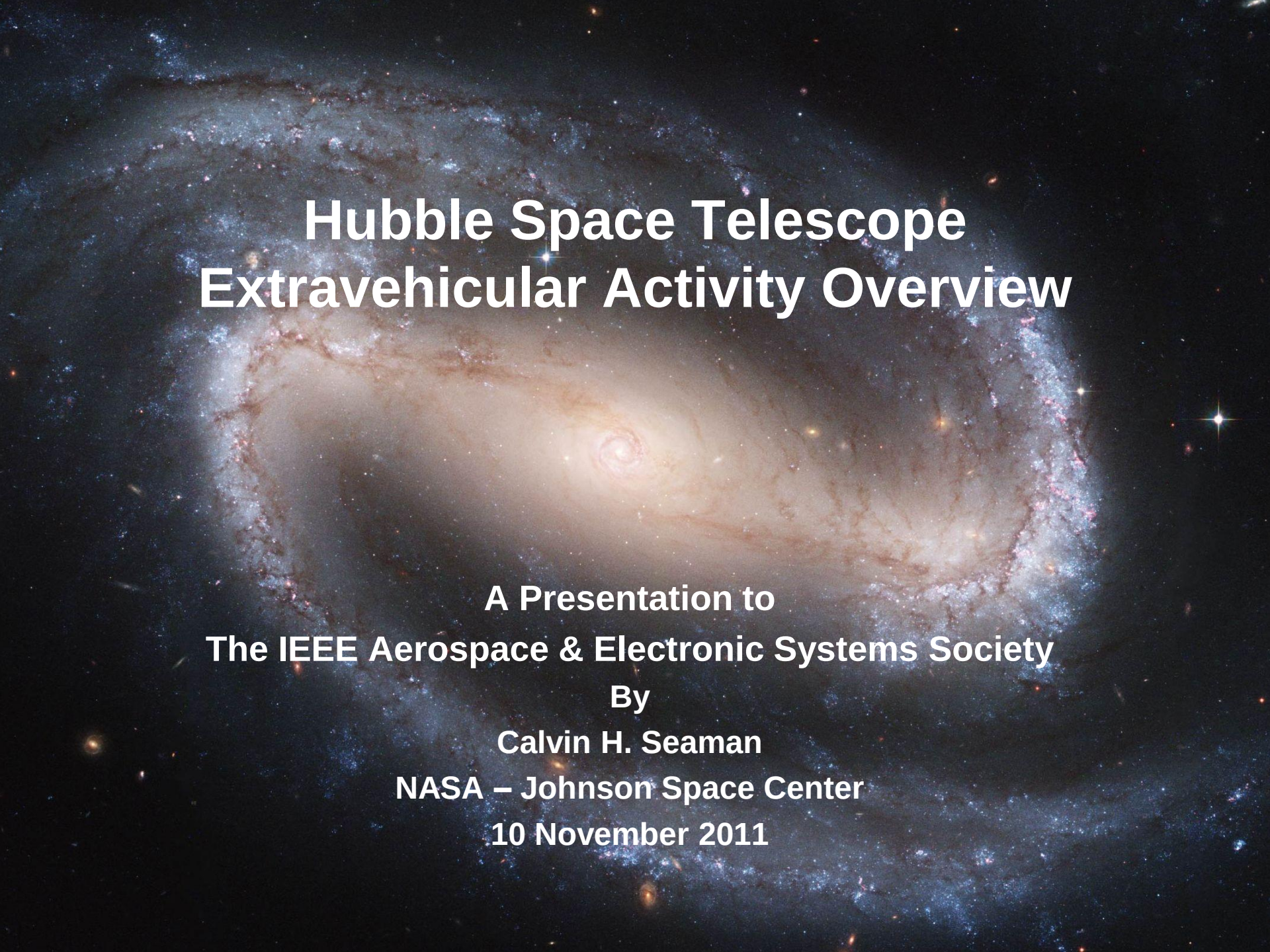


Hubble Space Telescope Extravehicular Activity Overview

A Presentation to

The IEEE Aerospace & Electronic Systems Society

By

Calvin H. Seaman

NASA – Johnson Space Center

10 November 2011

Introduction

- Hubble Space Telescope Overview
- Astronaut Servicing and Repair
- Questions

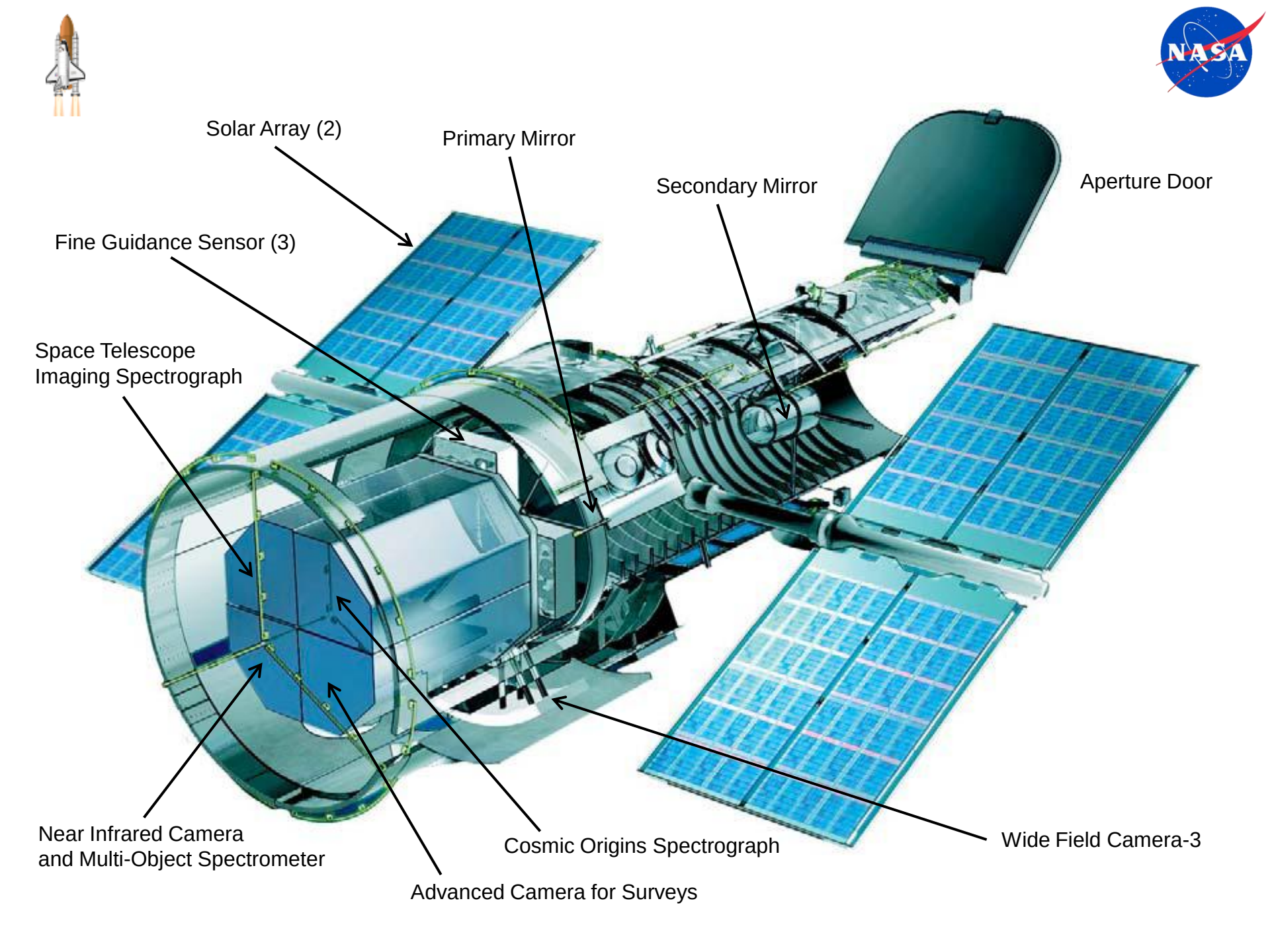
Hubble Space Telescope (HST)

Altitude	330 miles
Pictures Taken	1,200,000
Earth Orbits	125,000
Orbital Velocity	17,500 mph
Traveled	3,200,000,000 miles
Science Output	120 GB per week

One Orbit Every 97 Minutes

HST Overview

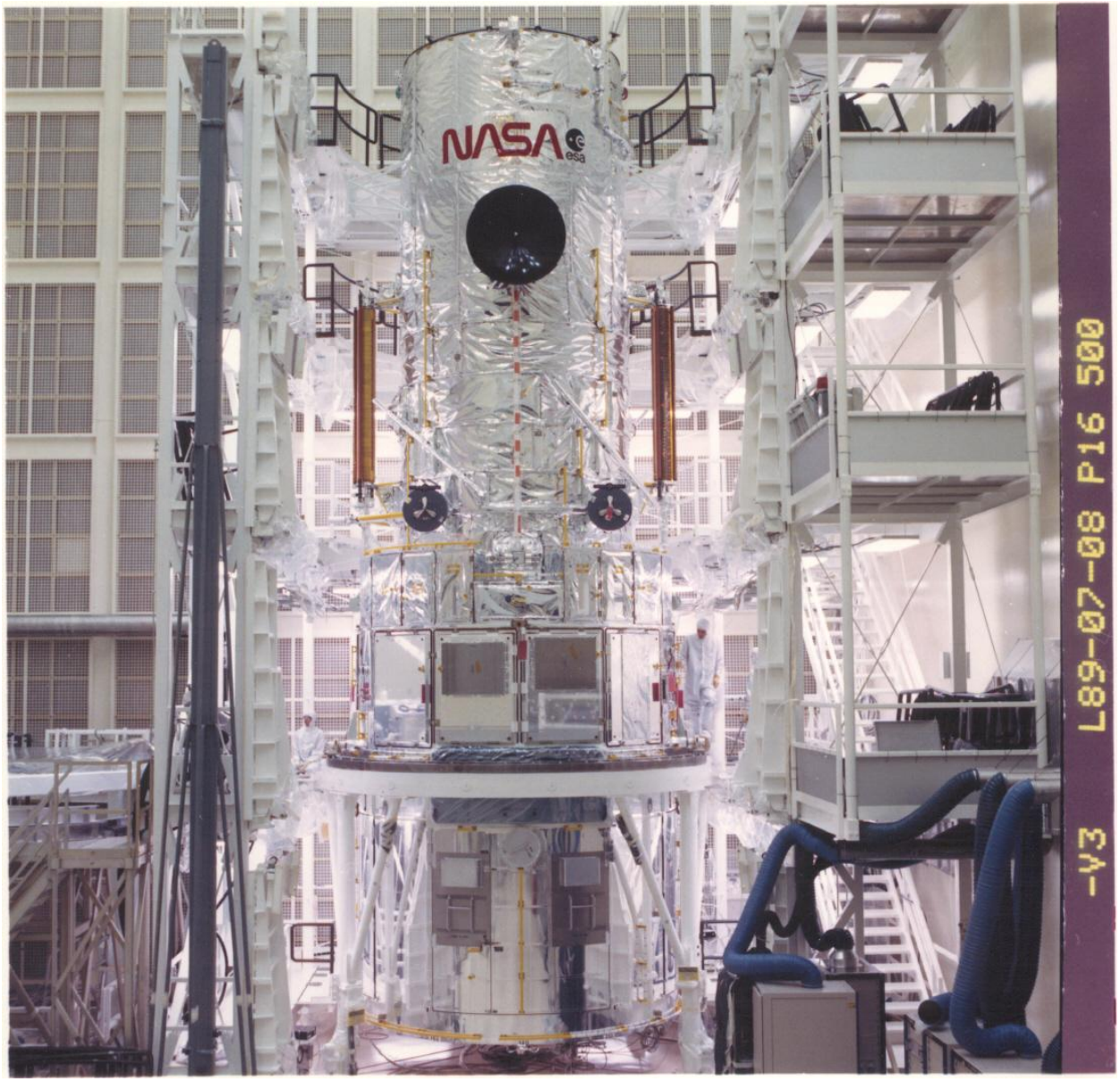
- Named after American Astronomer Edwin P. Hubble
- Ritchey-Chretien Cassegrain
- Length = 43.5 ft (13.3 m)
- Maximum Diameter = 14 ft (4.2 m)
- Weight = 24,500 lbs (11,000 kg)
- Primary Mirror = 94.5 in (2.4 m) Dia
- Secondary Mirror = 12.2 in (31 cm) Dia
- Solar Powered → Ni-H Batteries (6)
- 10x Better Resolution than Ground-based Telescopes
- HST can detect objects 13 billion light years away


Solar Array (2)
Primary Mirror
Secondary Mirror
Aperture Door
Fine Guidance Sensor (3)
Space Telescope
Imaging Spectrograph
Near Infrared Camera
and Multi-Object Spectrometer
Advanced Camera for Surveys
Cosmic Origins Spectrograph
Wide Field Camera-3

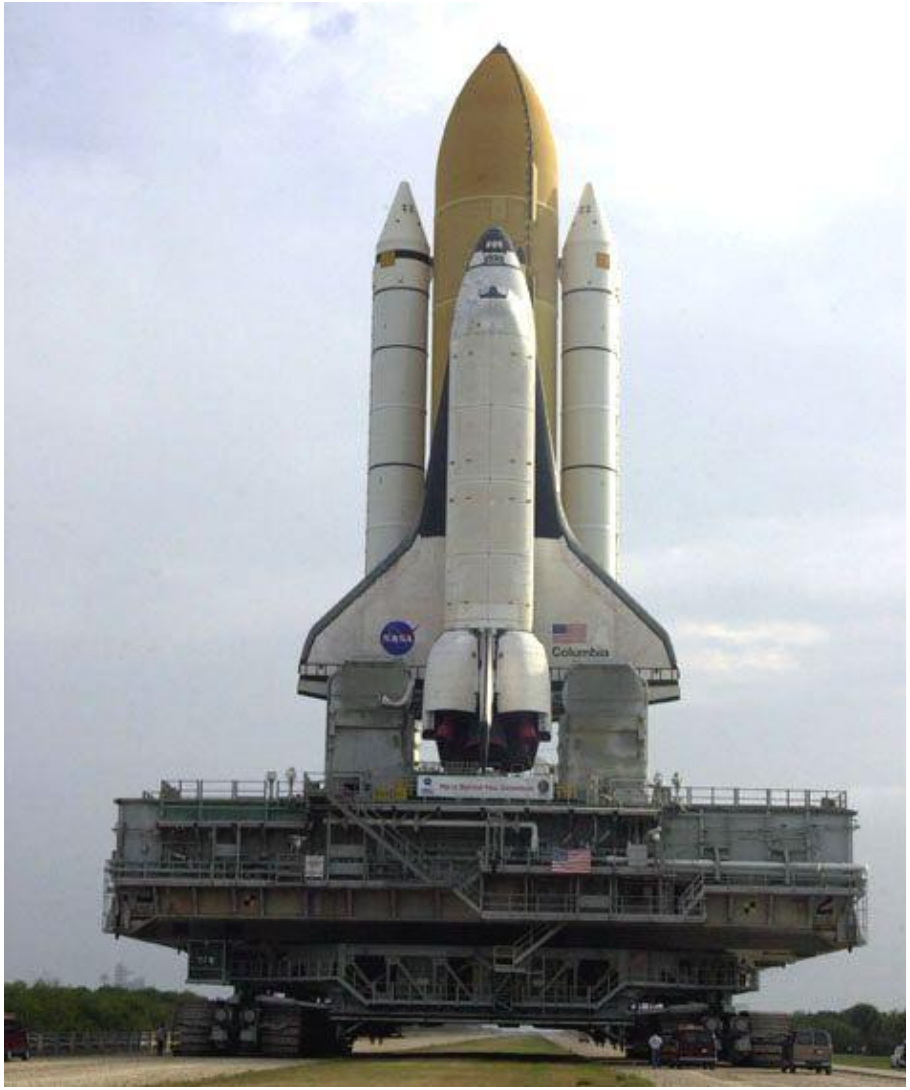
Physical Characteristics

- **5 science instruments and 3 fine guidance sensors “share” the focal plane by a system of folding mirrors**
- **Pointing Stability = 0.007 arc seconds for 24 hours**
  - About the width of a human hair seen at a distance of 1 mile
- **Though never intended to point at the Earth, HST could distinguish the light of a firefly from orbit; and if positioned in Dallas, it could focus on a coin located in Corpus Christi.**
- **In 21 years, HST has taken over 1.2 million exposures and observed over 30,000 astronomical targets**
- **Astronomers using HST data have published over 40,000 scientific papers**
- **Circling the Earth once every 97 minutes for over 21 years, HST has traveled over 3.2 billion miles (the distance from Earth to half-way between Neptune and Pluto)**
- **HST was originally designed to be serviced by astronauts in space**
  - Equipped with over 300 feet of Extravehicular Activity (EVA) Handrails and 31 Portable Foot Restraint Sockets

HST Assembly – Sunnyvale, CA



Space Shuttle *Columbia* – April 24, 1990



Spherical Aberration

- After HST was deployed in 1990, the engineering team discovered a spherical aberration in the primary mirror.
- The problem was ultimately traced to faulty test equipment used to measure the curvature of the mirror.
- The outer edge of the primary mirror was ground “too flat” by 2 microns (1/50th the thickness of a piece of paper).
- After the discovery, Ball Aerospace engineers built the Corrective Optics Space Telescope Axial Replacement (COSTAR), which was successfully installed during the first servicing mission (STS-61).
- Installation of COSTAR brought HST back to its original specifications.

HST Astronaut Servicing

S109E5481

S109E5406

- Improved Optical Focus
- New Scientific Instruments
- New Solar Arrays
- New Gyroscopes
- New Batteries
- New Computers

<u>Our mission</u>: To successfully service, repair, and improve HST to maximize science gathering operations.

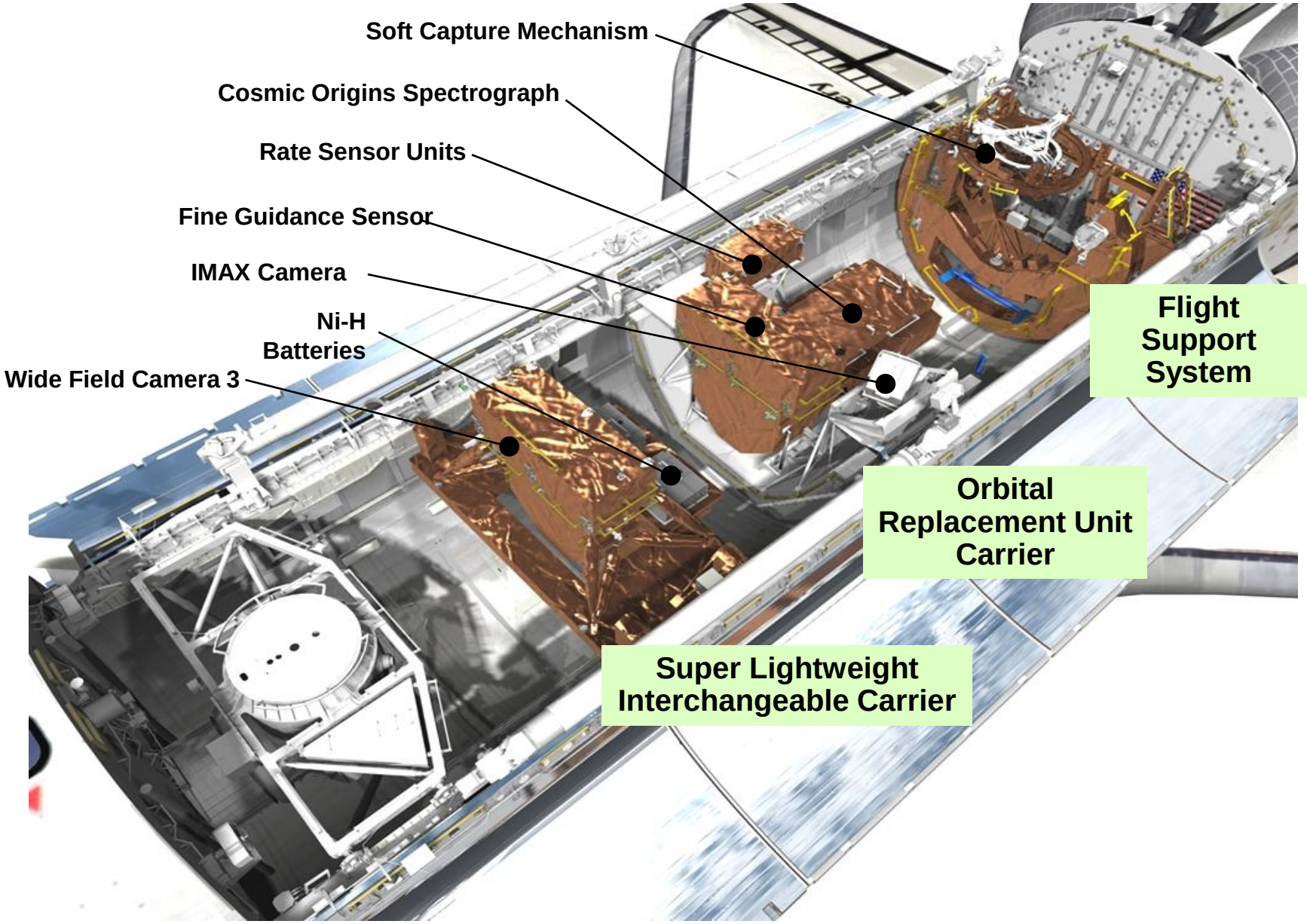
NASA Space Suit

- Self-contained “Space Ship”
- 7-hour Spacewalk
- 100% Oxygen Environment
- 4.3 PSI Operating Pressure
- CO_2 Removal System
- - 200C to +200C Temperature Protection
- Solar Radiation Protection
- Cooling System
- Radio Communication
- Master Computer

A "Typical" HST Servicing Mission

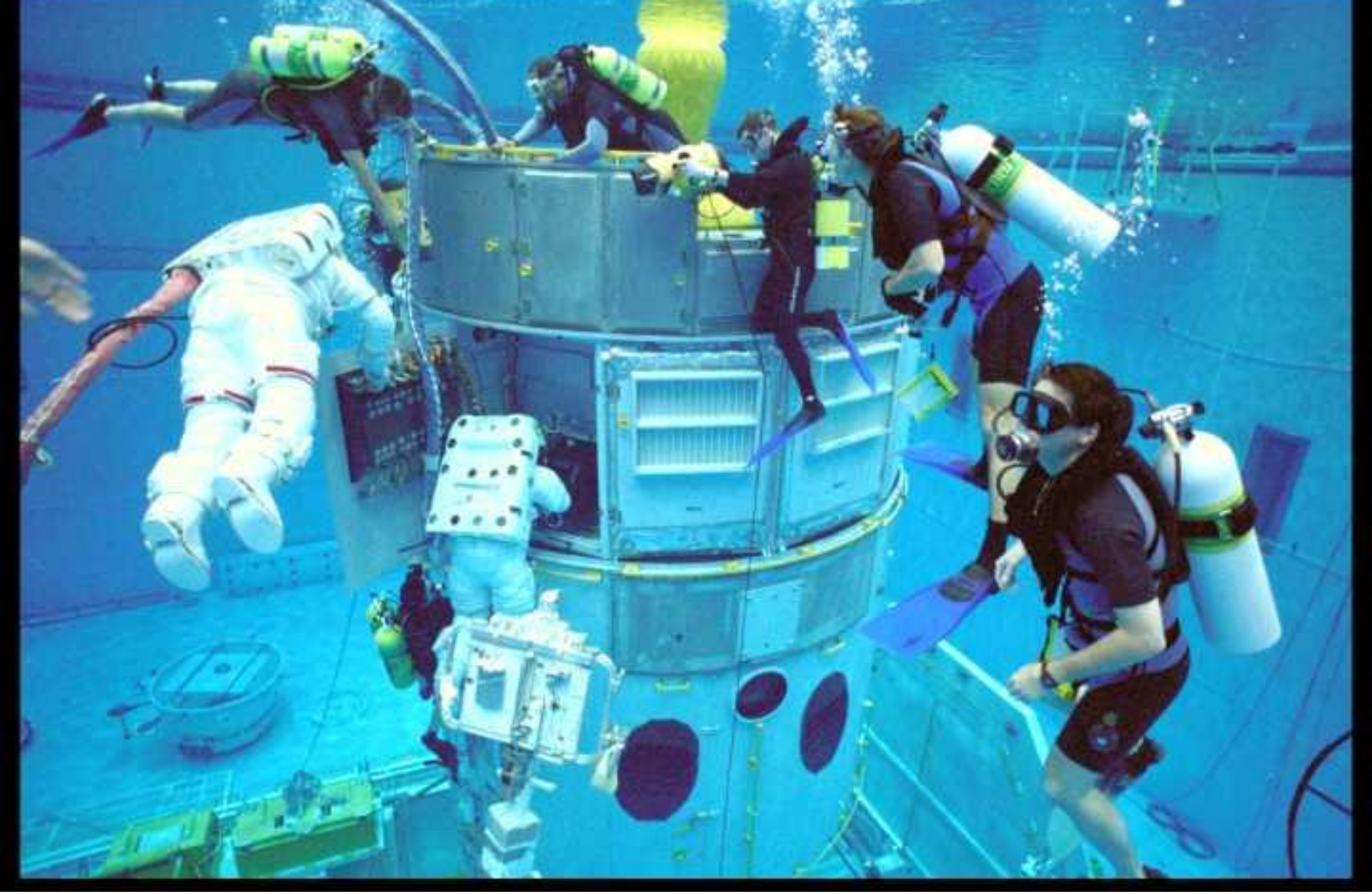
- Approximately 2 years of pre-launch preparation and training
- Launch and Rendezvous with HST – orbiting at approximately 310-330 mile altitude and 28.45 deg inclination
- Grapple the HST spacecraft using the shuttle's "Robot Arm"
- Berth the observatory with the Flight Support System "turntable" mounted in the Shuttle payload bay (the "Lazy Susan")
- 2 "Teams" of EVA crewmembers and 4 EVA space suits
- Conduct 4-5 EVAs to restore operational science capabilities, to make life extending changes, and to improve productivity
- Re-boost HST to highest orbit possible using the Space Shuttle
- 11 Middeck lockers containing 285 EVA tools and crew aids
- 10 : 1 "Water Tank" Training Ratio (i.e. 10 hours in the pool for each hour of EVA time on orbit)
- Above all, do no damage! Leave the telescope in "as good or better" condition than before the mission

STS-125 (SM4) Space Shuttle Configuration



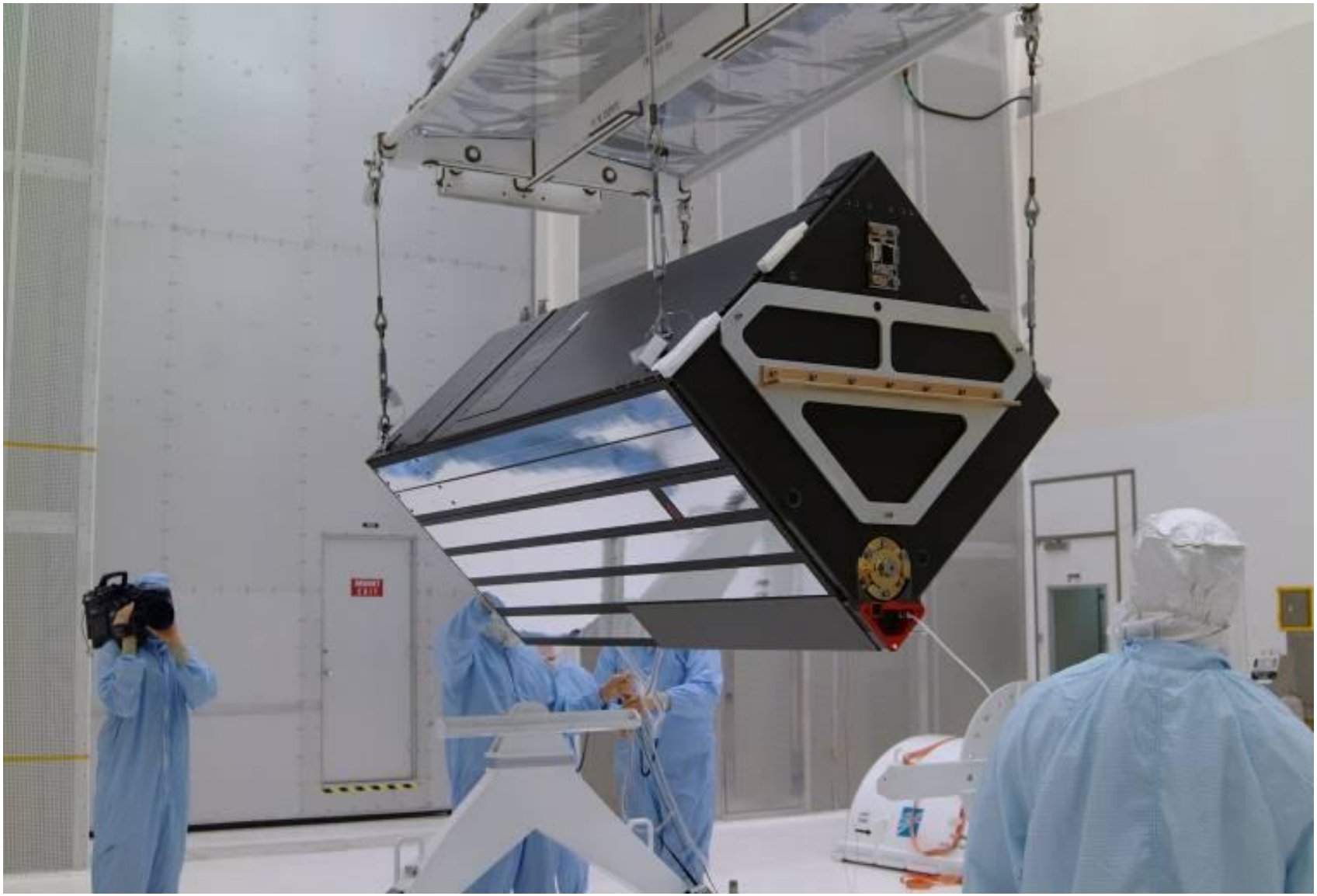
The HST Clean Room at the Goddard Space Flight Center in Greenbelt, MD – HST Test Equipment, Mock-ups, and Shuttle Carriers

Astronaut training in the clean room. (Note that the astronaut on the left is wearing his space suit glove while operating the tool.)

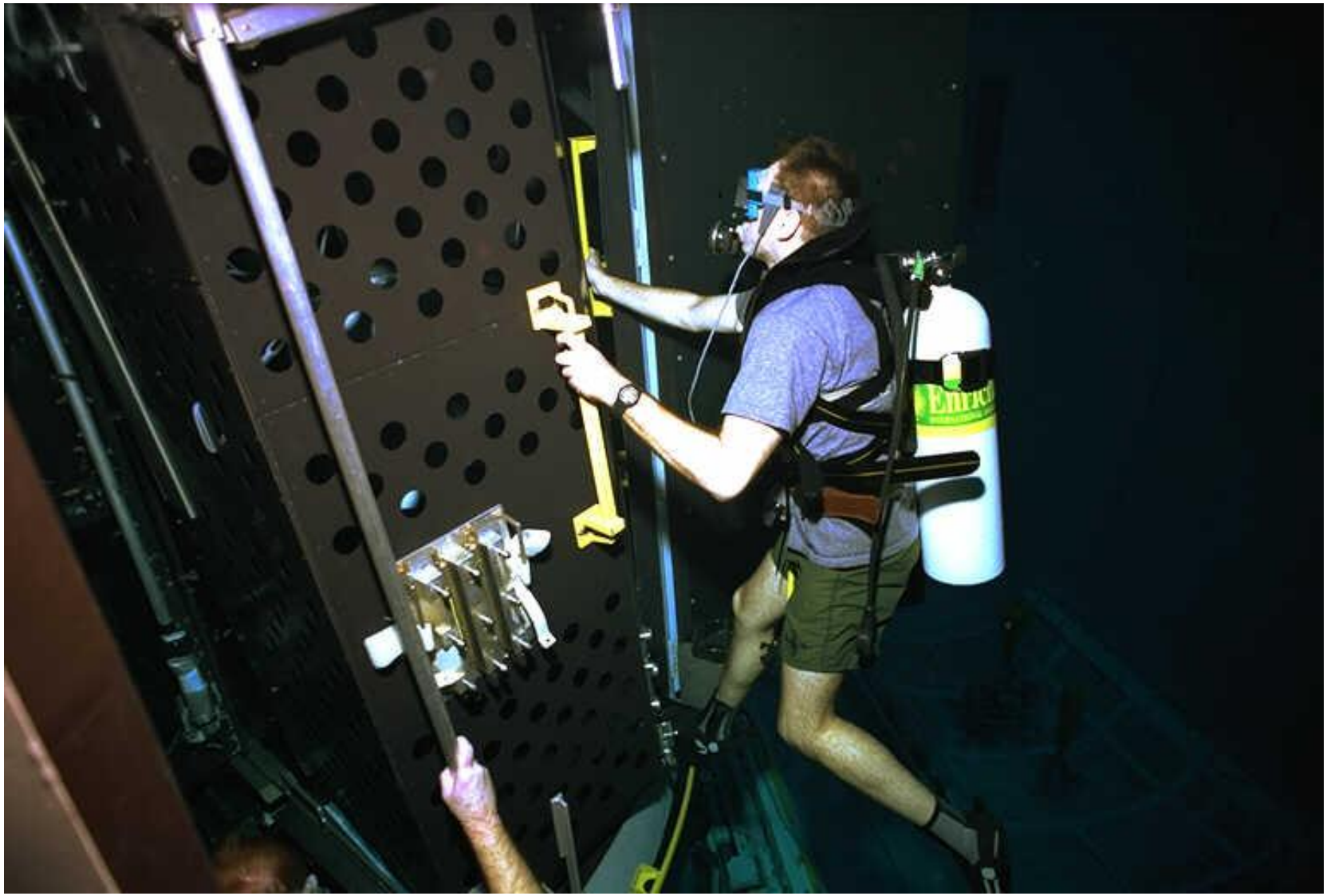


Astronaut training in the Neutral Buoyancy Laboratory at the Johnson Space Center in Houston, TX

Advanced Camera for Surveys (ACS) – Flight Unit

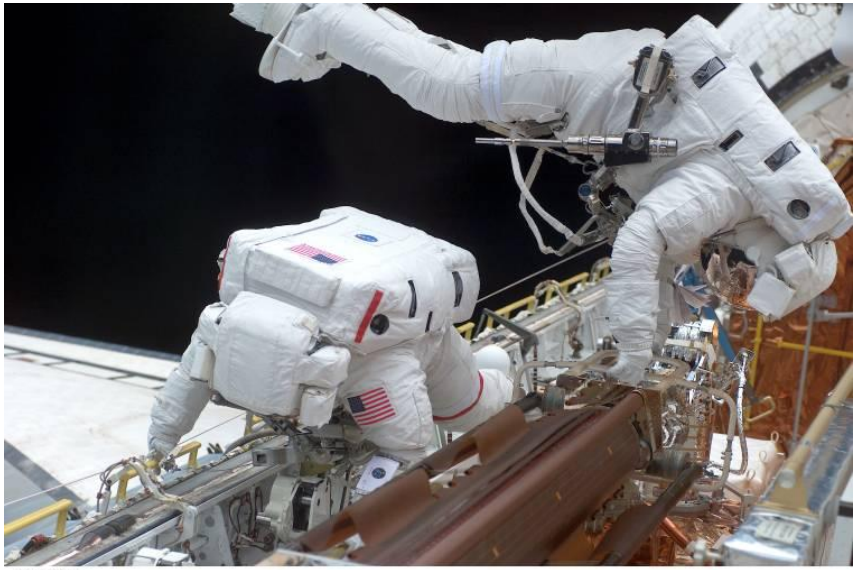


ACS Replacement Simulation in NBL



Cosmic Origins Spectrograph Installation

HST Astronauts at Work



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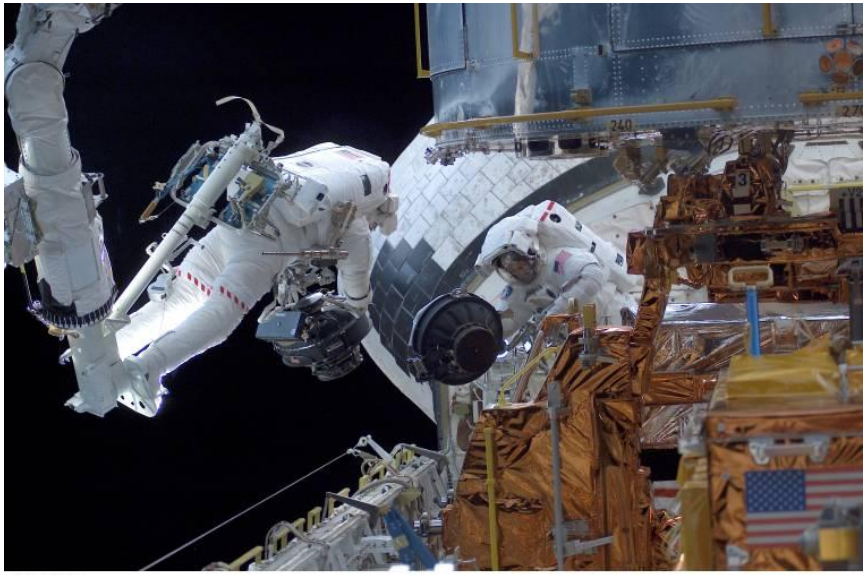

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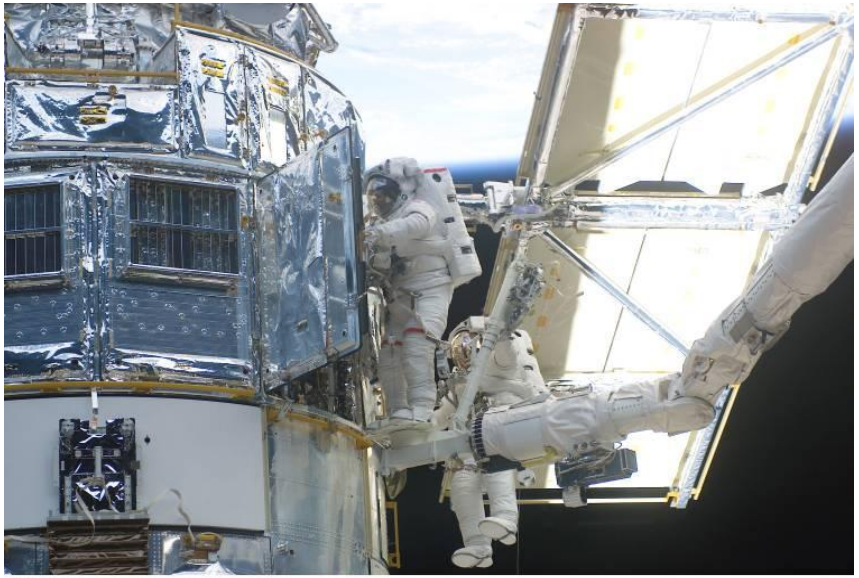

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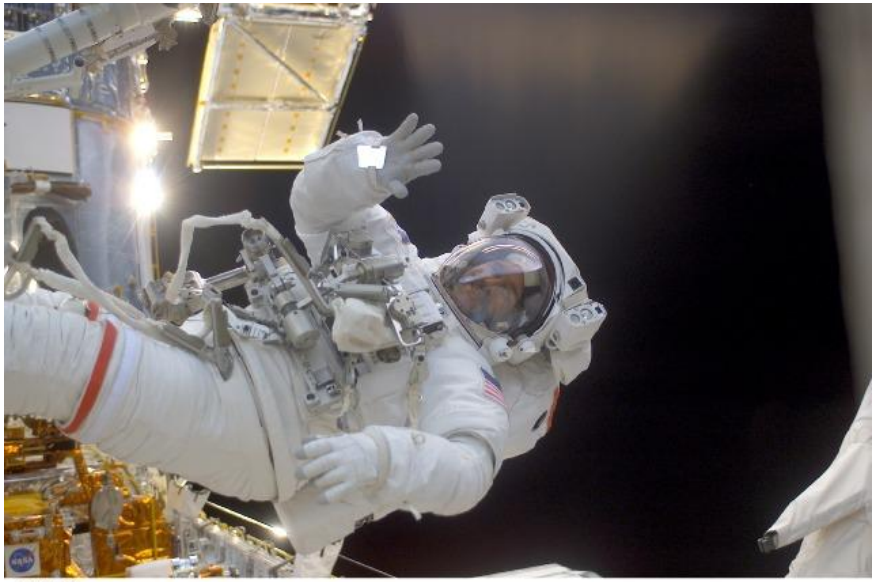

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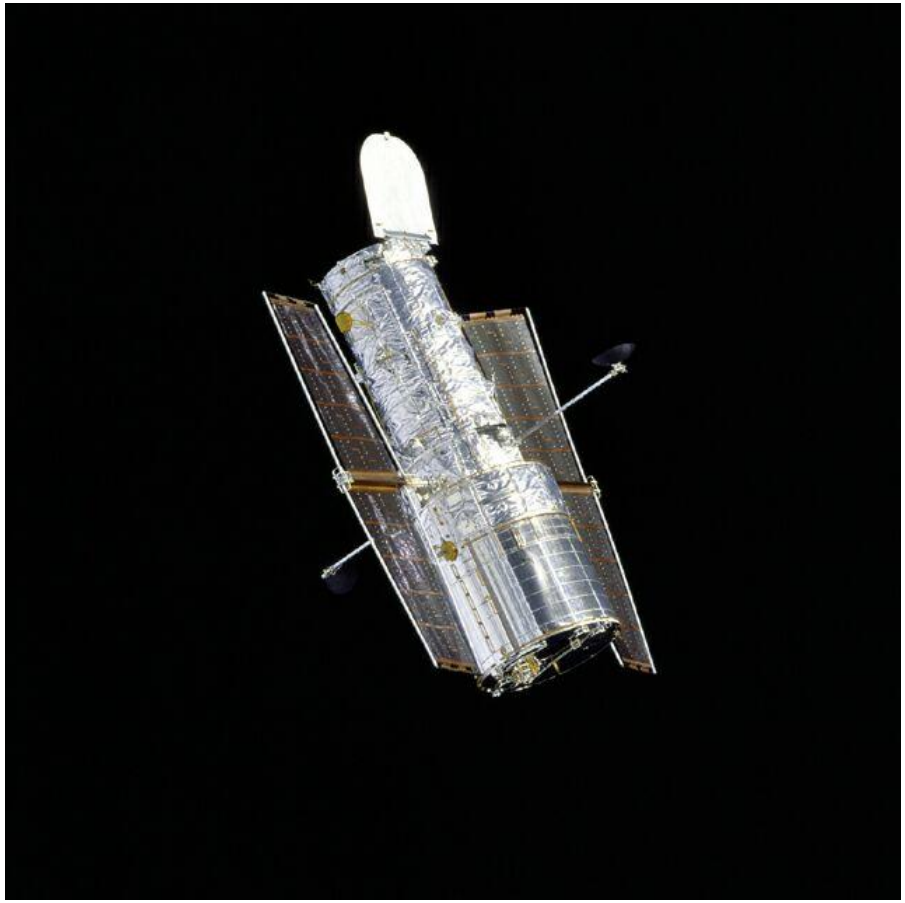
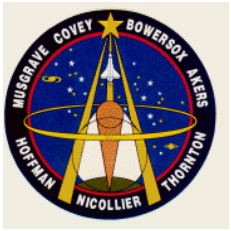
HST Re-Deployment Into Space



HST Mission Overview



20 year planned lifespan, with regularly scheduled, on-orbit, servicing missions

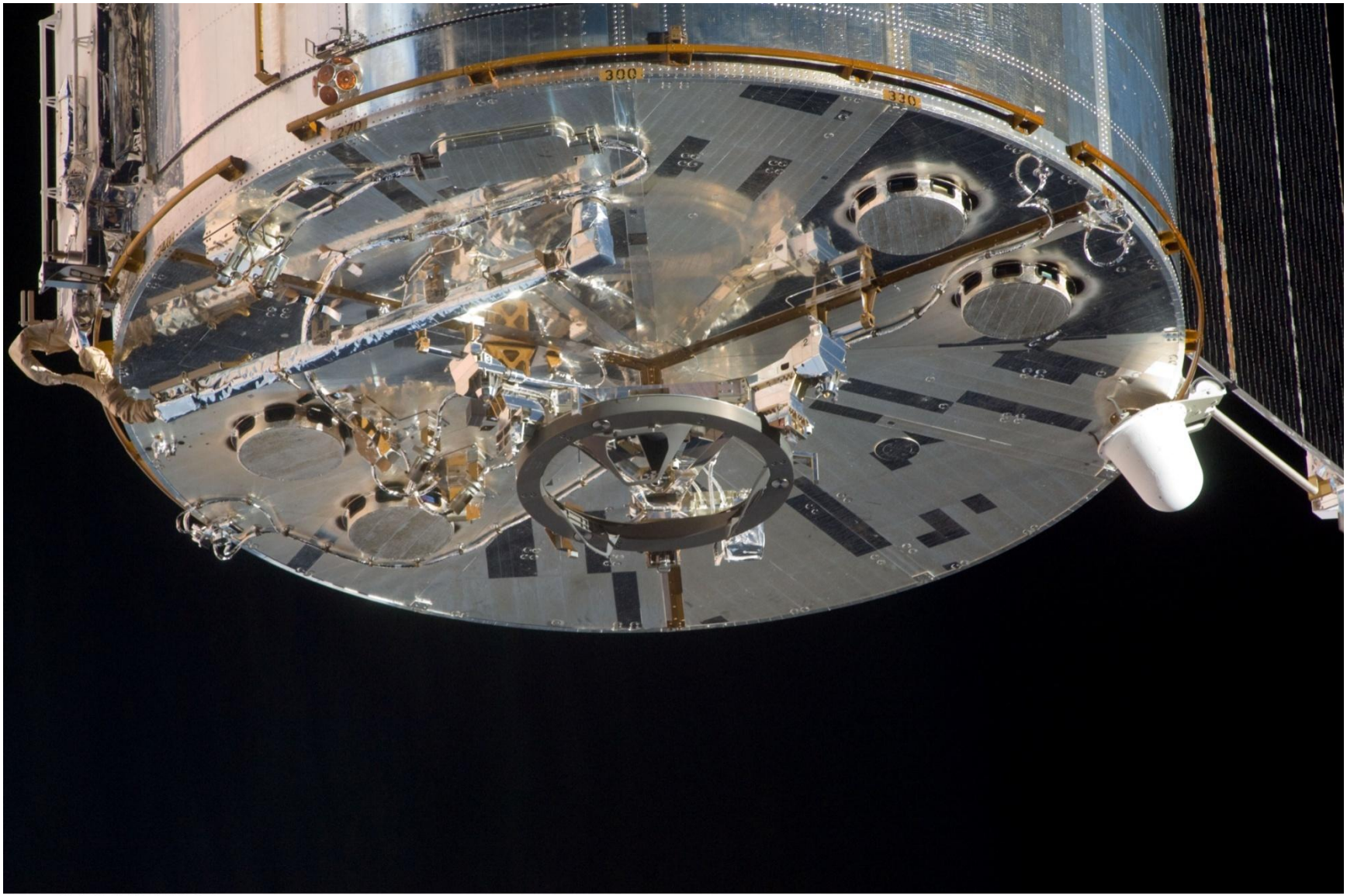
Mission	Date	Objective
STS-31	24-29 Apr 1990	HST Deploy Mission
STS-61	2-13 Dec 1993	HST Servicing Mission-1 (SM-1)
STS-82	11-21 Feb 1997	HST SM-2
STS-103	19-27 Dec 1999	HST SM-3A
STS-109	1-12 Mar 2002	HST SM-3B
STS-125	11-24 May 2009	HST SM-4

HST Mission Summary

The End of the HST (Orbital) Mission

- **Equipment Failure**
  - Without continued servicing missions, key HST instruments, control mechanisms, and communication systems will eventually fail. (e.g. gyroscopes, batteries, command & data handling components, etc.)
- **Orbital Decay**
  - Without continued “reboosts” by the Space Shuttle, the HST orbit will gradually decrease in altitude due to atmospheric drag.
    - The rate of orbital decay depends on solar activity, and HST spacecraft attitude as it orbits the earth.
  - Without intervention, HST will likely re-enter the Earth's atmosphere between 2020 and 2032.
- **De-Orbit**
  - The original plan was to retrieve HST with the Space Shuttle and return it safely to earth
  - With the mandated retirement of the Space Shuttle, this is no longer possible.
  - Instead, the STS-125 crew installed a device called the Soft-Capture Mechanism (SCM) on the aft bulkhead of HST.
  - The SCM provides a docking interface for an automated de-orbit vehicle to attach and guide the observatory into a safe, controlled, re-entry at the end of its useful life.

Soft-Capture Mechanism (SCM)



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Final Comments

- When the astronauts left Hubble for the last time, it was upgraded to the peak of its capabilities – better than it has *ever* been before.
- Over half of Hubble's highest-impact scientific achievements are in areas of research that were unanticipated prior to launch.
- Because of the partnership between NASA, support contractors, and academia, the Hubble Space Telescope has been the most scientifically productive program in the history of the Agency.


Thank you!

For Your Reference

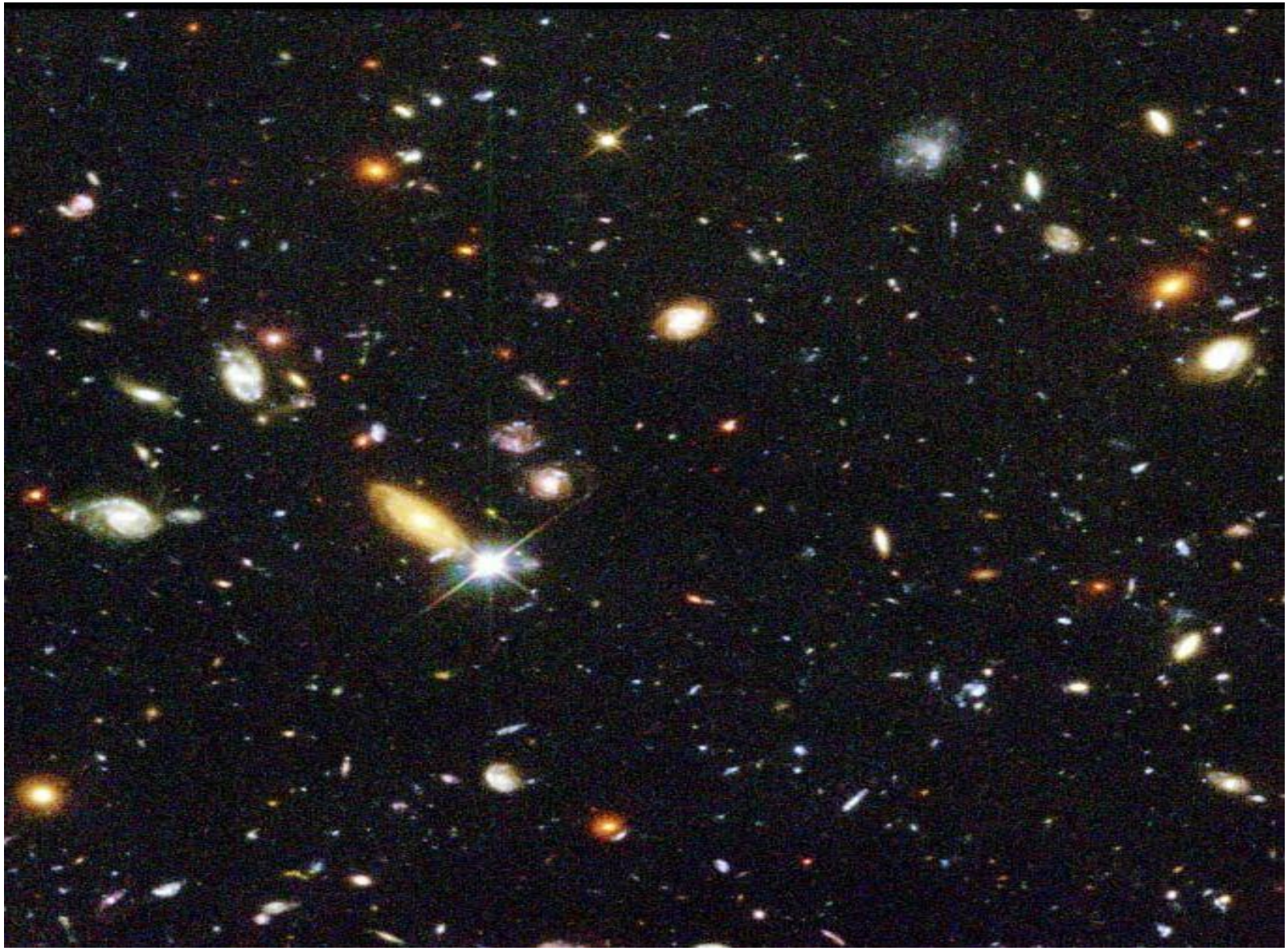
- **Hubble Space Telescope**
  - http://hubblesite.org/
- **Space Telescope Science Institute**
  - http://www.stsci.edu/portal
- **Astronomy Picture of the Day**
  - http://antwrp.gsfc.nasa.gov/apod/astropix.html
- **NASA – HST**
  - http://hubble.nasa.gov/
- **NASA**
  - http://www.spaceflight.nasa.gov

STS-125: The Final HST Servicing Mission

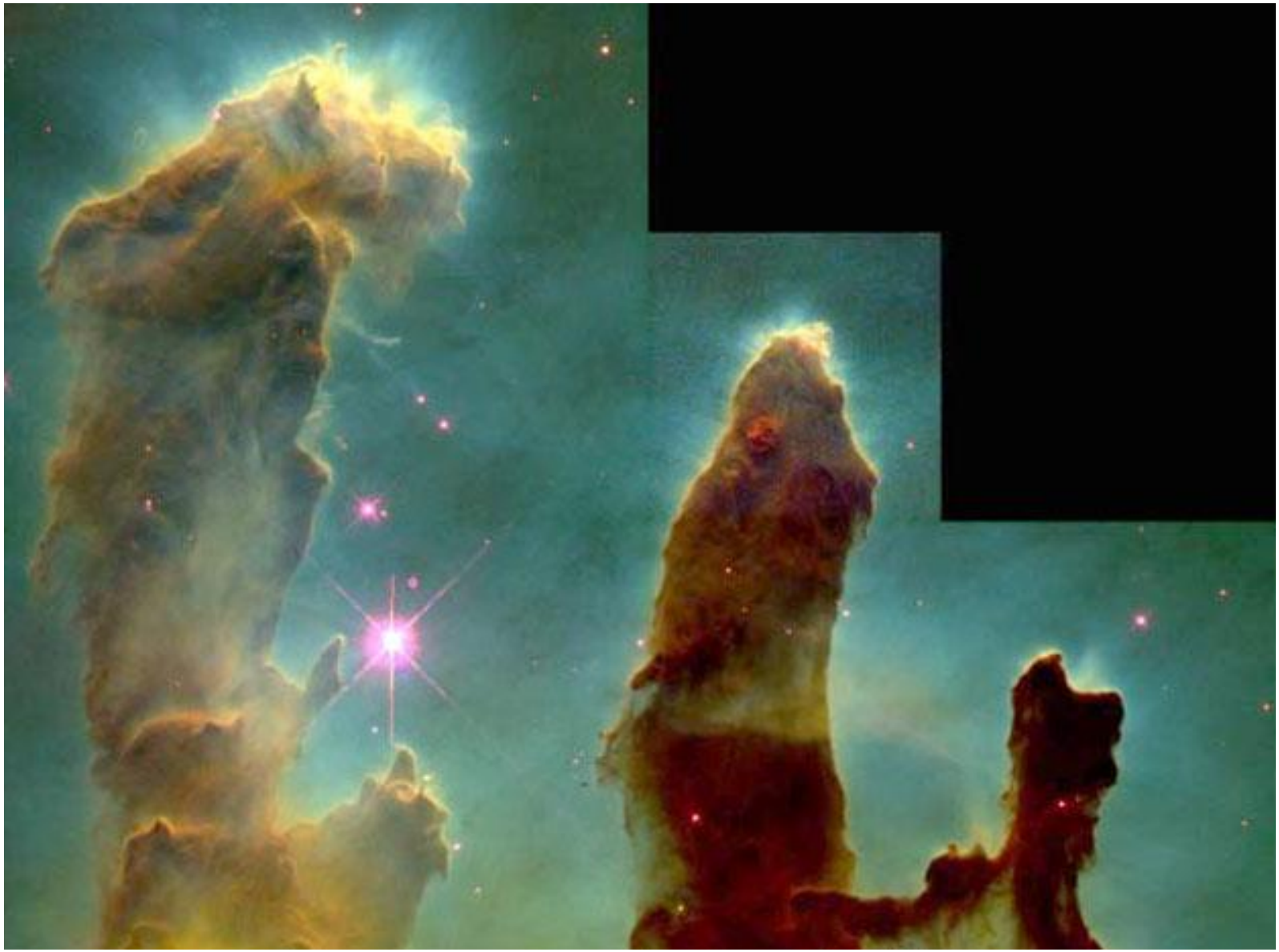
Back-up Charts

Horsehead Nebula

HST “Deep Field” Image - 15 Jan 1996



M16 Eagle Nebula - Young Star Formation



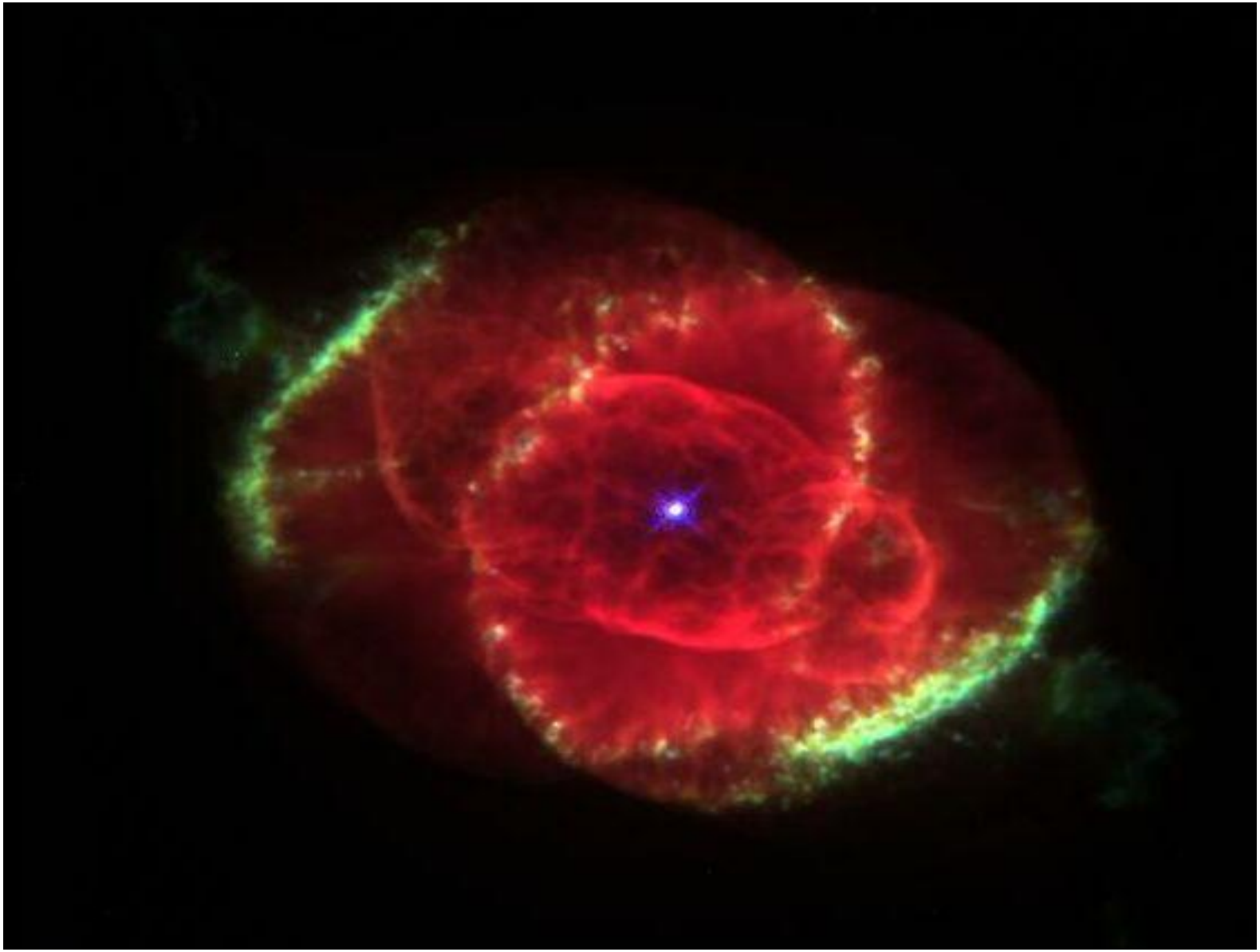
M80 Globular Cluster

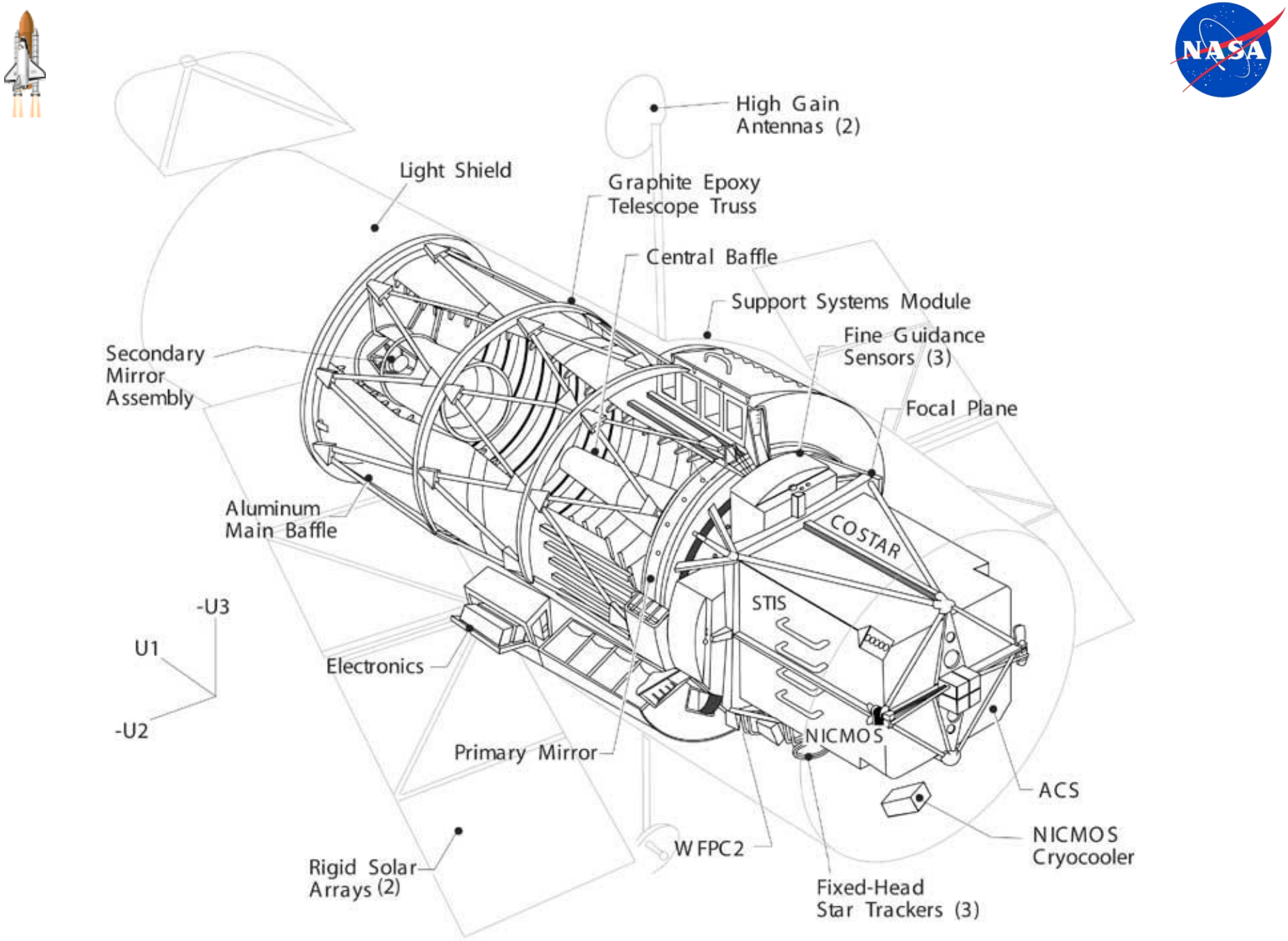
M51 Whirlpool Galaxy

NGC2392 Eskimo Nebula

NGC2264 Cone Nebula

NGC6543 Cat's Eye Nebula




High Gain Antennas (2)
Light Shield
Graphite Epoxy Telescope Truss
Central Baffle
Support Systems Module
Fine Guidance Sensors (3)
Secondary Mirror Assembly
Focal Plane
Aluminum Main Baffle
COSTAR
STIS
-U3
U1
-U2
Electronics
NICMOS
Primary Mirror
ACS
NICMOS Cryocooler
WFPC2
Rigid Solar Arrays (2)
Fixed-Head Star Trackers (3)

Quick Look Mission Summaries

- **SM-1: COSTAR, WFPC-2, SA-2, SADE-1, 2 RSUs**
- **SM-2: STIS, NICMOS, FGS, SSR, RWA, DIU-2, SADE-2**
- **SM-3A: 3 RSUs, Advanced Computer, FGS, SSR, SSAT, VIK, MLI Repair**
- **SM-3B: ACS, PCU, SA-3, NICMOS Cooling System, MLI Repair**
- **SM-4: WFC-3, Remove COSTAR / Install COS, 3 RSUs, Repair ACS, Repair STIS, FGS, Replace all six Ni-H Batteries, MLI Repair, Install Soft Capture Mechanism**
- **<u>Final Configuration</u>: STIS, NICMOS, ACS, COS, WFC-3, FGS (x3)**

Acronyms

- **ACS** — Advanced Camera for Surveys
- **COS** — Cosmic Origins Spectrograph
- **COSTAR** — Corrective Optics Space Telescope Axial Replacement
- **ECU** — Electronics Control Unit
- **FGS** — Fine Guidance Sensor
- **FOC** — Faint Object Camera
- **FOS** — Faint Object Spectrograph
- **GHRS** — Goddard High Resolution Spectrograph
- **NICMOS** — Near Infrared Camera and Multi-Object Spectrometer
- **NOBL** — New Outer Blanket Layer
- **OCE-EK** — Optical Control Electronics-Enhancement Kit
- **RSU** — Rate Sensor Unit

Acronyms

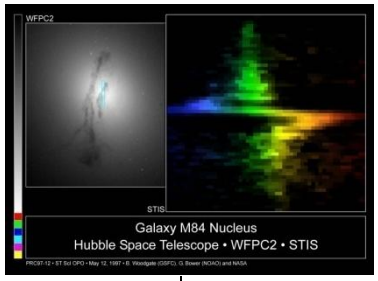
- **SSAT** — S-Band Single Access Transmitter
- **SSR** — Solid State Recorder
- **SSRF** — Shield/Shell Replacement Fabric
- **STIS** — Space Telescope Imaging Spectrograph
- **STOCC** — Space Telescope Operations Control Center
- **STScI** — Space Telescope Science Institute
- **VIK** — Voltage/Temperature Improvement Kit
- **WFC** — Wide Field Camera
- **WFPC** — Wide Field Planetary Camera

Grapple and berth HST into the Space Shuttle Payload Bay

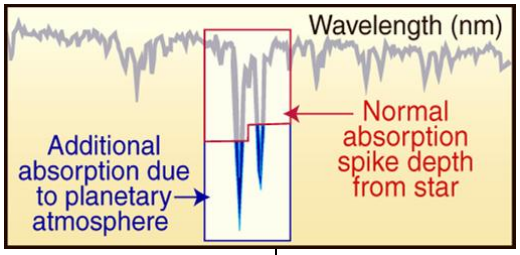
STIS – The Most Versatile Spectrograph To Fly In Space

Objectives: Demographics of Supermassive Black Holes, Active Galactic Nuclei, Interstellar Medium, Exoplanetary Atmospheres, Solar System Aurorae

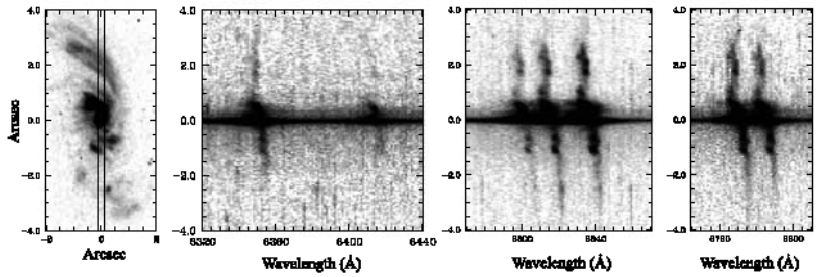
- STIS brought 2D/Hi-Res/UV-Opt-Near IR spectroscopy to HST (a unique capability)
- Pioneered studies of supermassive black holes, complex dynamics of galaxy nuclei
- Produced first detection of an exoplanetary atmosphere
- Was producing more papers than any other HST instrument when operations ceased
- With COS, would bring the full set of spectroscopic tools to HST



Supermassive black holes & dependencies on galaxy properties

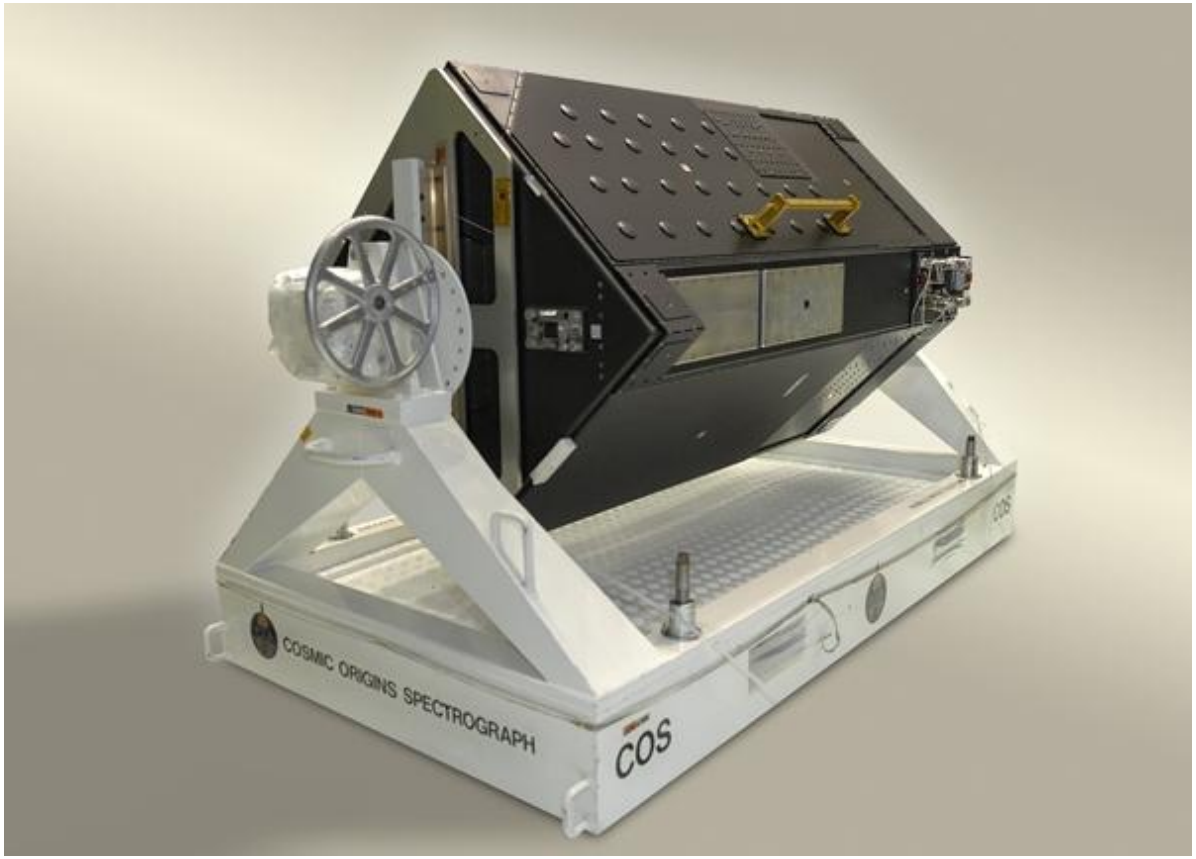


Exoplanetary atmospheres: increasing the sample to ~ 10!



Active galactic nuclei—making full use of STIS's unique spatial coverage to probe dynamics of complex objects

COS is the Most Sensitive UV Spectrograph Ever to Fly on HST



- COS is designed to observe point sources (stars, quasars)
- Two independent channels provide low and moderate spectral resolution
- Far-UV channel is up to 70x faster than STIS at wavelengths 115 - 200 nm
- Near-UV channel is up to 5x faster than STIS at wavelengths 200 – 300 nm

The Cosmic Web

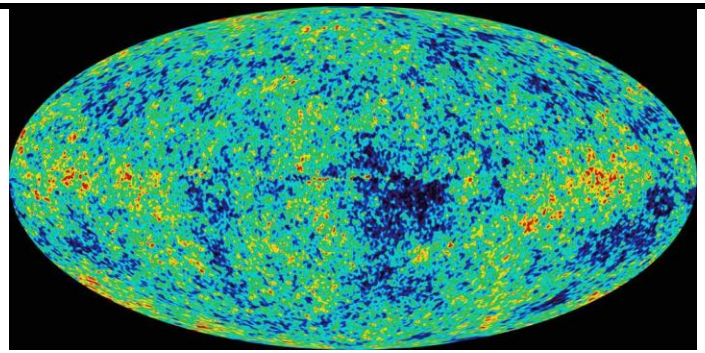
Small scale density fluctuations in dark matter and baryons

+

Gravity

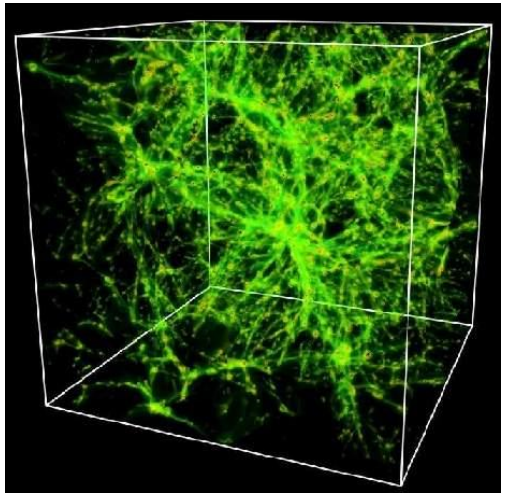
+

Time

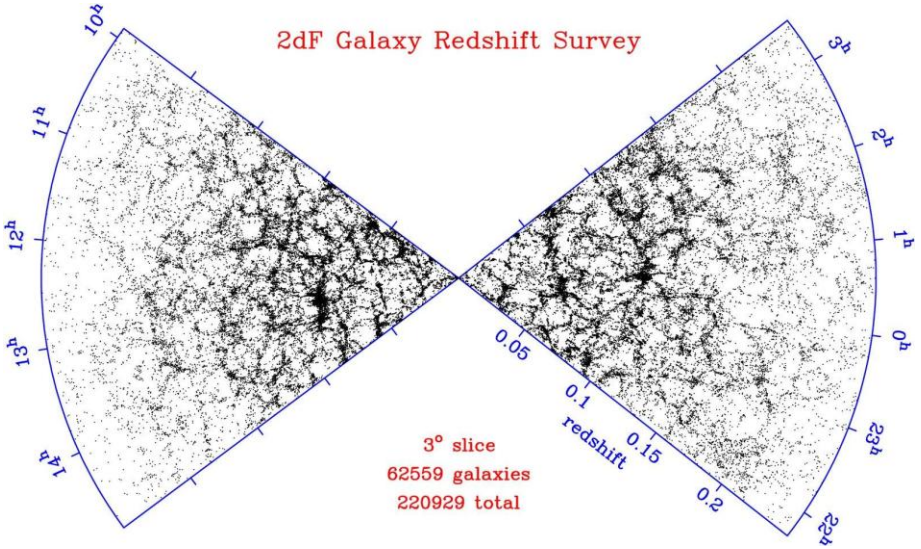


cosmic microwave background from WMAP

Large-Scale Structure: web-like distribution of galaxies and intergalactic gas, tracing underlying "scaffolding" of dark matter

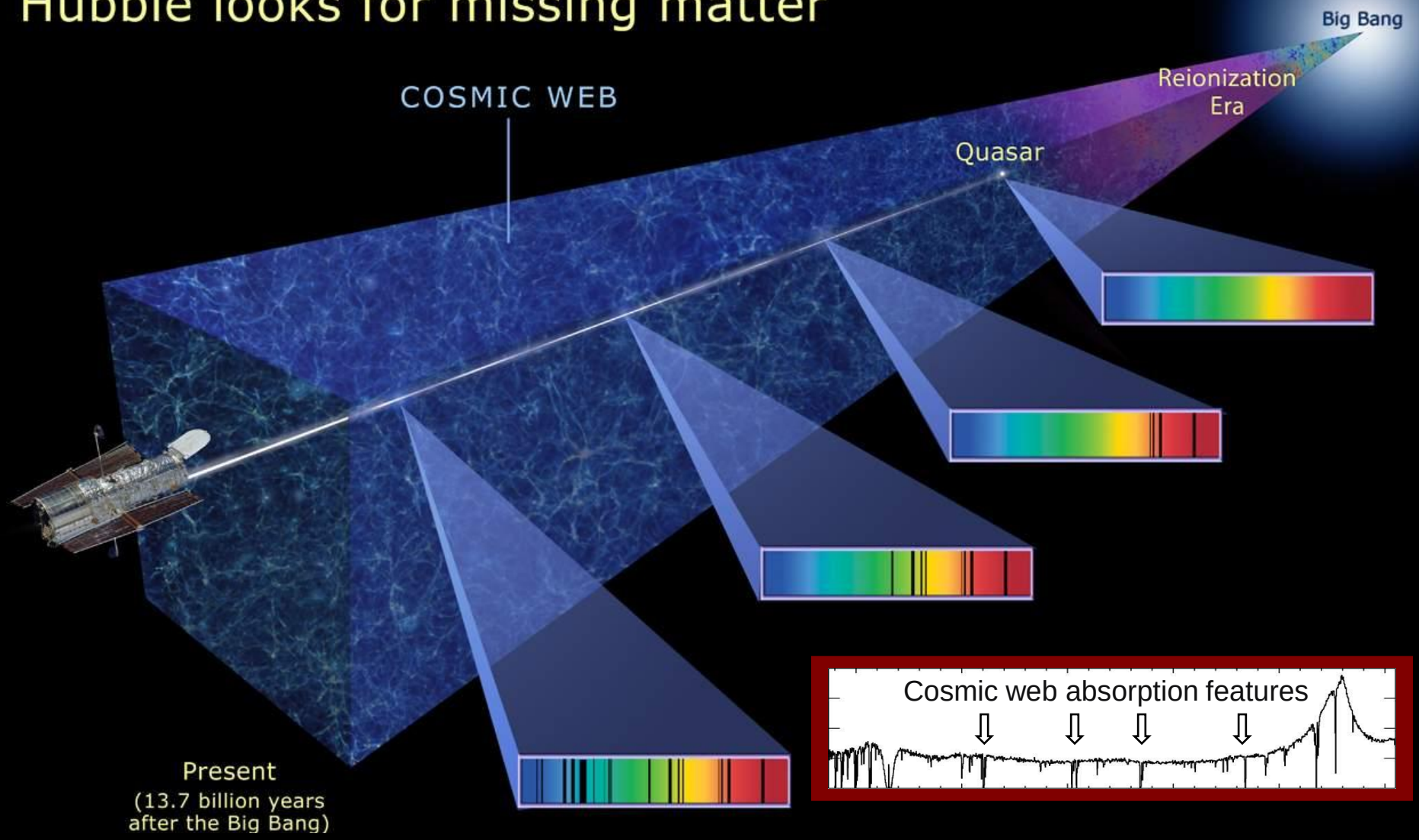


computer simulation



observed nearby galaxy distribution

Hubble looks for missing matter



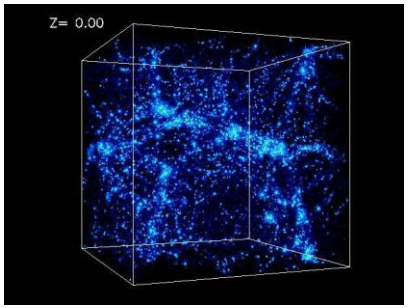
With just a few weeks of observing time, Hubble's new Cosmic Origins Spectrograph will probe more of the cosmic web than all previous Hubble spectrographs combined.

When the astronauts left Hubble for the last time, it was upgraded to the apex of its capabilities – better than it has ever been before.

WFC3 + ACS + NICMOS = Most powerful imaging ever

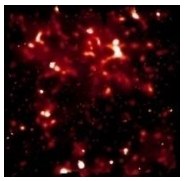
COS + STIS = Full set of tools for astrophysics

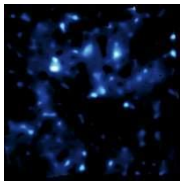
The architecture of the universe



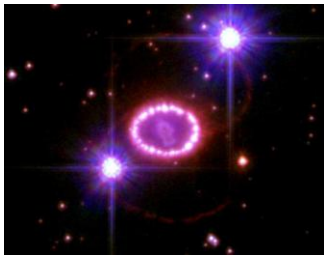
The life story of galaxies

The mysteries of dark matter and dark energy

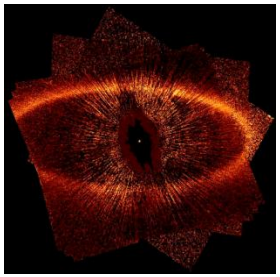


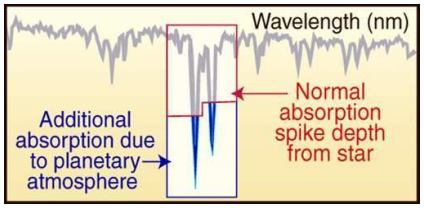


The birth and death of stars

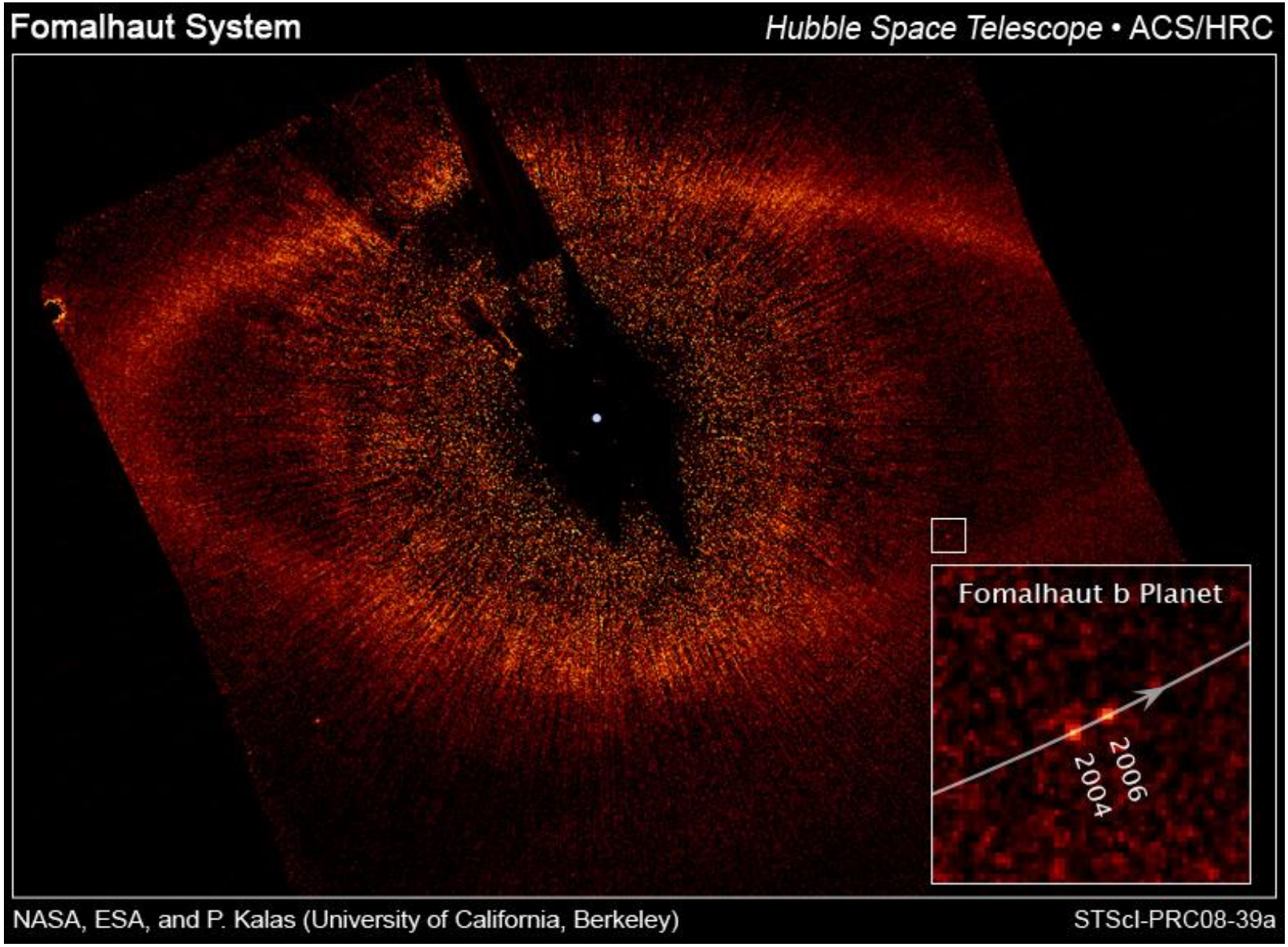


Recipes for building planets



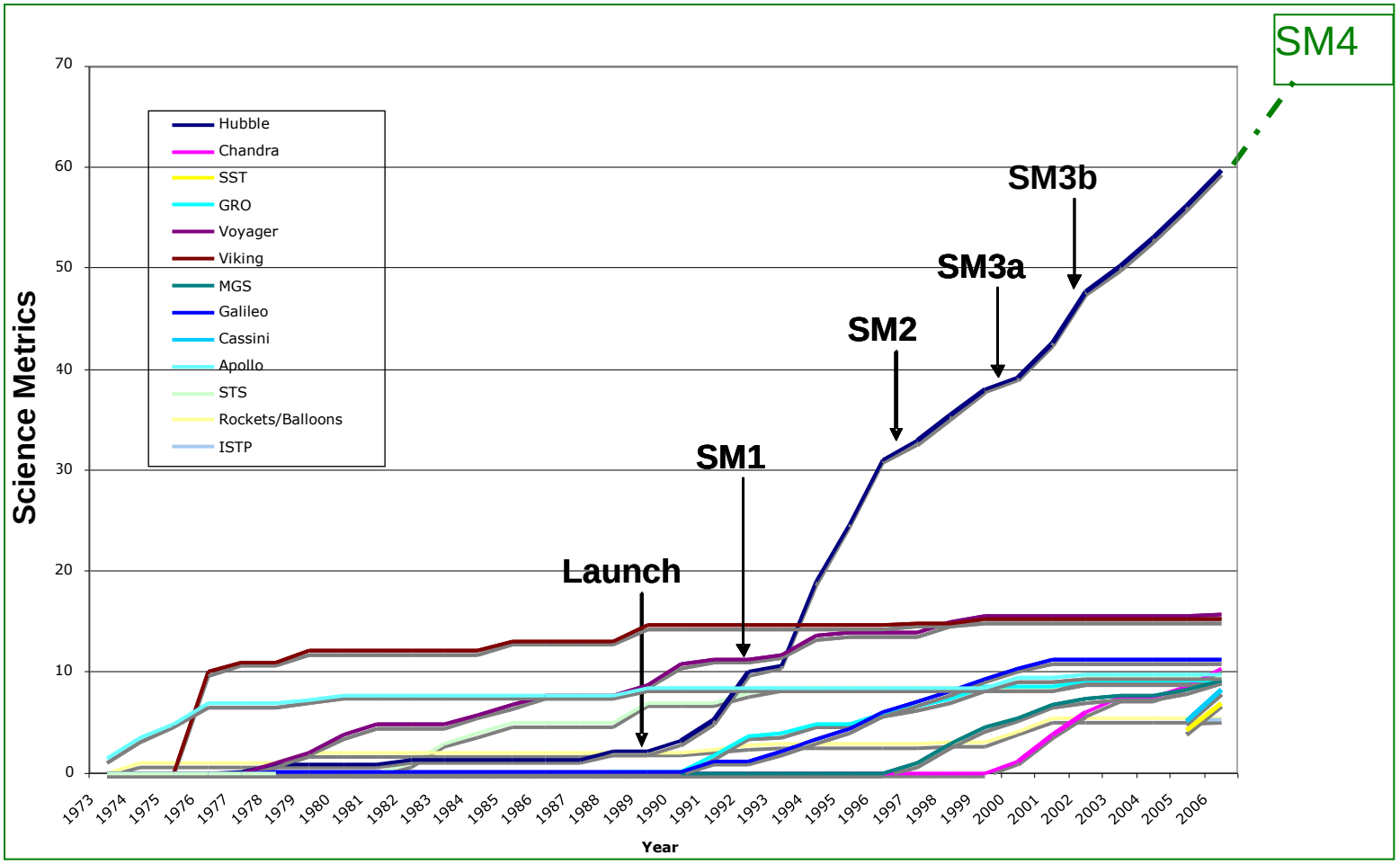


Hubble Images its first planet outside our solar system



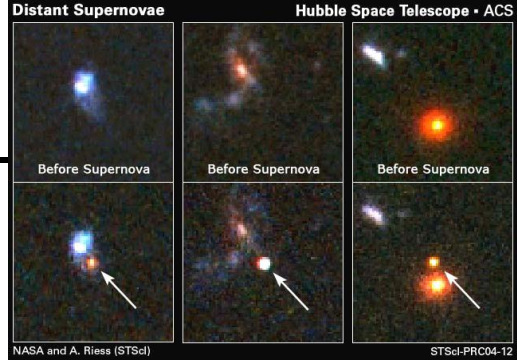
The Hubble Paradigm:
A Partnership Between Science and Human Space Flight

- **Because of the partnership of NASA civil servants, contractors, and suppliers, the Hubble Space Telescope has been the most scientifically productive program in the history of the Agency.**



The 10 Most Heavily Cited Achievements of HST

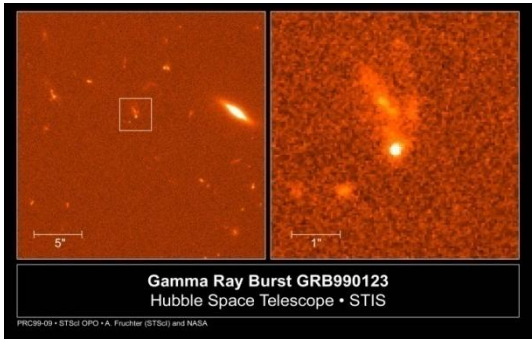
SM-1 and SM-2



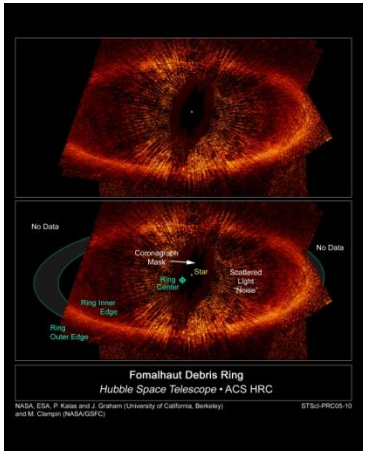
SM-1 and SM-3B

- anticipated
- unanticipated

- **Creation of galaxies (HDF, UDF)**
- **Acceleration of Universe: SN Ia**
- Distance scale of the Universe: H_0
- Giant black holes in galaxies
- Emission lines in active galaxies
- Intergalactic medium (QAL)
- Interstellar medium chemistry
- **Gamma Ray Burst sources**
- **Protoplanetary disks**
- **Extrasolar planets**

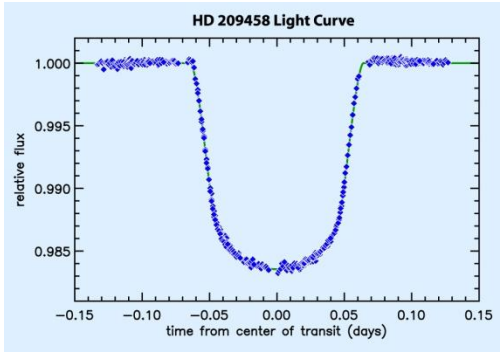


SM-1 and SM-2



SM-3B

Half of Hubble's highest-impact scientific achievements are in areas of research unanticipated prior to launch.



SM-3B

What Can be Expected Now?

- Looking further back in time – IR Ultra-deep fields when the universe was under 1 billion years old
- Probing and measuring the composition of the cosmic web
- Extra-solar planet finding and imaging
- Evaluating supernovae and the origin of elements
- Star and galaxy evolution as viewed in the UV-IR
- Probing dark energy
- Determining the chemical evolution of galaxies