

Hubble SM4



John Mace Grunsfeld PhD

NASA Astronaut

**ASTR 4800 – Space Science:
Practice & Policy**

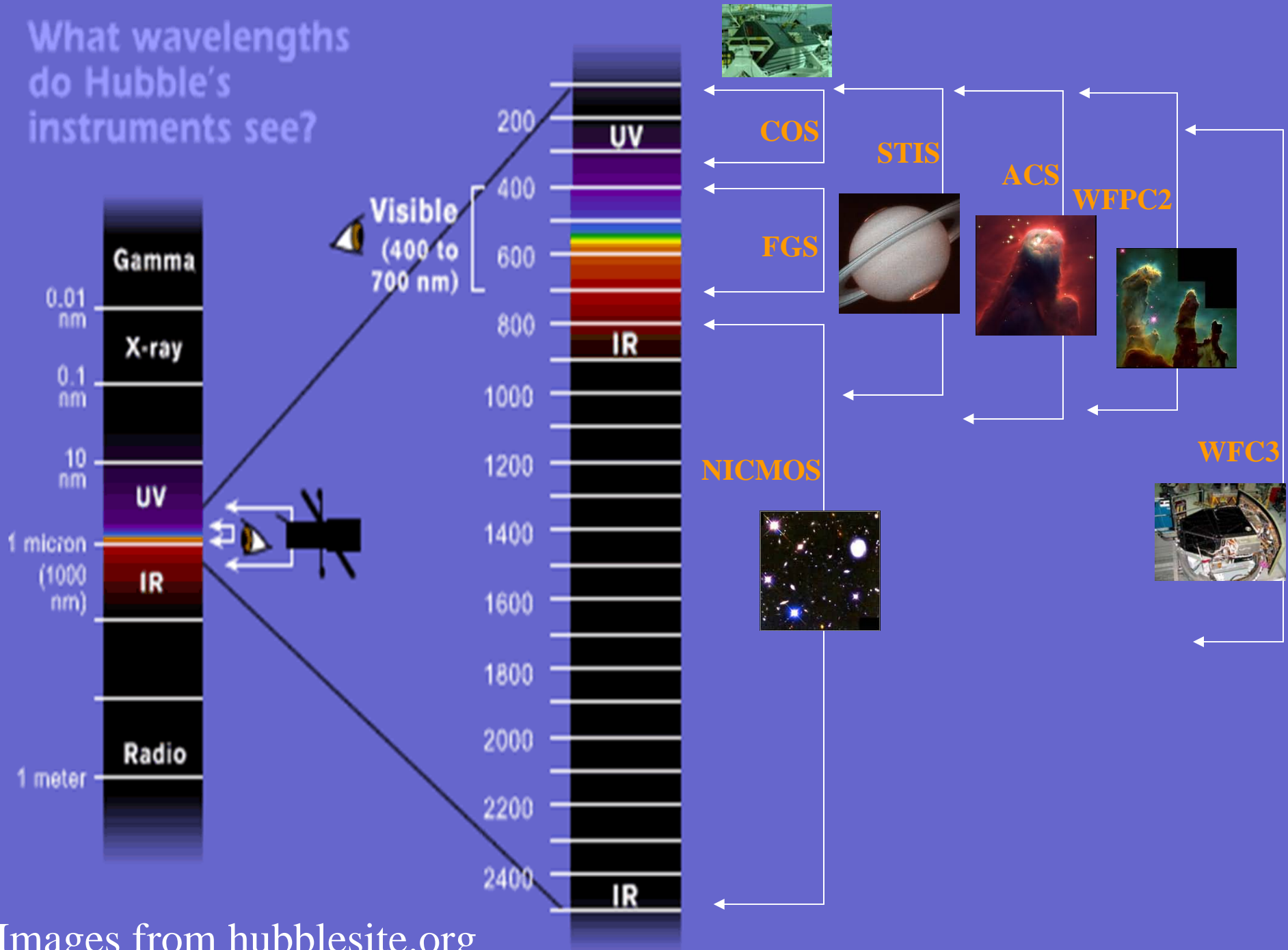




Hubble Space Telescope (HST)

Weight	25,500 lb
Length	43.5 ft
Diameter	14 ft (Aft Shroud)
Optical System	Ritchey-Chretien design Cassegrain telescope
Primary mirror	94.5 in. dia.
Pointing accuracy	0.007 arcsec for 24 hours
Wavelength range	1,100 to 24,000 Å
Angular resolution	0.1 arcsec at 6328 Å
Orbit	305 nmi, inclined at 28.5 degrees
Orbit time	97 minutes per orbit

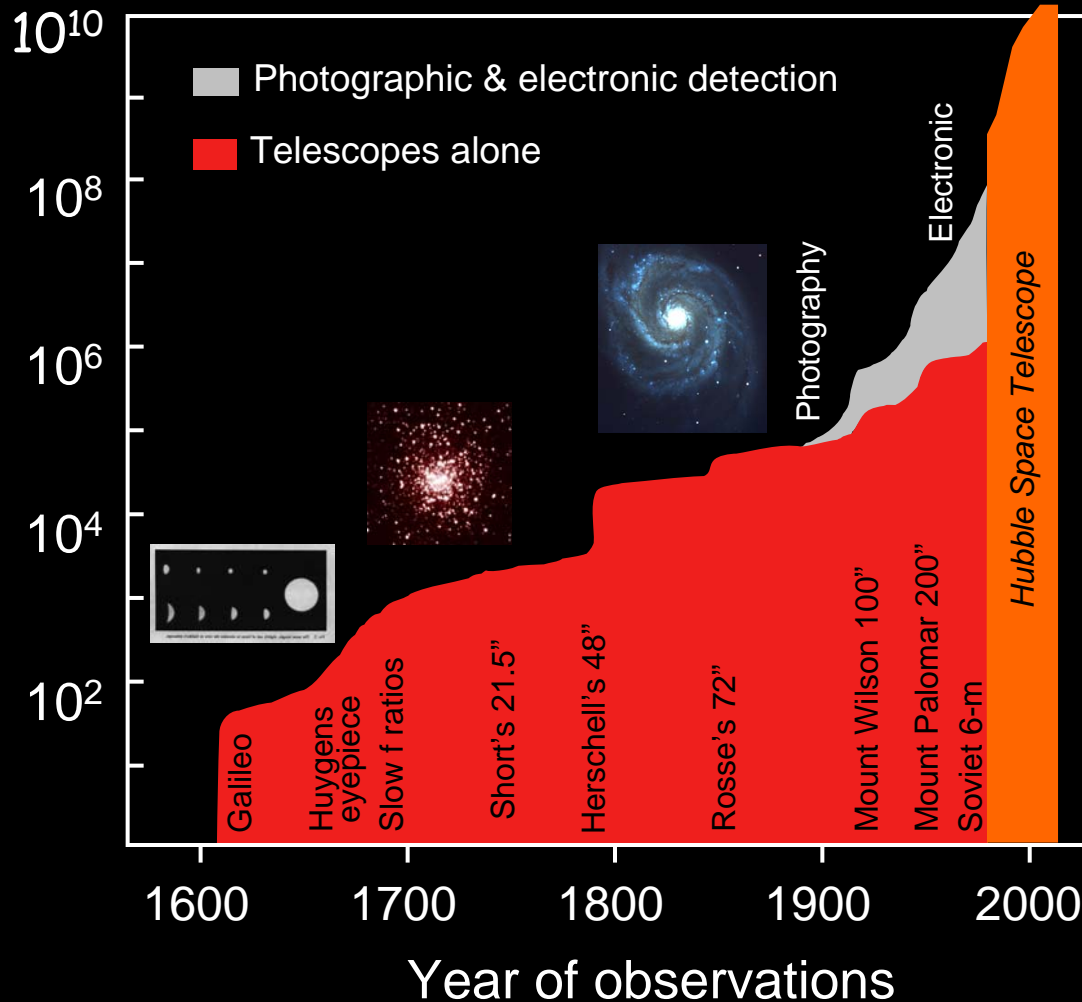
What wavelengths do Hubble's instruments see?



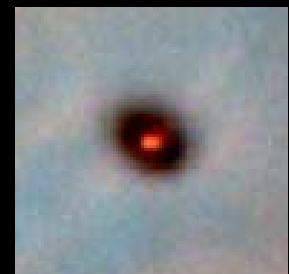
Search & Discovery

After Fig. 3.10 in *Cosmic Discovery*, M. Harwit

Sensitivity
Improvement
over the Eye



Hubble Deep Field HST - WFPC2
PR06-01a - ST ScI OPO - January 15, 1996 - R. Williams (ST ScI), NASA

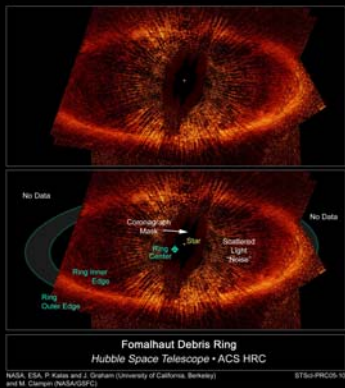
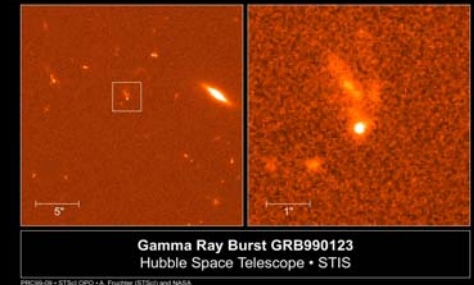
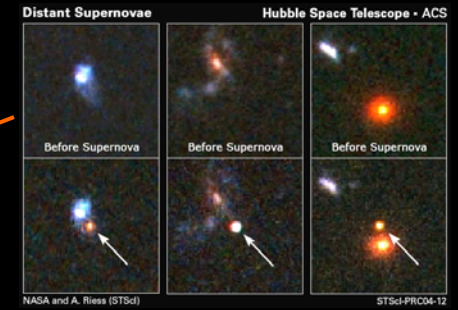


The 10 Most Heavily Cited Achievements of HST

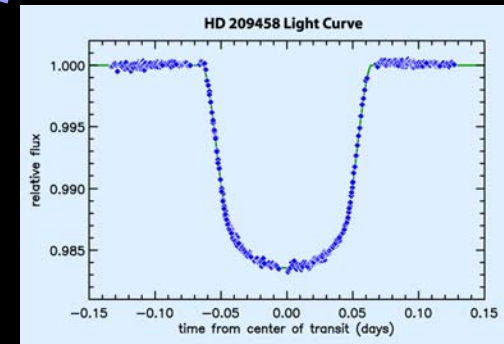


- anticipated
- unanticipated

- 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



Half of Hubble's highest-impact scientific achievements are in areas of research unanticipated prior to launch. Broadly capable flagship missions promote the element of surprise.



NASA, ESA, P. Kalas and J. Graham (University of California, Berkeley) and M. Cernich (NASA/GSFC) STScI-PRC04-13

HUBBLE MISSIONS

De-Orbit
Mission

SM4



Cosmic Origins Spectrograph
Wide Field Camera 3
Fine Guidance Sensor
Aft Shroud Cooling System
Batteries
Gyros

SM3B



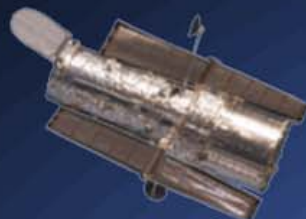
Advanced Camera
Solar Arrays
Power Control Unit
NICMOS Cooling System

SM3A



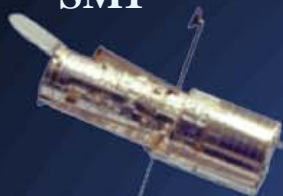
Gyros
Advanced Computer
Fine Guidance Sensor

SM2



Imaging Spectrograph
Near Infrared Camera
Fine Guidance Sensor

SM1



Wild Field Planetary Camera 2
COSTAR
Gyros
Solar Arrays

Launch!



1990

1993

1997

1999

2002

2008

2013

Hubble Servicing Mission 4

- Loss of Columbia
- Columbia Accident Investigation Board Report
- Vision for Exploration and Budget
- Announcement of Cancellation of SM4
(on the basis of risk and cannot comply with CAIB recommendations)
- Public Service, defending leaderships position

- Politics and Science

- Priorities

- Decadal Surveys

- Budgets

- White House (Executive Office of President, OSTP)

- Congress (Mikulski, Udall)

- Community (AURA, STSCI, AAS)

- Media (editorial boards)

- Individuals (Bahcall, Beckwith, Turner, kids, non-astronomers)

- GAO, NRC, Aerospace

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United States Senate

COMMITTEE ON APPROPRIATIONS

WASHINGTON, DC 20510-6025

www.senate.gov/~appropriations

January 21, 2004

Honorable Sean O'Keefe
Administrator
National Aeronautics and Space Administration
300 E Street NW
Washington, DC 20024

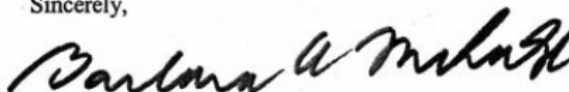
Dear Administrator O'Keefe:

I was shocked and surprised by your recent decision to terminate the next scheduled servicing mission of the Hubble Space Telescope (HST). I fully appreciate and support your emphasis on astronaut safety. Astronaut safety is my number one priority. However, given Hubble's extraordinary contributions to science, exploration and discovery, I ask you to reconsider your decision and appoint an independent panel of outside experts to fully review and assess all of the issues surrounding another Hubble servicing mission.

This panel should report its findings to you and the relevant committees in both houses of Congress this year so we can understand fully the risks, costs and benefits of another Hubble servicing mission. In addition, I request that all planning, preparation and astronaut training activities continue without interruption until Congress has reviewed and decided this issue. Should this panel confirm the need, value and safety of another servicing mission, it is critical that time not be lost. Given Hubble's extraordinary contributions to science, exploration and discovery and its value to the nation and the world, a decision to terminate the next servicing mission must not be made without a thorough, rigorous and comprehensive analysis.

Hubble has become the most successful NASA program since Apollo. It can not be terminated prematurely with the stroke of a pen without a thorough and rigorous review while planning, preparation and training activities continue. I look forward to hearing from you.

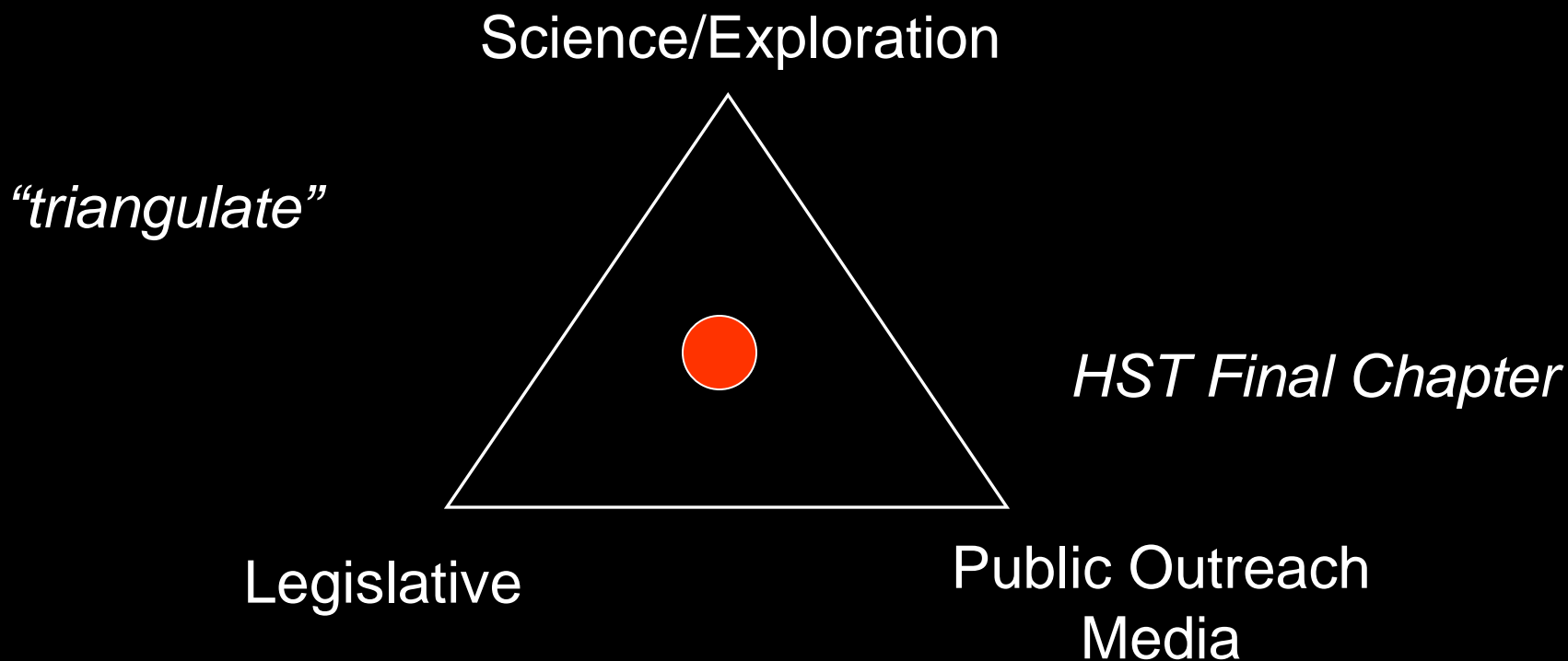
Sincerely,



Barbara A. Mikulski
Ranking Member
Subcommittee on VA/HUD
And Independent Agencies

Moving Forward on HST/Strategy

Use same strategy as STS-61/SM1: intense effort to “save HST”
Engage broader team to kick start exploration effort through HST



Robot to the Rescue!



The Climb Back for SM4



June 04: NRC Preliminary Recommendation – Service HST (Shuttle or Robotic, but favor Shuttle)

April 04: Robotic Preliminary Assessment

March 04: Congressional Mandate and CAIB letter recommending an in-depth Assessment

Jan 04: SM4 Cancelled

Jan 03: Columbia Accident

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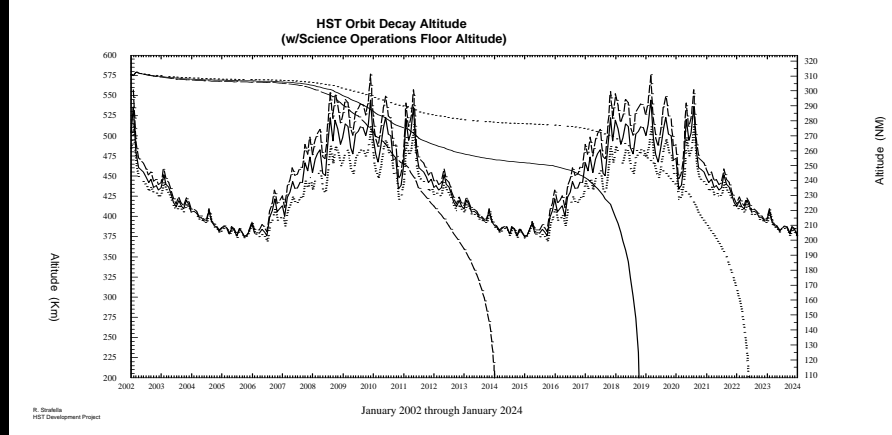
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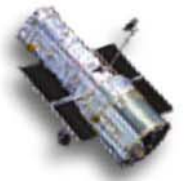
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S&MA Assessment

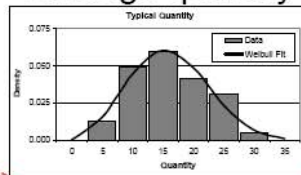
HST Expected Ascent Debris Environment



The S&MA assessment is based on a Monte Carlo model (ADAM) that simulates missions with respect to ascent related lower surface tile damage.

INPUTS

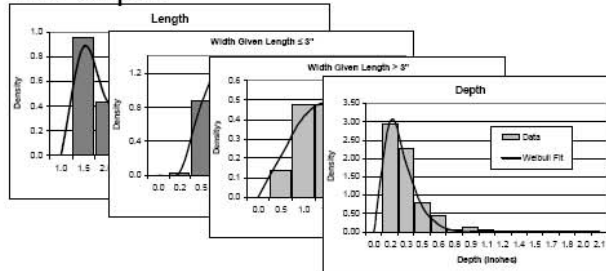
Damage quantity



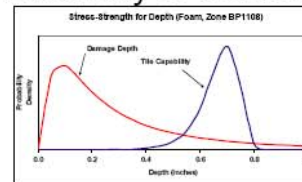
Damage Location based on the proportion of hits in each zone

Ice/ Foam assessment based on damage width

Damage Length, width and depth



Probability of criticality

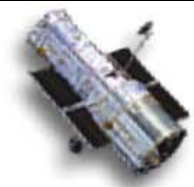


100,000 replications

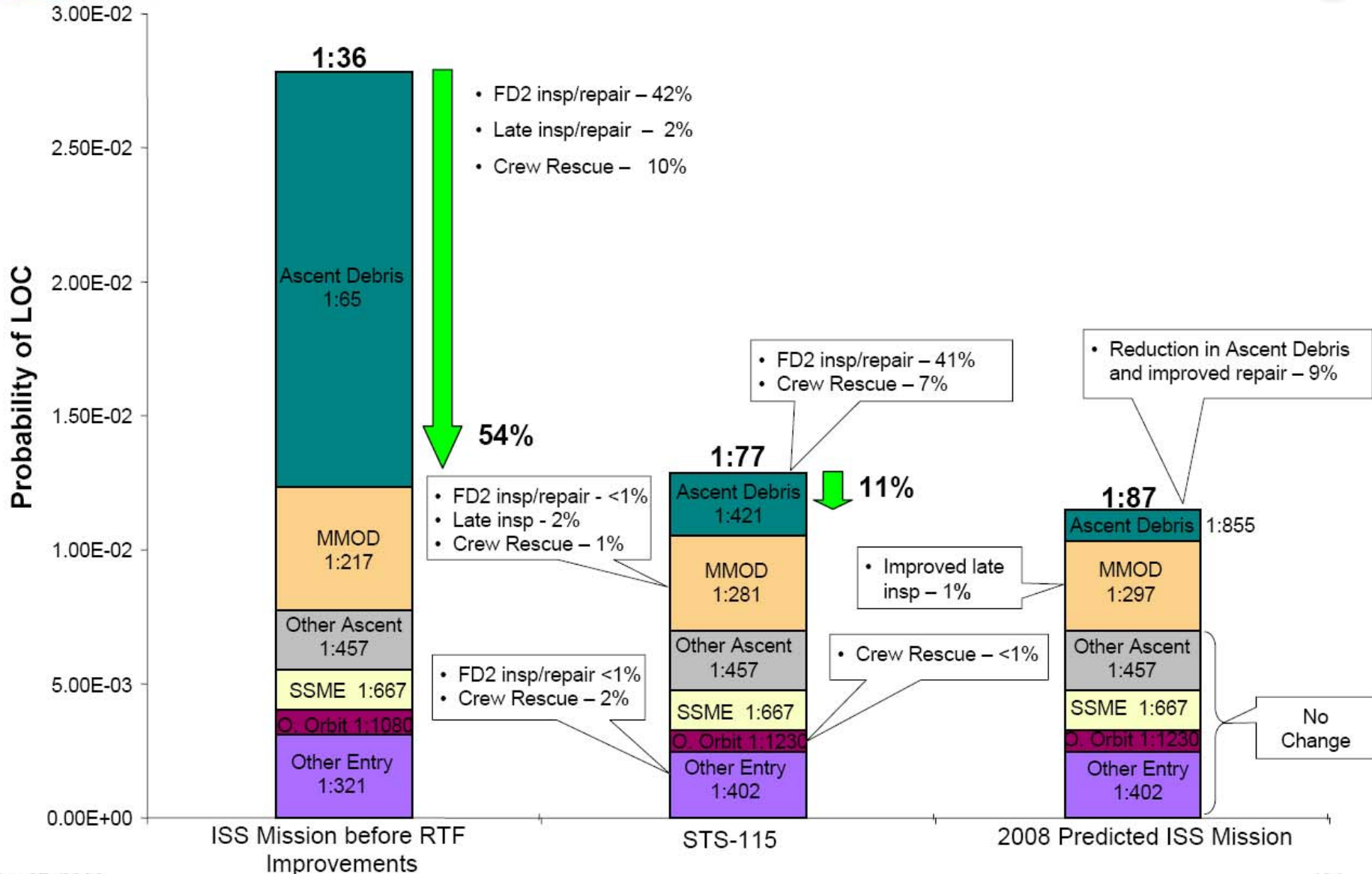
Probability of critical damage.

Inputs are based on:

- Historical Ascent Debris Hit Maps (~83 flights)
- Orbiter Project Office Damage Tolerance Distributions
- Orbiter Project Office Inspection Criteria

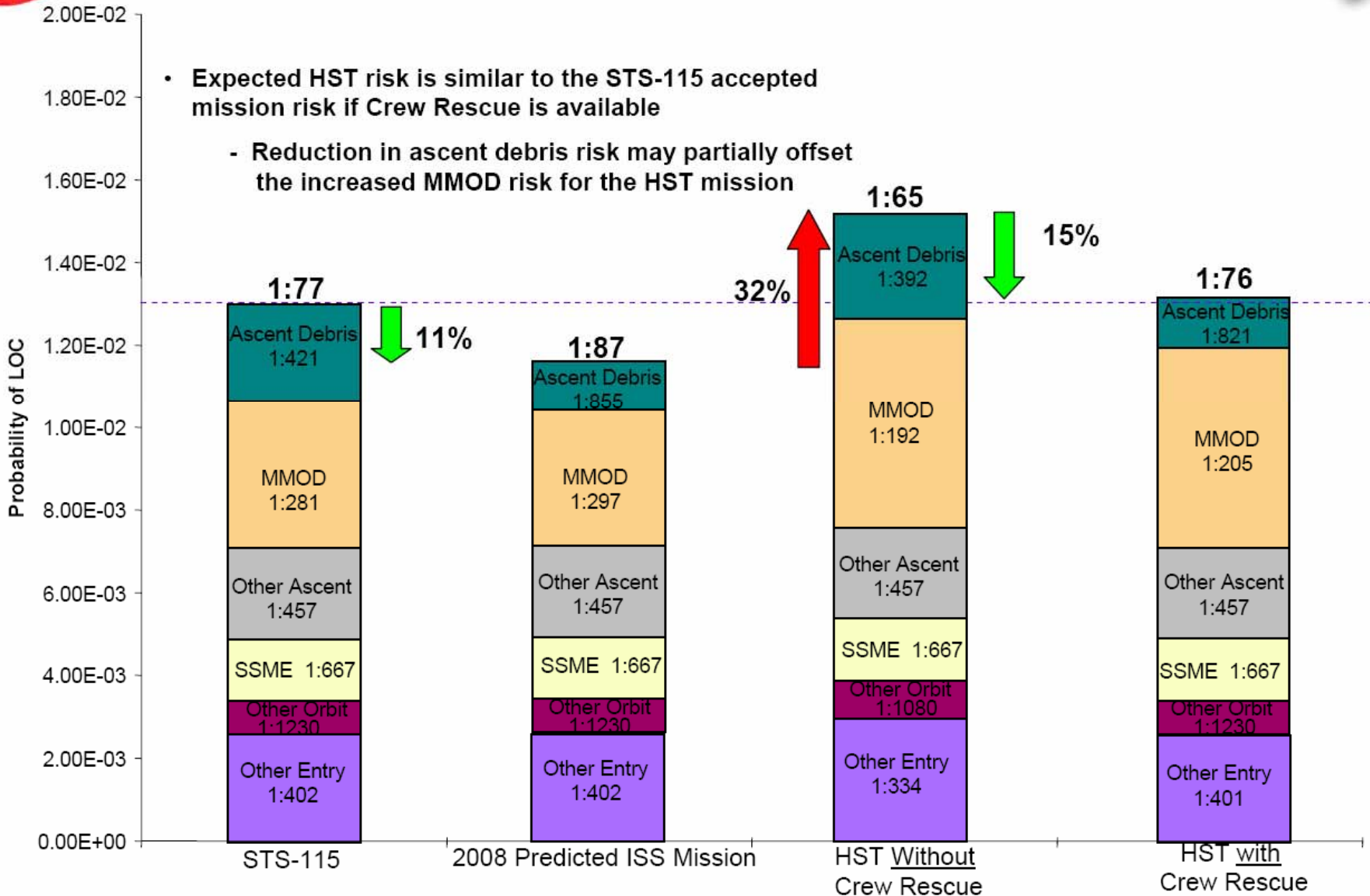


ISS Mission Risk Reduction





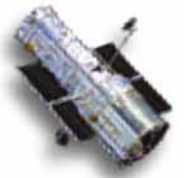
Risk Comparisons





Expected 2008 Operations Environment

Unique Risks for a Stand Alone Mission

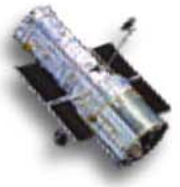


The 2004 Case Against HST (Cancellation Rationale)	The 2006 Case FOR HST SM4 (Mitigation/Risk Acceptance Rationale)
<p>1) Lack of Safe Haven – Typical ISS Mission will provide 60-90 Days of CSCS which allows for additional planning and near standard processing of the rescue vehicle</p>	<p>SM4 planning will assure sufficient consumables are onboard to support a stranded crew for at least 25 days till rescue. This will require manifesting additional LIOH and implementing a significant power down protocol</p>
<p>a) Limited time to modify rescue vehicle to avoid whatever situation damaged the HST vehicle</p>	<p>Low likelihood that the same catastrophic failure scenario will occur on consecutive flights based on expected ascent debris environment</p>
<p>b) “Double workload” associated with processing two vehicles for launch within 10-15 days of each other. Risk associated with a fatigued Launch Team</p>	<p>Compliance with Personnel work load requirements will assure fatigue risk is mitigated. KSC plans for either single or dual pad ops not judged to be a significant Human Factors impact.</p>
<p>2) TPS Inspection Capability Compromised if not docked to the ISS. No RPM for Tile Inspection</p>	<p>OBSS capability exists for accomplishing all RCC and TPS inspections. This was demonstrated during the TPS focused inspection on STS-115.</p>



Expected 2008 Operations Environment

Unique Risks for a Stand Alone Mission

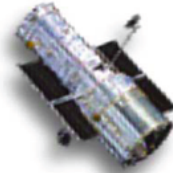


The 2004 Case Against HST (Cancellation Rationale)	The 2006 Case FOR HST SM4 (Mitigation/Risk Acceptance Rationale)
3) Repair Capability Compromised if not docked to the ISS. SSRMS required to provide adequate worksite reach and stability	DTO on SS-121 demonstrated SRMS/OBSS provides adequate reach and stability to serve as a repair worksite if required.
4) Hazards associated with temporary storage of rescue vehicle in VAB with hypergolic propellants loaded	Similar protocol was in place for STS-115 hurricane contingency planning and process was actually initiated.
5) Risks of Shuttle to Shuttle rendezvous and grapple	Rendezvous and grapple not outside previous experience base for targets both in planned and unplanned attitudes/rates, and not considered a significant risk driver for an HST rescue mission.
6) Crew transfer via EVA translation results in additional risk to crew. Some stranded crew not EVA trained. Suits not sized for all stranded crewmembers. Whole process is untried and uncertified.	Human Factors Analysis estimates the probability of loss of a crewmember at ~ 1 in 100 for the EVA translation activities. Full EVA training is not required. Certified EVA crewmembers will execute standard incapacitated crewmember translation techniques



Expected 2008 Operations Environment

Unique Risks for a Stand Alone Mission



The 2004 Case Against HST (Cancellation Rationale)

11) Cannot fully comply with the CAIB Report and also execute an HST Servicing Mission

The 2006 Case FOR HST SM4 (Mitigation/Risk Acceptance Rationale)

SM4 is able to maintain compliance with the 4 mandatory CAIB requirements for a return to flight:

- 1 Measures were taken to understand foam shedding and reduce it
- 2 Measures were taken to understand TPS tolerance
- 3 On-Orbit inspection capabilities exists to allow re-certification of Orbiter TPS for entry
- 4 Capability to perform limited Tile and RCC repairs exists

The capability to comply with these requirements in a timeframe that would have been not only during the midst of the Return to Flight effort, but also within the then predicted HST health constraints would have been an near overwhelming challenge.

However, the current and expected status of the Return to Flight initiatives and the schedule relief due to improved HST battery management allow compliance will all 4 requirements

The Climb Back for SM4

Current Manifest planning set August 7, 2008

November 06: Announcement of Approval of SM4

October 06: Manifesting Decision Review at NASA HQ

May 06: RTF going well, started Formal assessment of SM4 in RTF environ

September 05: Looked at Orbital Lifetime, and Cancelled DM

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Hubble Servicing Mission 4 Crew



HST Spacecraft Health

Equipment Section

- Degraded MLI:
Install NOBLs on
Bays 5, 7, 8 in SM4

Fine Guidance Sensors

- FGS2R: degrading servo LED
- FGS3: degrading bearings
replace one FGS on SM4

Aft Shroud

- Higher power
instruments causing
warming
- Install STIS Cooling
System on SM4

Axial Scientific Instruments

- STIS, failed 8/04
STIS Repair on SM4
- ACS, failed 1/07
- Install COS on SM4

Rate Sensor Units

- Gyros 2,3 and 5 failed:
replace all 6 gyros on SM4

High gain antenna

Secondary
mirror

Aperture door

Primary
mirror

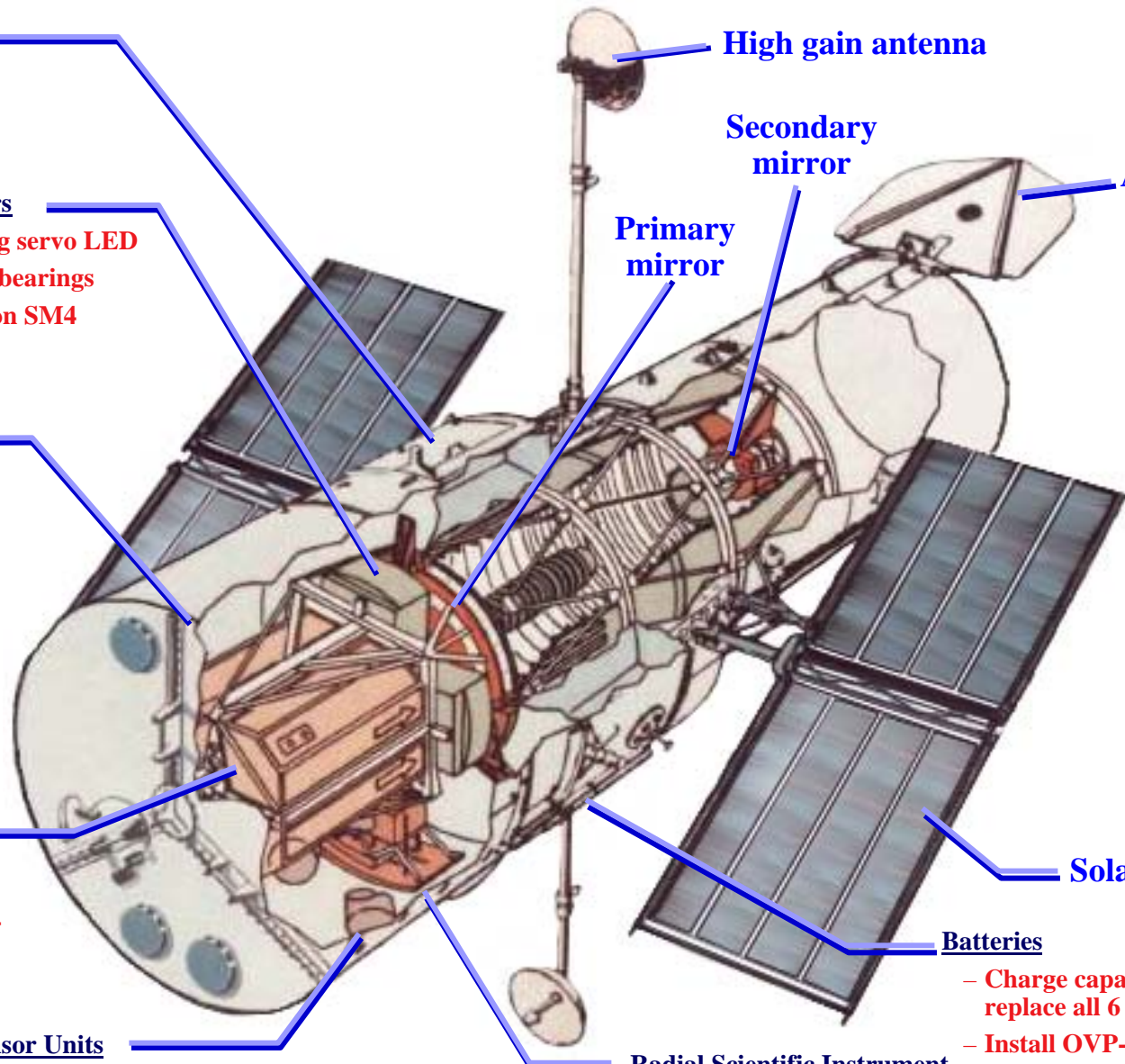
Solar Arrays

Batteries

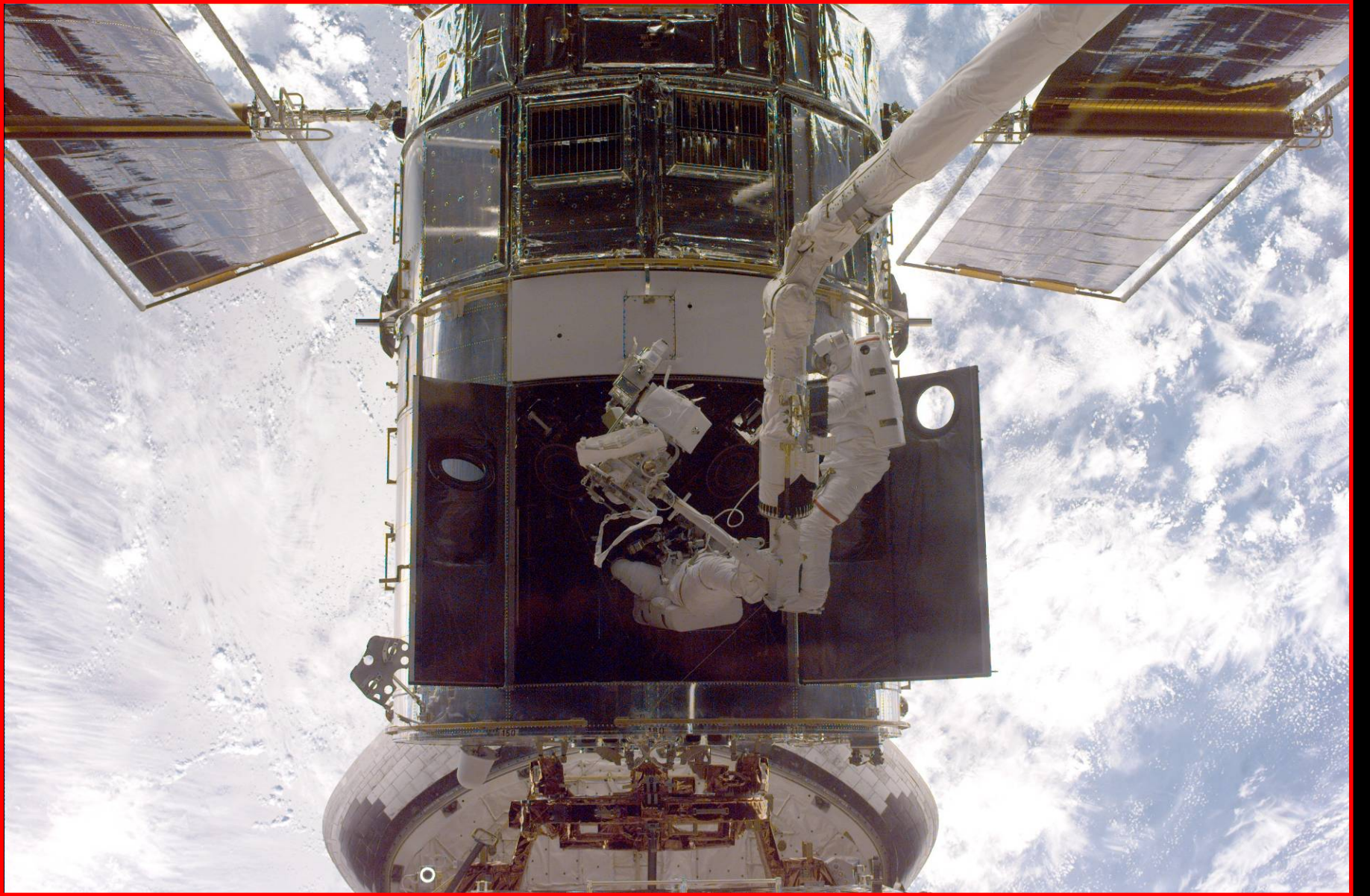
- Charge capacity trending downward;
replace all 6 batteries on SM4
- Install OVP-Kit on SM4

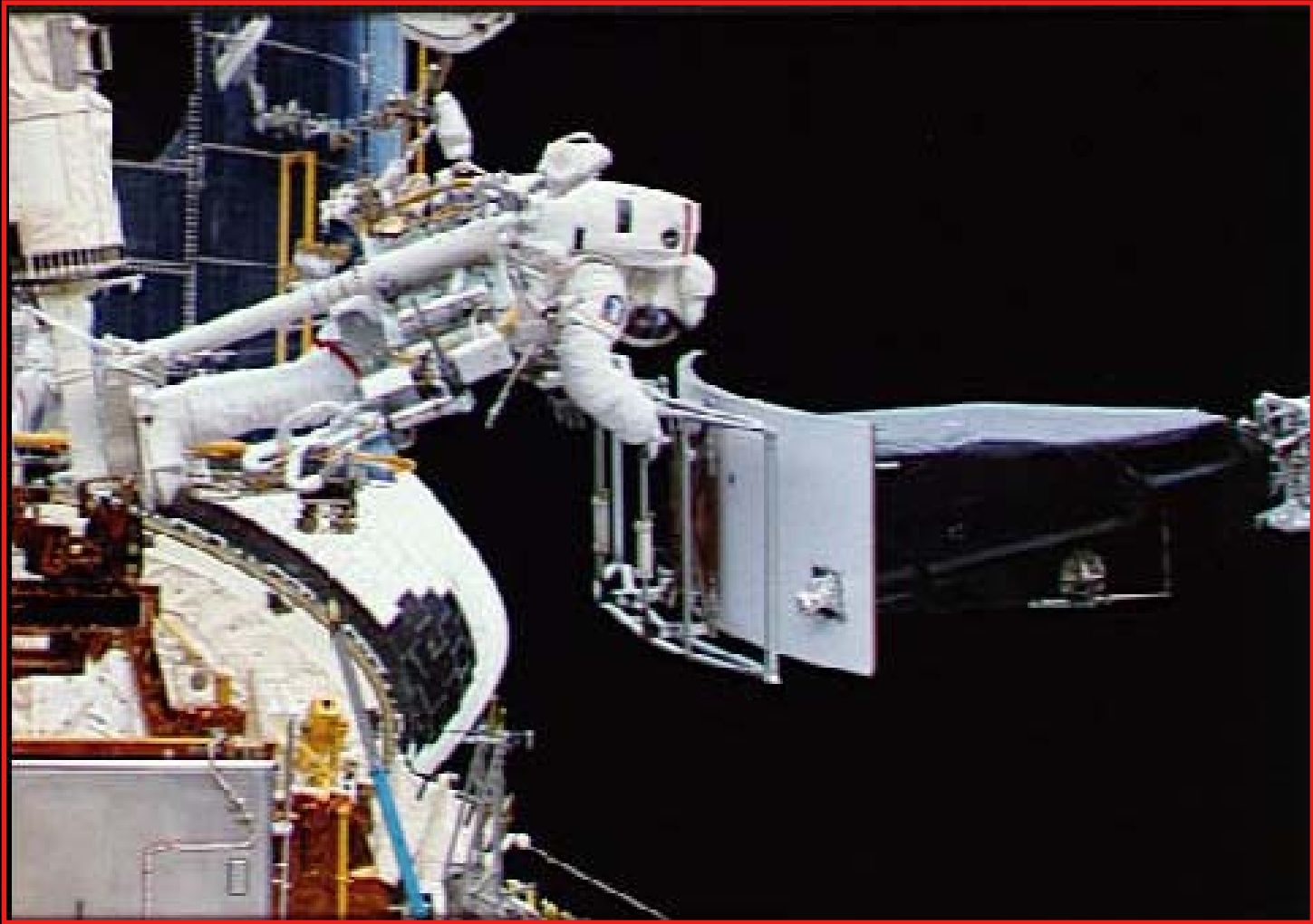
Radial Scientific Instrument

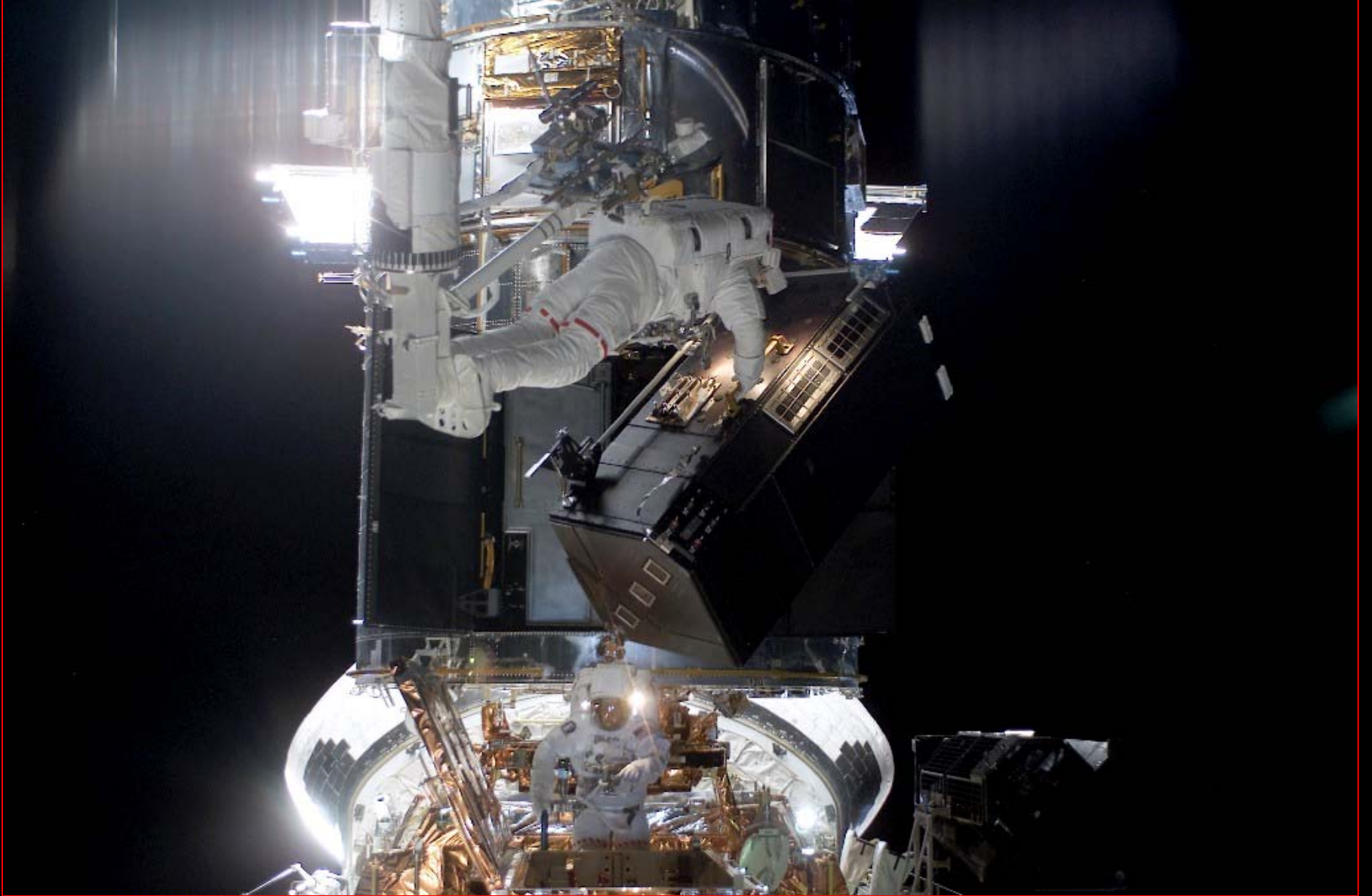
- Replace WFPC-II w/
WFC3 on SM4











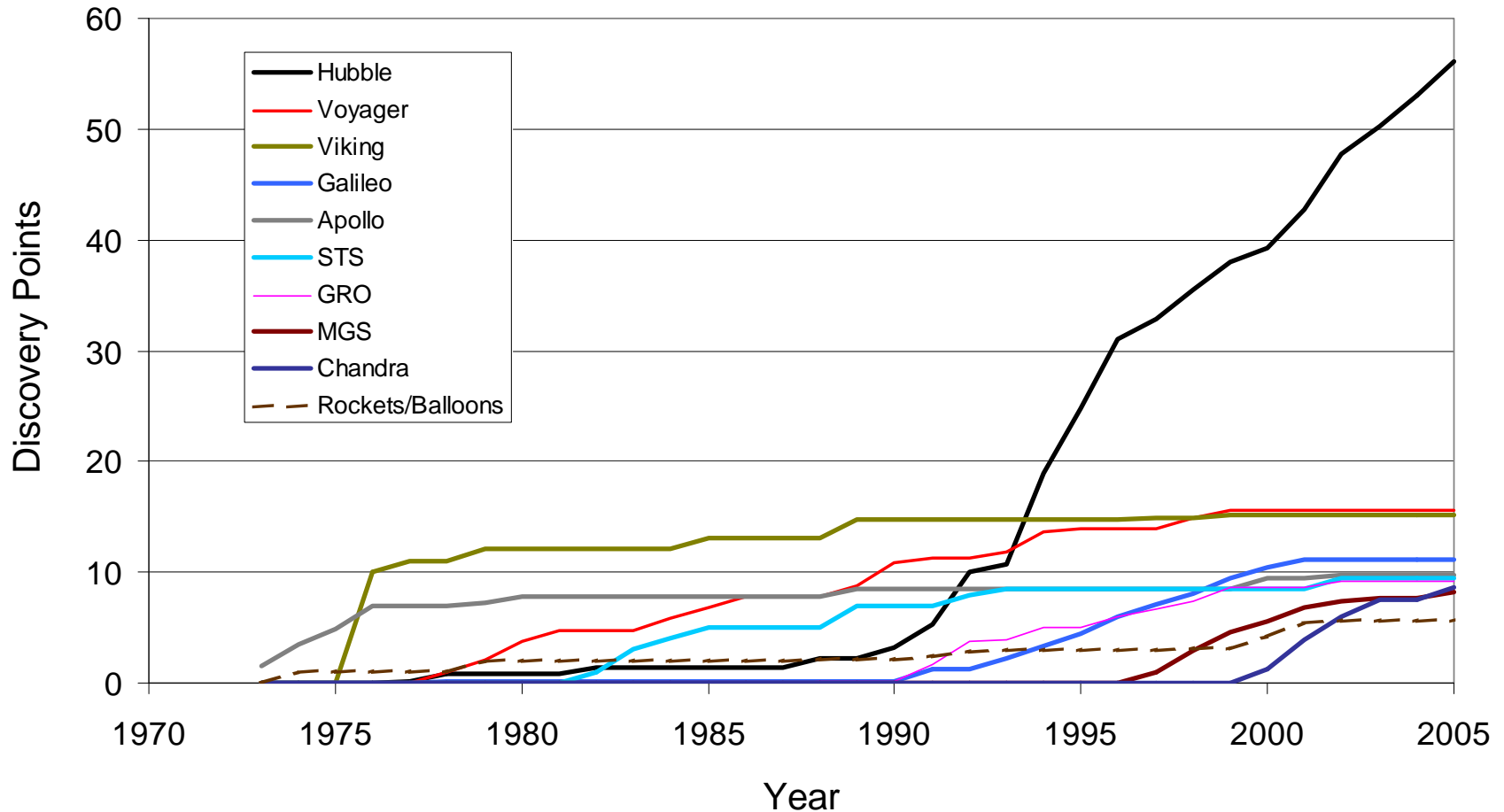
NASA Spares No Expense to get the BEST Tool Consultants





HST is an Incredible Science Machine

Cumulative Contributions of NASA's 10 Most Productive Programs



“Davidson Science News Metric” for 2005

And in popular media

Astronomers Peer Into Black Hole

Research Bolsters Theory, Provides Portrait of Matter Spiraling Into Oblivion



As a star swarms toward a black hole, it is pulled into a glowing ring of gas and dust. This is the accretion disk. The inner part of the disk is the hottest and brightest, and it is here that the most intense X-ray emission is produced. The outer part of the disk is cooler and dimmer, and it is here that the most intense radio emission is produced. The black hole itself is a region of space where the gravitational pull is so strong that nothing can escape, not even light.

What a Black Hole Is

A black hole is a region of space where the gravitational pull is so strong that nothing can escape, not even light.



At the center of a black hole is a singularity, a point where the density is infinite and the laws of physics as we know them break down. The singularity is surrounded by the event horizon, the boundary beyond which nothing can escape. The region between the event horizon and the singularity is the accretion disk, where matter is being pulled in and heated to extreme temperatures.

EINSTEIN'S REPULSIVE IDEA

He invented antigravity in desperation and abandoned it first chance he got—but it may be the most powerful force in the universe



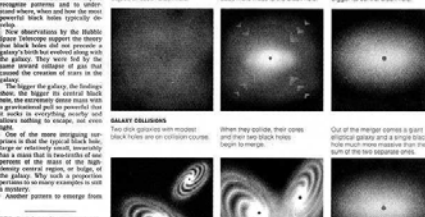
GRAVITY
What it is: An attractive force that pulls objects toward each other.
How it operates: Gravity weakens over distance, but it is always present. It is the force that keeps planets in orbit around the sun and galaxies together.

ANTIGRAVITY
What it is: A property of space that repels objects from each other.
How it operates: Antigravity is a repulsive force that acts between two masses. It is the force that is thought to be driving the expansion of the universe.

WHAT THIS MEANS: As the universe expands, gravity is less and less effective at holding things together. Antigravity, on the other hand, is getting stronger and stronger.

Why Some Galaxies Have Black Hearts

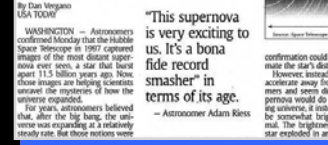
By JOHN NOBLE WILFORD
The Where, When and How of Black Hole Formation
Astronomers believe that many galaxies have a black hole at their center. These black holes are thought to have formed from the collapse of massive stars or the merging of smaller black holes.



WEIGHING IMPORTANT CLUES TO HOW THE GALAXIES FORMED.
The observation that the more compact a galaxy is, the more likely it is to have a black hole at its center is a key clue to how these galaxies formed. Astronomers are studying the relationship between galaxy size and black hole mass to better understand the process.

A supernova bursts into view

Hubble finding has researchers rethinking how universe works

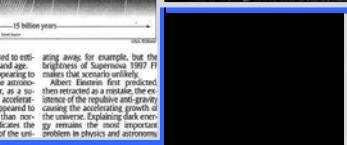


WASHINGTON — Astronomers confirmed Monday that the Hubble Space Telescope in 1987 captured images of the most distant supernova ever seen, a star that had died about 11.5 billion years ago.

This supernova is very exciting to us. It's a bona fide record smasher—in terms of its age. For years, astronomers believed that, after the big bang, the universe was expanding at a relatively steady rate. But those notions were confirmed only last week.

Health and science

A universe in motion
The universe's expansion is accelerating, according to new data from the Hubble Space Telescope. This discovery challenges the long-standing theory that the expansion of the universe is slowing down.



Confirmation could be used to estimate the star's distance and age. However, instead of appearing to accelerate away from the astronomer, it was found to be somewhat brighter than normal. The findings indicate that the star exploded in an era of the universe when it was still expanding.

Supernova Observations Bolster 'Dark Energy' Theory

Findings Could Alter Conception of Universe



The image of the supernova, recently photographed, is right at the heart of a theory. Astronomers detected the supernova blast by observing a dimming of light from a star that was thought to be a normal star.

FROM LIGHT TO DARKNESS: ASTRONOMY'S NEW UNIVERSE
The discovery of dark energy has revolutionized our understanding of the universe. It is a mysterious force that is causing the universe to expand at an accelerating rate. This discovery challenges the long-standing theory that the expansion of the universe is slowing down.

A Dark Force in the Universe

Scientists try to determine what's revving up the cosmos



California, Calif. There is a ball into the air. The ball is a dark matter halo, a cloud of invisible matter that surrounds galaxies and clusters of galaxies. It is thought to be the most abundant form of matter in the universe.

From Light to Darkness: Astronomy's New Universe

By DENNIS DEBERNARDI
Astronomers have discovered a new force in the universe, one that is causing the universe to expand at an accelerating rate. This discovery challenges the long-standing theory that the expansion of the universe is slowing down.

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Photo Gives Weight To Einstein's Thesis of Negative Gravity

By JAMES GLAZ
A photograph of a distant galaxy, taken by the Hubble Space Telescope, shows a dark region in the center. This dark region is thought to be a black hole, a region of space where the gravitational pull is so strong that nothing can escape, not even light.

Black holes and galaxies may grow up together

Two theories may explain the findings, says Kormendy. In one scenario, black holes come in a standard initial size, and 12 percent of the mass of the first galaxy fragments. After that, black holes and bulges grow only when galaxies merge.



STAR VELOCITIES
The relationship between galaxy size and black hole mass is a key clue to how these galaxies formed. Astronomers are studying the relationship between galaxy size and black hole mass to better understand the process.

PHOTO GIVES WEIGHT TO THESIS OF NEGATIVE GRAVITY
A photograph of a distant galaxy, taken by the Hubble Space Telescope, shows a dark region in the center. This dark region is thought to be a black hole, a region of space where the gravitational pull is so strong that nothing can escape, not even light.

WASHINGTON — Astronomers confirmed Monday that the Hubble Space Telescope in 1987 captured images of the most distant supernova ever seen, a star that had died about 11.5 billion years ago.

Confirmation could be used to estimate the star's distance and age. However, instead of appearing to accelerate away from the astronomer, it was found to be somewhat brighter than normal. The findings indicate that the star exploded in an era of the universe when it was still expanding.

The discovery of dark energy has revolutionized our understanding of the universe. It is a mysterious force that is causing the universe to expand at an accelerating rate. This discovery challenges the long-standing theory that the expansion of the universe is slowing down.

Two theories may explain the findings, says Kormendy. In one scenario, black holes come in a standard initial size, and 12 percent of the mass of the first galaxy fragments. After that, black holes and bulges grow only when galaxies merge.

The Moon

Aristarchus Plateau ■ The Moon

HST ■ ACS/HRC



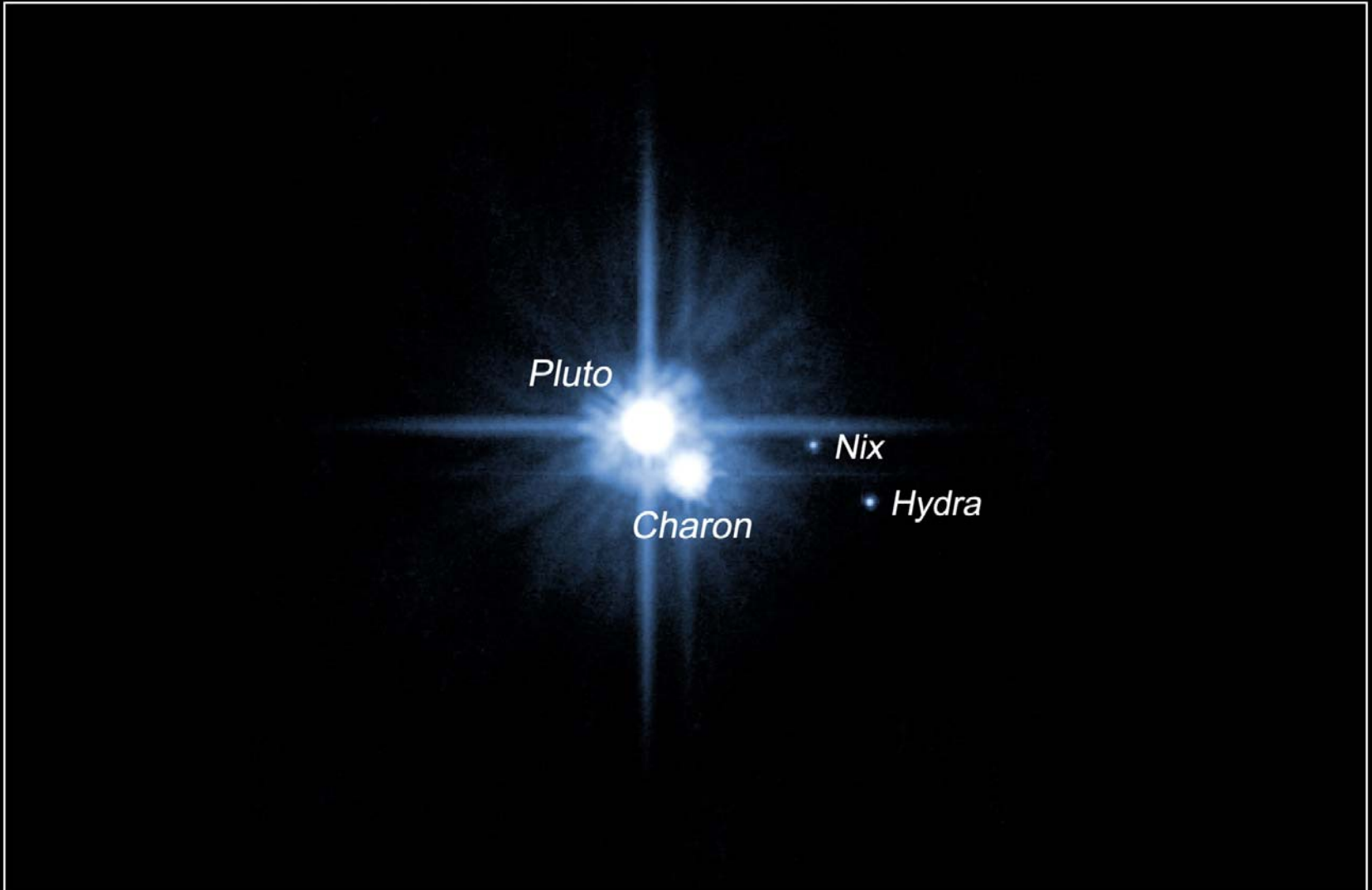
NASA, ESA, and J. Garvin (NASA/GSFC)

STScI-PRC05-29a

Pluto

Pluto System ■ February 15, 2006

Hubble Space Telescope ■ ACS/HRC

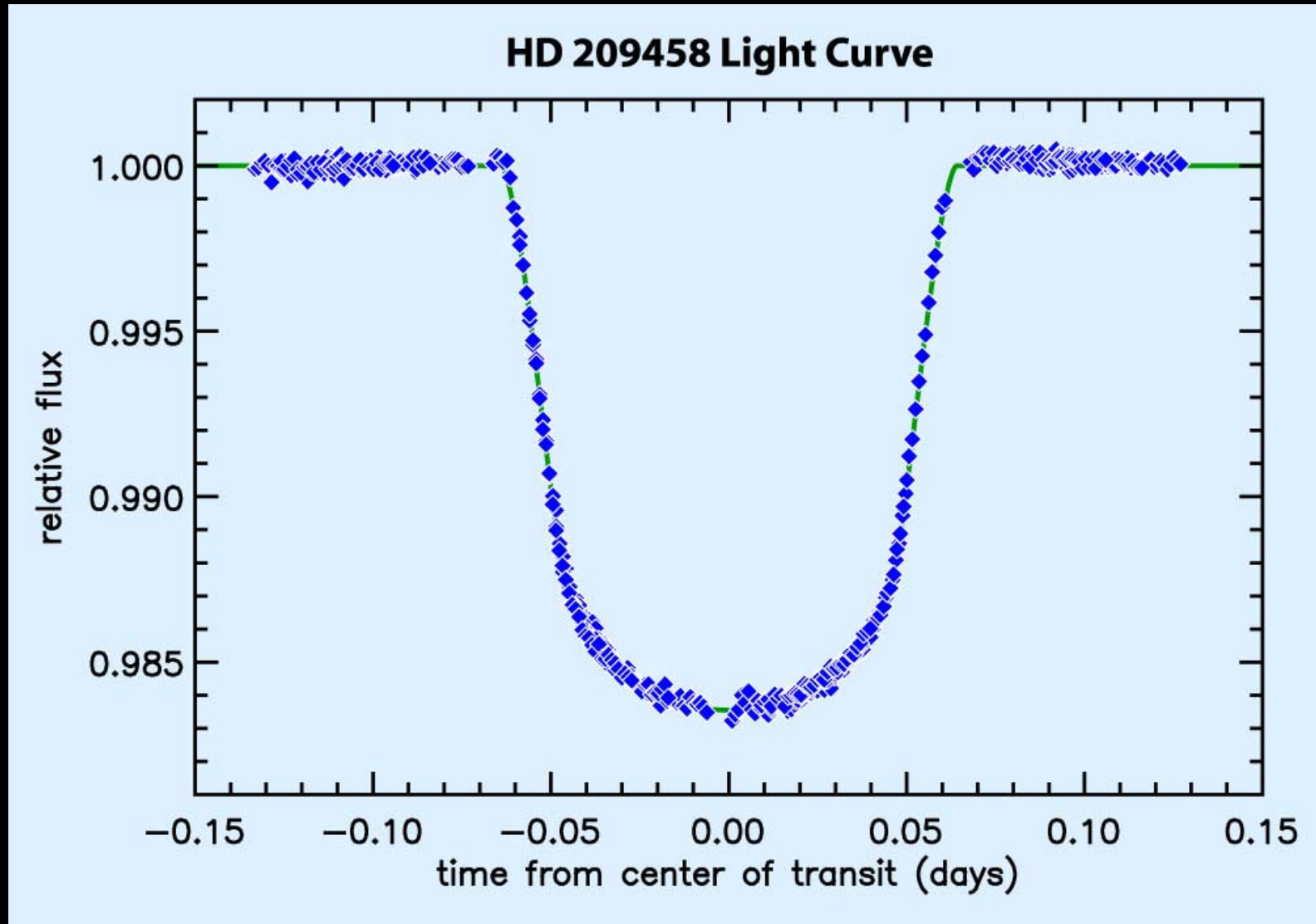


Planetary Atmospheres

- Twenty years ago we new of 9 planets in the Universe (demoted to 8)
- Today we have discovered more than 200 outside our own solar system

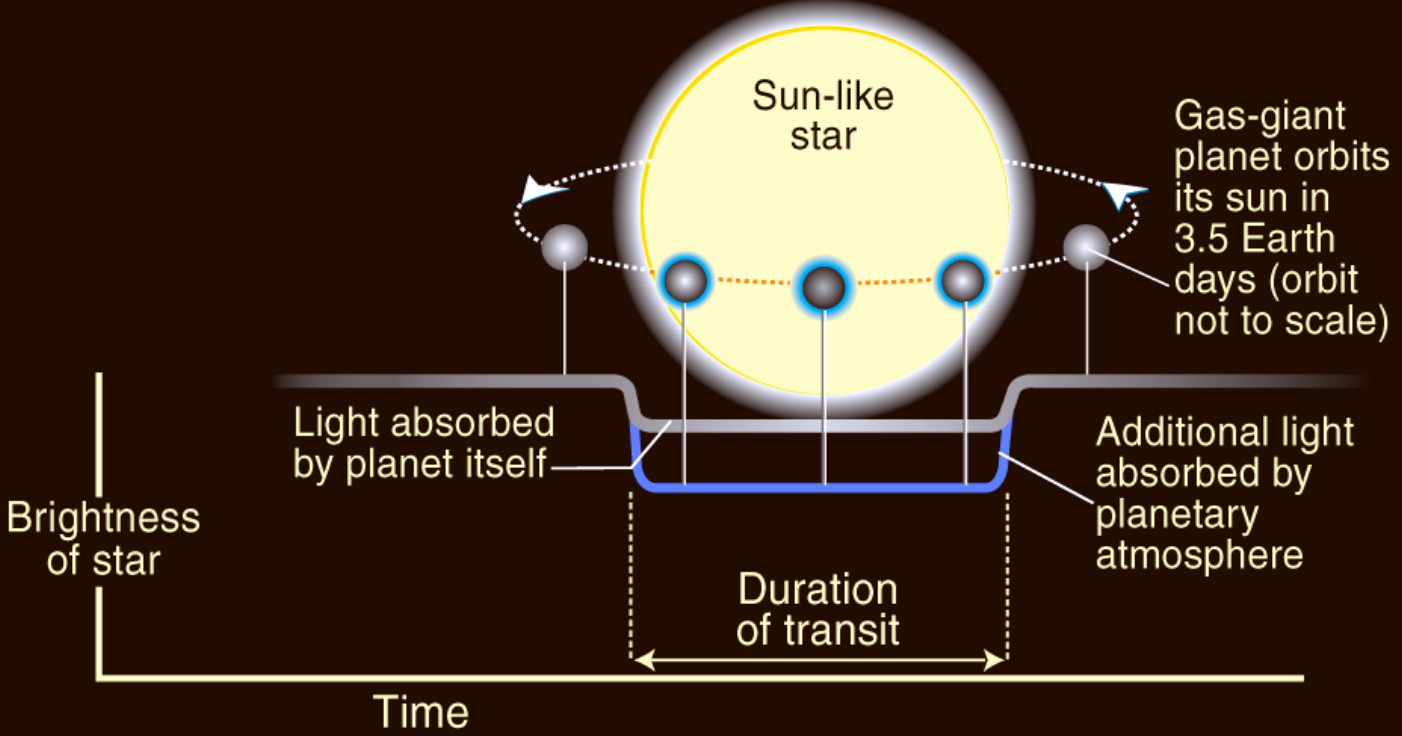
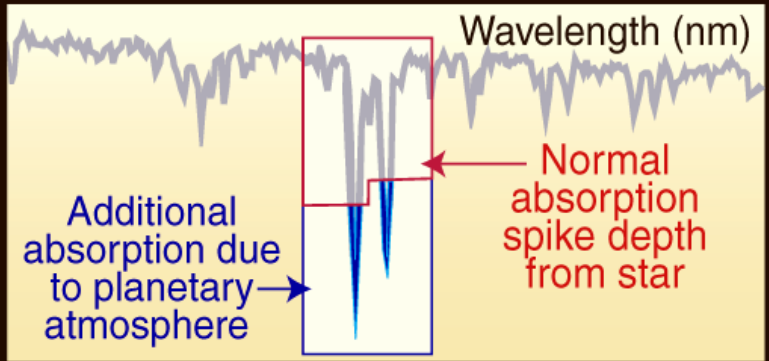


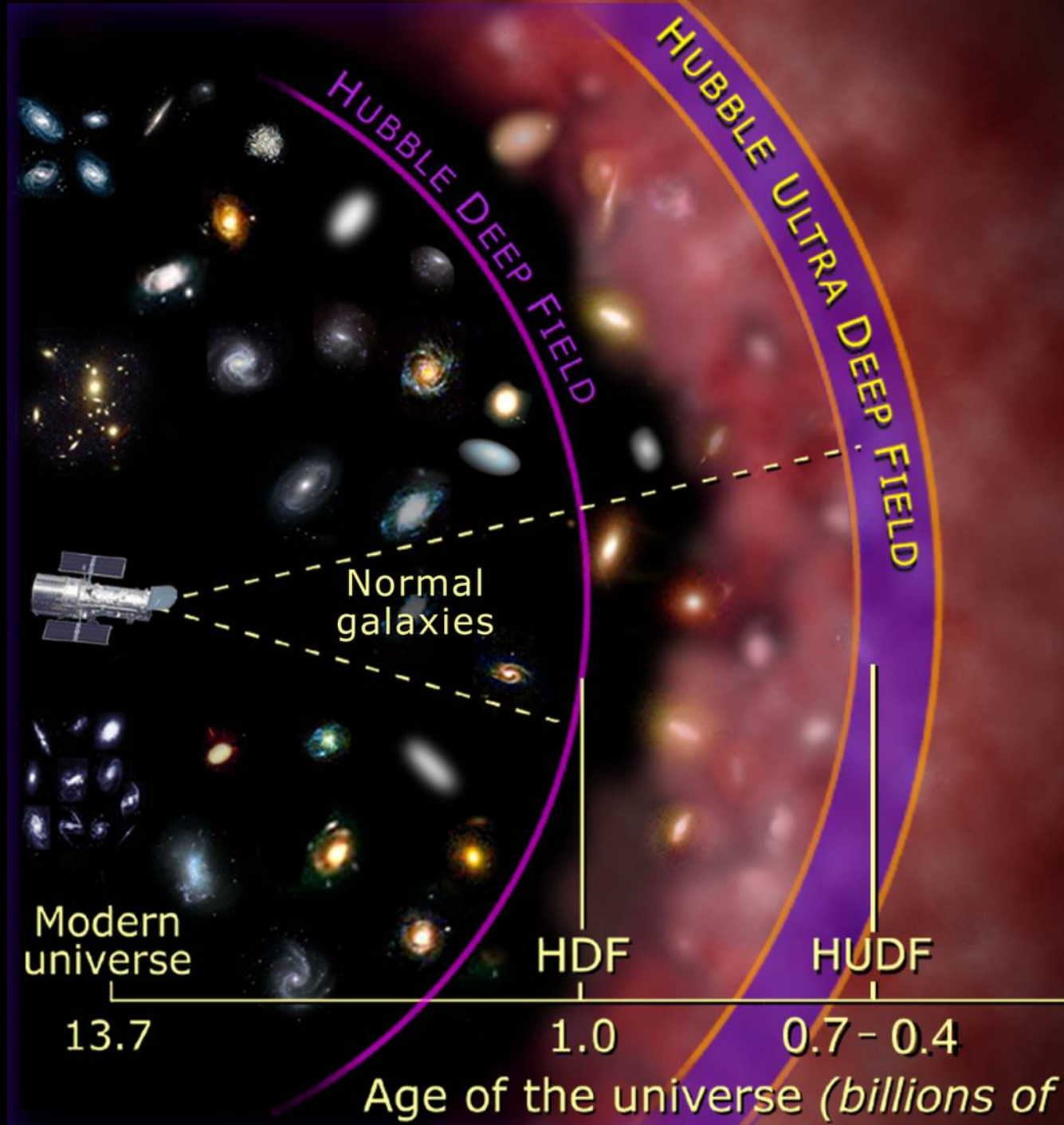
Planetary Atmosphere



Planetary Atmosphere

HST detects additional sodium absorption due to light passing through planetary atmosphere as planet transits across star



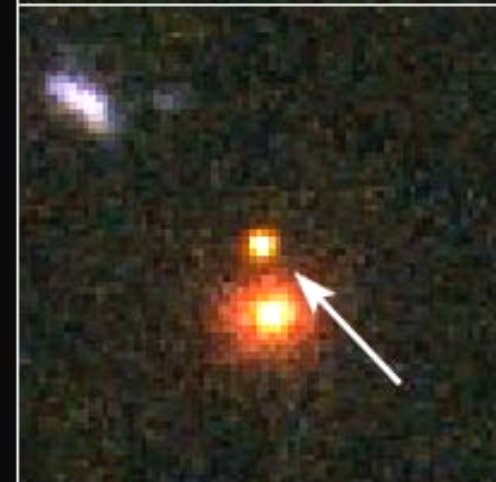
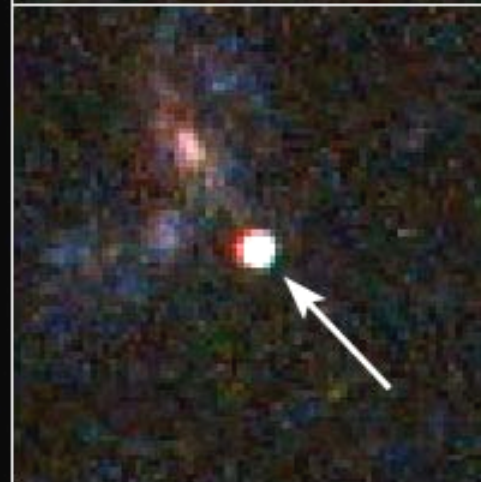
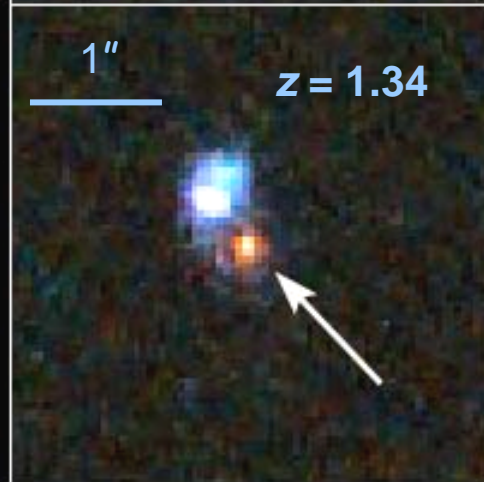


Age of the universe (*billions of*

HST Images of SN Ia

Distant Supernovae

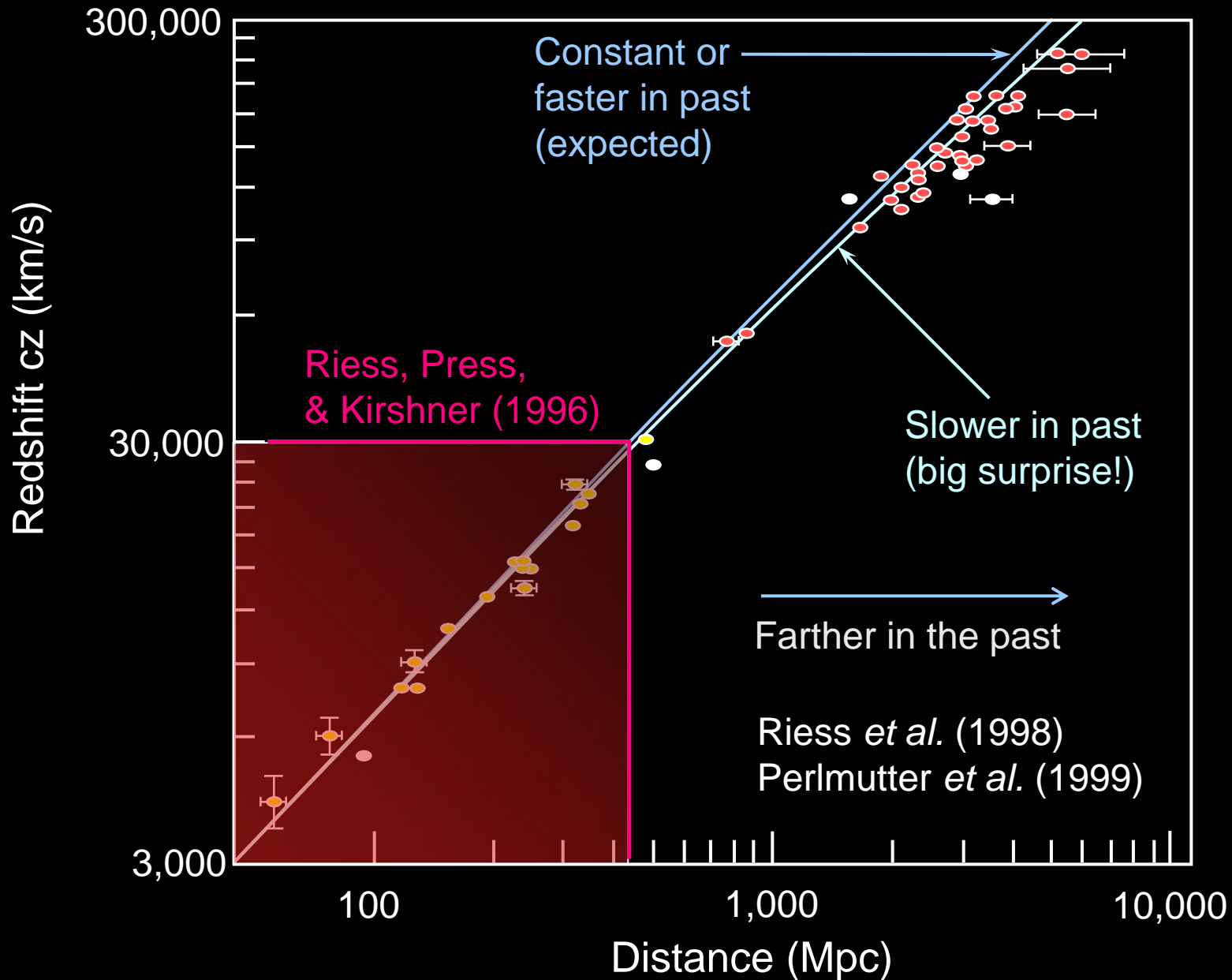
Hubble Space Telescope - ACS



NASA and A. Riess (STScI)

STScI-PRC04-12

Expansion history of the universe



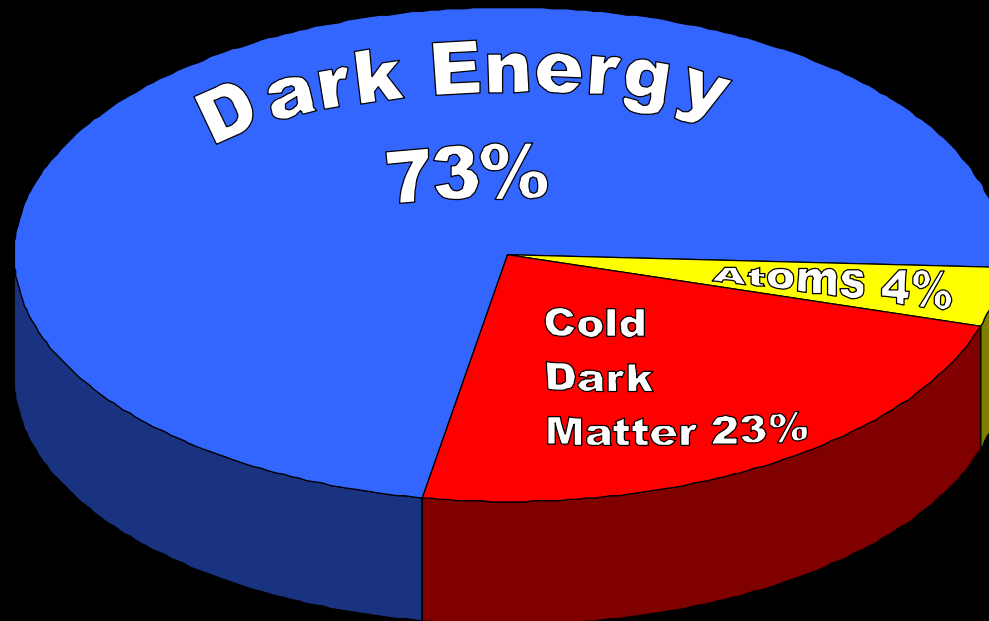
Some kind of energy (pressure) is responsible for accelerating the Universe of an unknown nature

“Dark Energy”



Based on the supernova observations, and other observations, we can estimate the energy content of the various forms of energy and matter in the Universe.

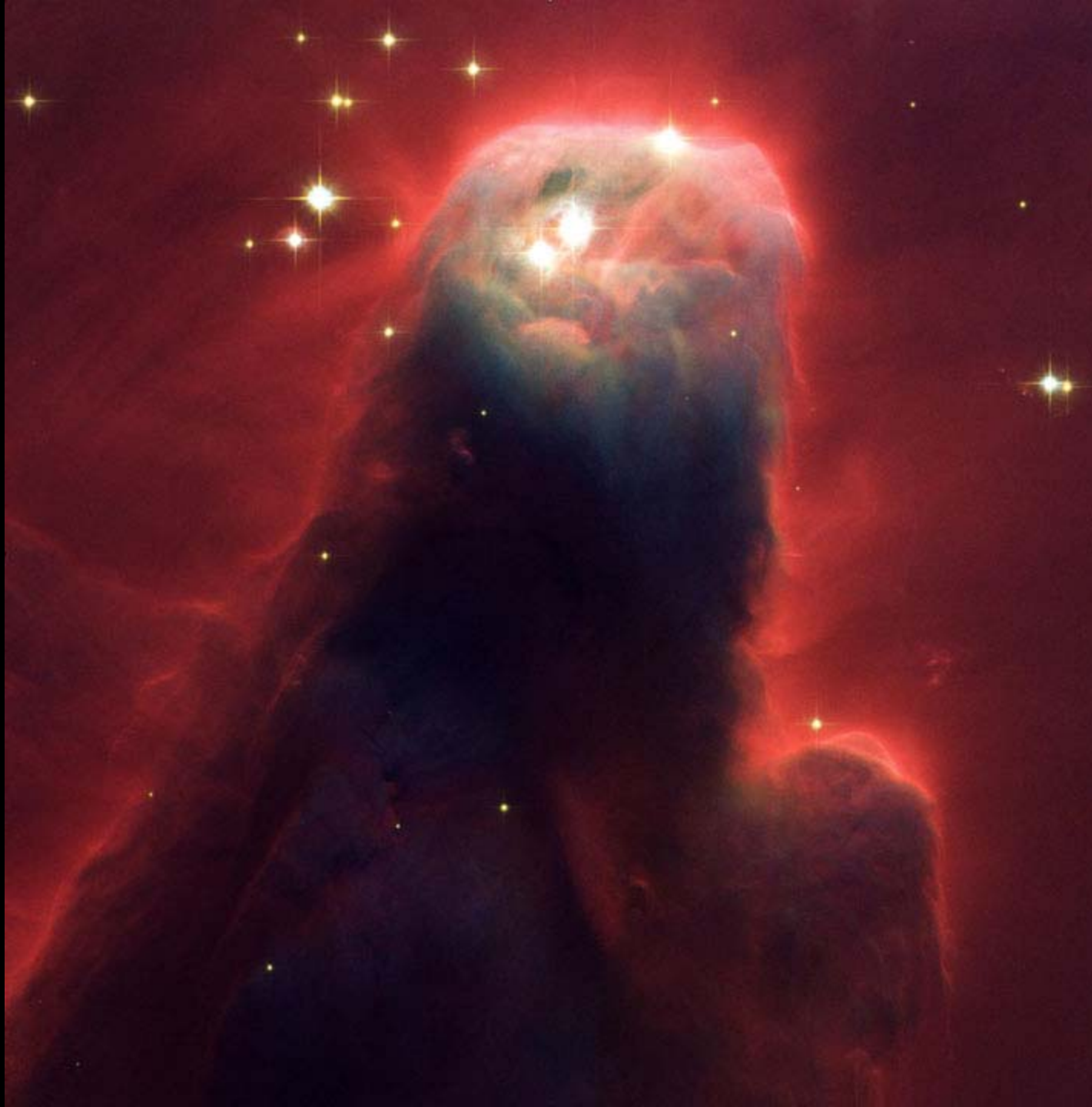
How much do we know about our Universe?



We don't know what 96% of the Universe is made of!









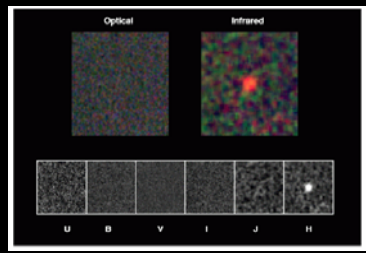
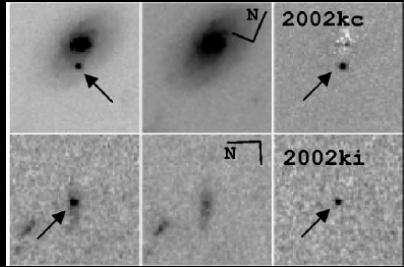
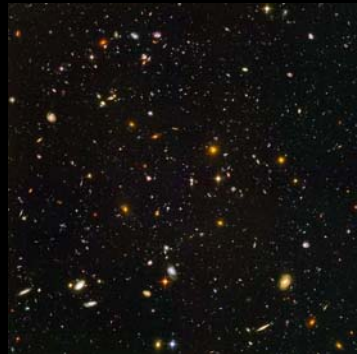


HUBBLE Will be at the Apex of Its Capabilities After SM4 in 2008

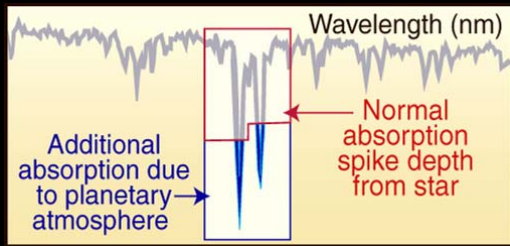
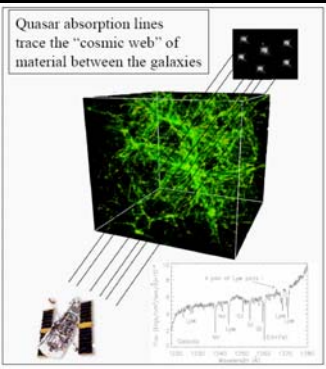
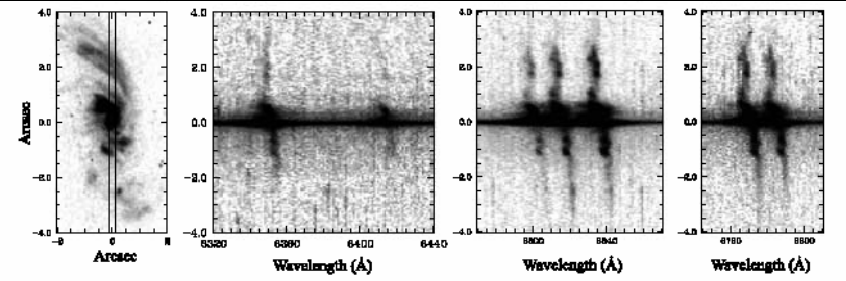


Batteries+Gyros+FGS = Sustained HST Lifetime

WFC3+ACS = Most powerful imaging ever



COS+STIS = Full set of tools for astrophysics



How much do Americans spend on NASA?

Exploration at what cost?



Much less than our annual
Spending on Beer or Pizza!



About the same as one family of 4
going to a feature film with
popcorn and drinks
(\$54 per taxpayer).



**Stay tuned for SM4, with
CU on board!**

