you think this is not a bargain, you need look only as far as your pocket. Companies like Google and Apple have leveraged modest investments in computer science in the 1960s into trillions of dollars of economic activity. Not even Arthur C. Clarke, the vaunted author and space-age prophet, saw that coming." Dennis Overbye, NY Times

While JWST will help see the first light in the universe, is it possible to probe beyond first light?

Can we possibly see evidence of inflation?

Might there be a multiverse (multiple universes) and is there any way to probe the multiverse?

NASA is working on a way to probe gravitational waves using an atomic interferometer to detect tiny changes in laser light sent across space. So far, gravitational waves have only been measured indirectly…and might someday start to address these questions…

We would need another whole Science Café to talk about that….