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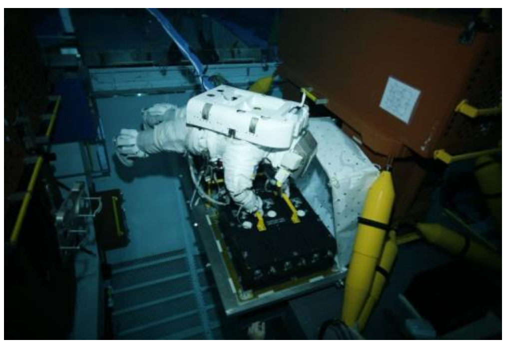
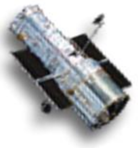
Operational Issues for Systems Engineers



Keith Walyus (441)

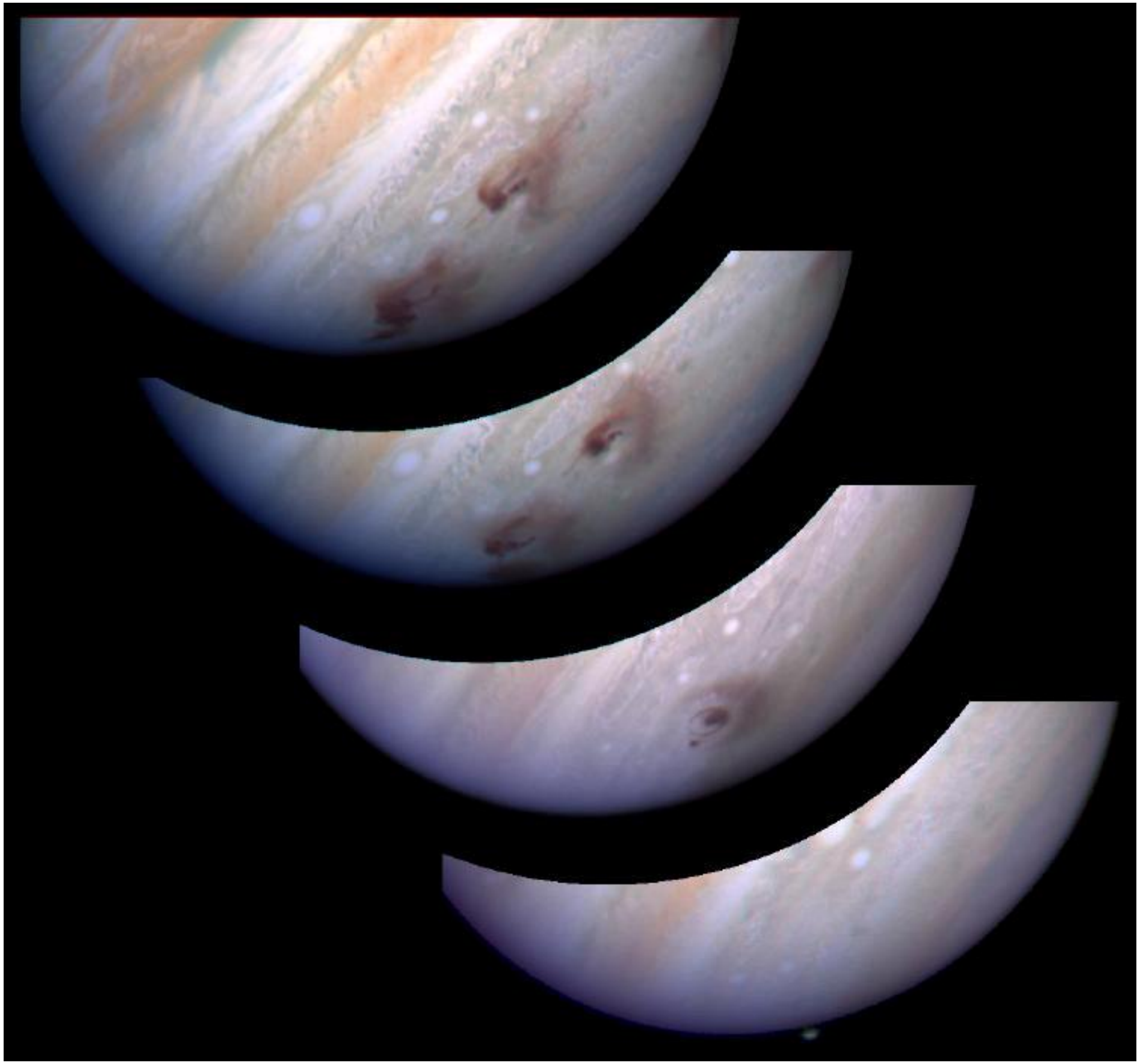
Jan 9, 2007



Agenda

- **Pre-Mission Concerns**
- **Operational Issues**
  - Small Missions
    - TRACE
  - Larger Missions
    - SoHO
    - HST
- **Gratuitous Pictures**

Comet Shoemaker-Levy Impact



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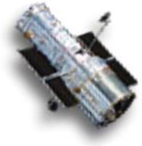

System Engineering Guidelines

- **Know your customer!**
  - Scientists/Public
  - Project Managers
  - Headquarters
  - Astronauts
  - And Many Others
- **Be flexible**
  - Operations means many different things to many different people
  - You'll be called on to fulfill many different roles as a system engineer
- **Good requirements and documentation are a key**
- **Bring operations personnel into the mission design early**

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Requirement Definition Begins Early

- **All proposals must include a section on mission operations**
- **Equally important in describing the mission operations is developing requirements tracebility matrix showing the flow down to operations**
  - Usually driven by the science requirements

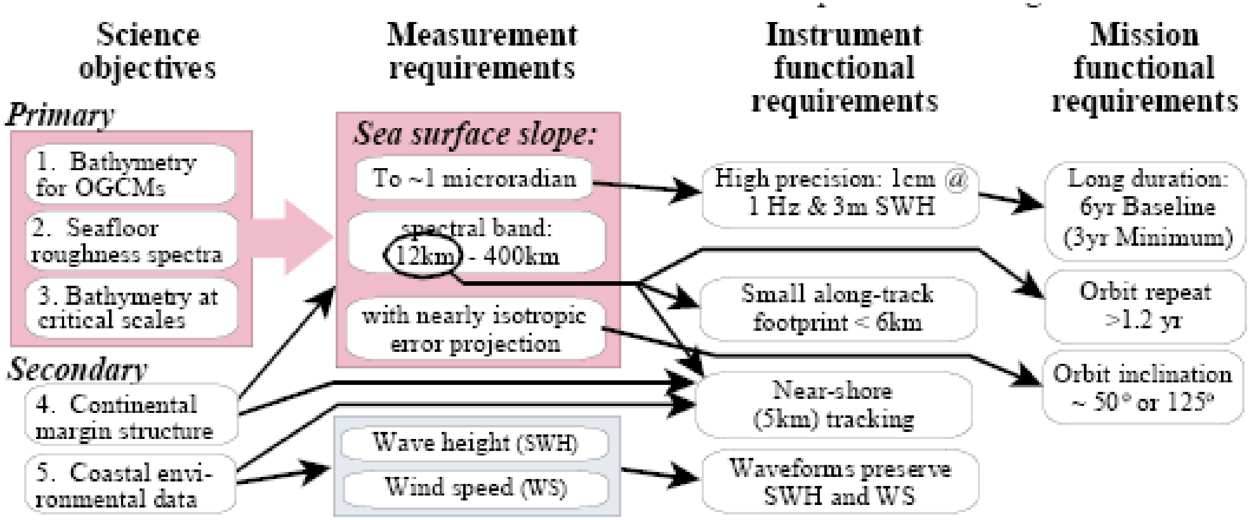

Figure F-9. Science Traceability Matrix

- **One level deeper for the requirements would be useful, including such items as data rate, downlink frequency, etc.**

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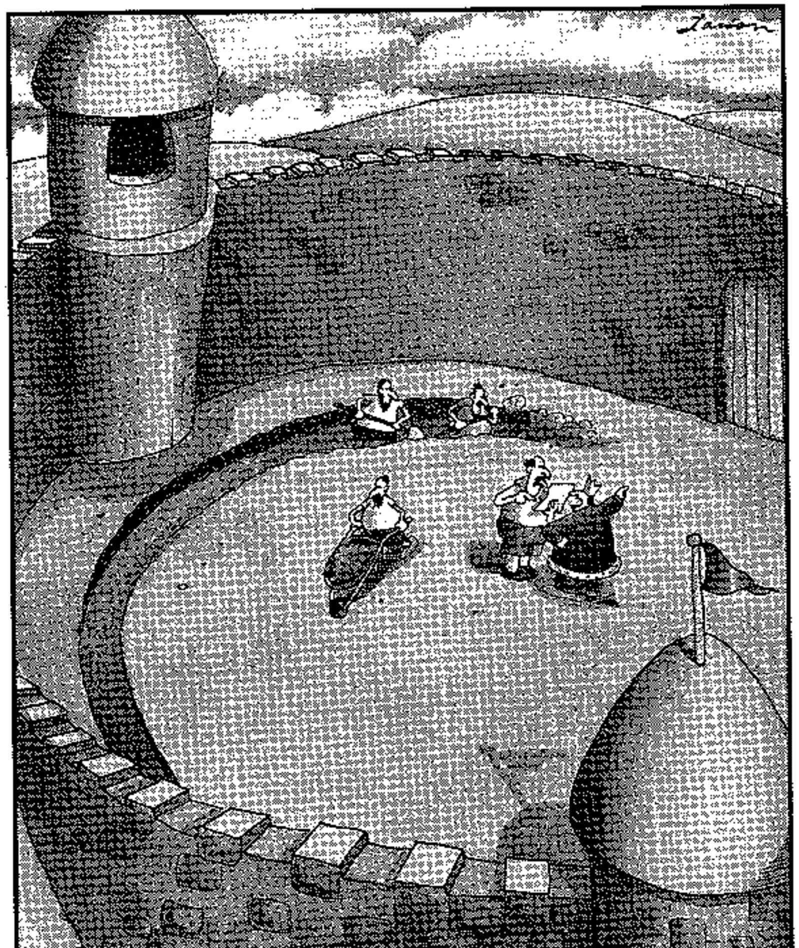
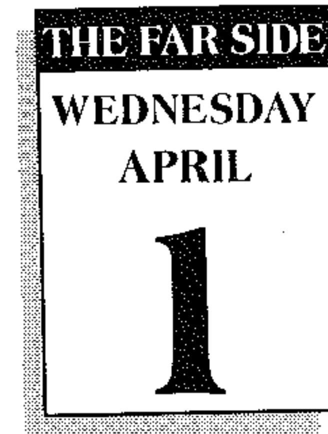
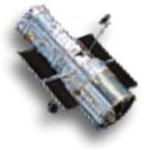
Unclear Requirements Can Have Disastrous Consequences



Suddenly, a heated exchange took place between the king and the moat contractor.



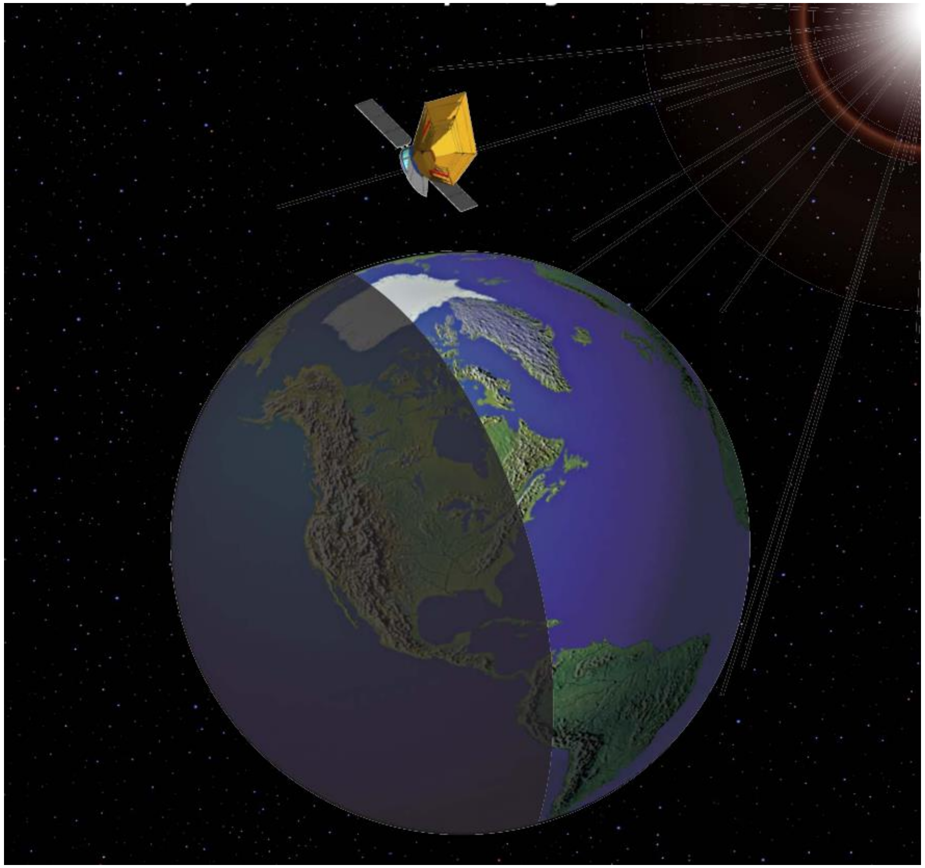


Well-Defined Requirements Will Enable a Clearer Operational Design

- **As part of your study, trades will need to occur in your requirements. Various reasons effect the original mission concept**
  - Technical issues
  - Budget issues
  - Scheduling issues
  - A combination of all of the above
- **A robust set of descope options will be required for any proposal**
  - Know your full mission success and minimum mission success requirements
- **Because operations are at the end of the mission cycle, most changes flow downhill to affect operations**
  - A good traceability matrix quickly allows an systems engineer to understand the impacts
  - Involving operations personnel from the beginning allows for an early check on any trades
- **Outstanding operational support for proposals is available in Code 581**

Exceptions Exist to Every Rule

- **For the ST9 Large Space Telescope effort, “science” requirements were not well defined**
  - Mission is a technology mission
  - Some of the requirements and hence the operational concept were driven by the capability of the flight system
  - Team used the integrated modeling effort to derive some of the requirements
- **System engineers will need to be flexible regarding the development of requirements**



Large Space Telescope Proposal Cover

Operations Personnel Can Make a Significant Contribution During Phases A-D

- **During the last 10 years, mission teams have evolved from having separate development teams and separate operational teams to having ops personnel more involved in the development effort**
  - Having a common ground system has been a key enabling technology
  - Operations personnel are now being included in mission teams from the beginning
  - Operational engineers are participating in I&T and assisting discipline specific engineers
- **Philosophy change provided for a huge improvement in efficiency**
- **SMEX and MIDEX teams were some of the first here at GSFC to incorporate this philosophy**

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Operations Personnel Can Make a Significant Contribution During Phases A-D (cont)

- **Operational engineers provide an excellent interface between science teams and the Project (use them!)**
  - Look upon the operational engineers as assistant systems engineers
  - They will eventually be responsible for the spacecraft
  - Ops engineers will already understand the capabilities and limitations of the ground system and the ops concept
- **Operational engineers are exceptionally important for that transition from developing hardware to developing an operational spacecraft**
  - Ex. Cmd and tlm database definition versus operational reality
- **Spend the time to adequately develop constraint and restrictions documents**
  - The operations personnel will be living with them for years, and very possibly longer than anyone expected!
  - The original engineering team will be hard to locate 17 years after launch

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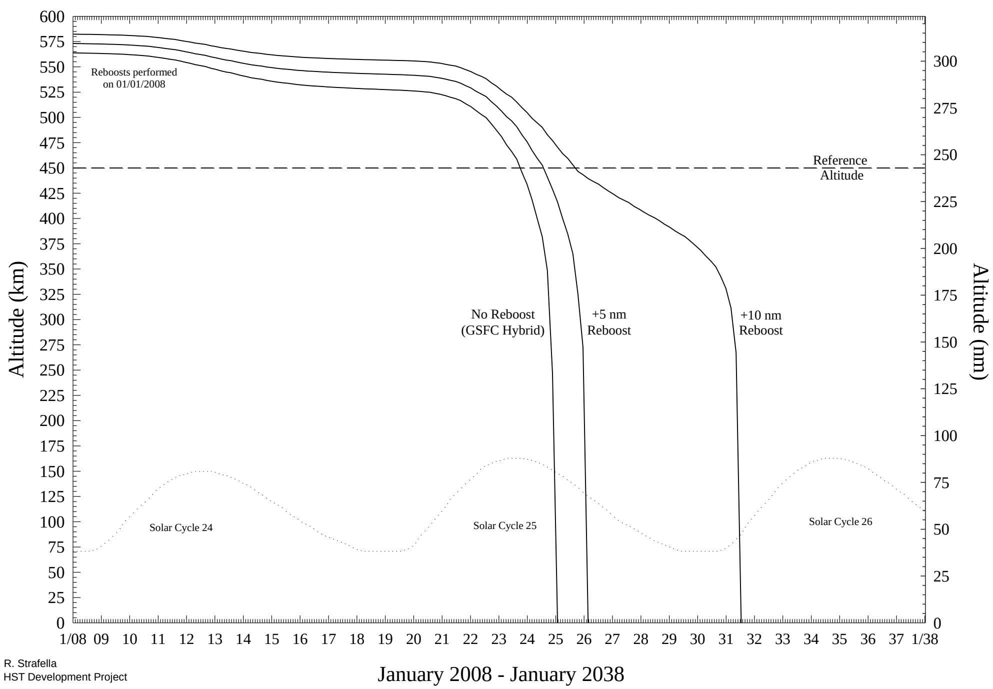
Healthy Tensions Exist Between Operations and Development Teams

- **Development teams will always need more time to prepare the spacecraft for launch**
- **Operations personnel will always want more time to test procedures and scripts versus real flight hardware**
- **Project management must balance these sometimes competing claims**
- **Key to success is adding operational tests to the project schedule**
- **Look for opportune times when other flight procedures can be tested (e.g., during plateau transitions of thermal vac)**
  - Great place to exercise the timeline

HST Orbit Decay and Re-boost

- **All reasonable forecasts indicate HST will “fly over” solar Cycle 24**
  - For HST to re-enter in Cycle 24 it would have to approach the intensity of the most active cycle since 1750
- **Outcome of conservative GSFC Flight Dynamics analysis, using recommended "hybrid" solar flux approach, is HST unlikely to re-enter before 2025, even without a reboost**
  - Expected Shuttle servicing mission propellant margins will allow reboost that gives years of additional HST orbit lifetime



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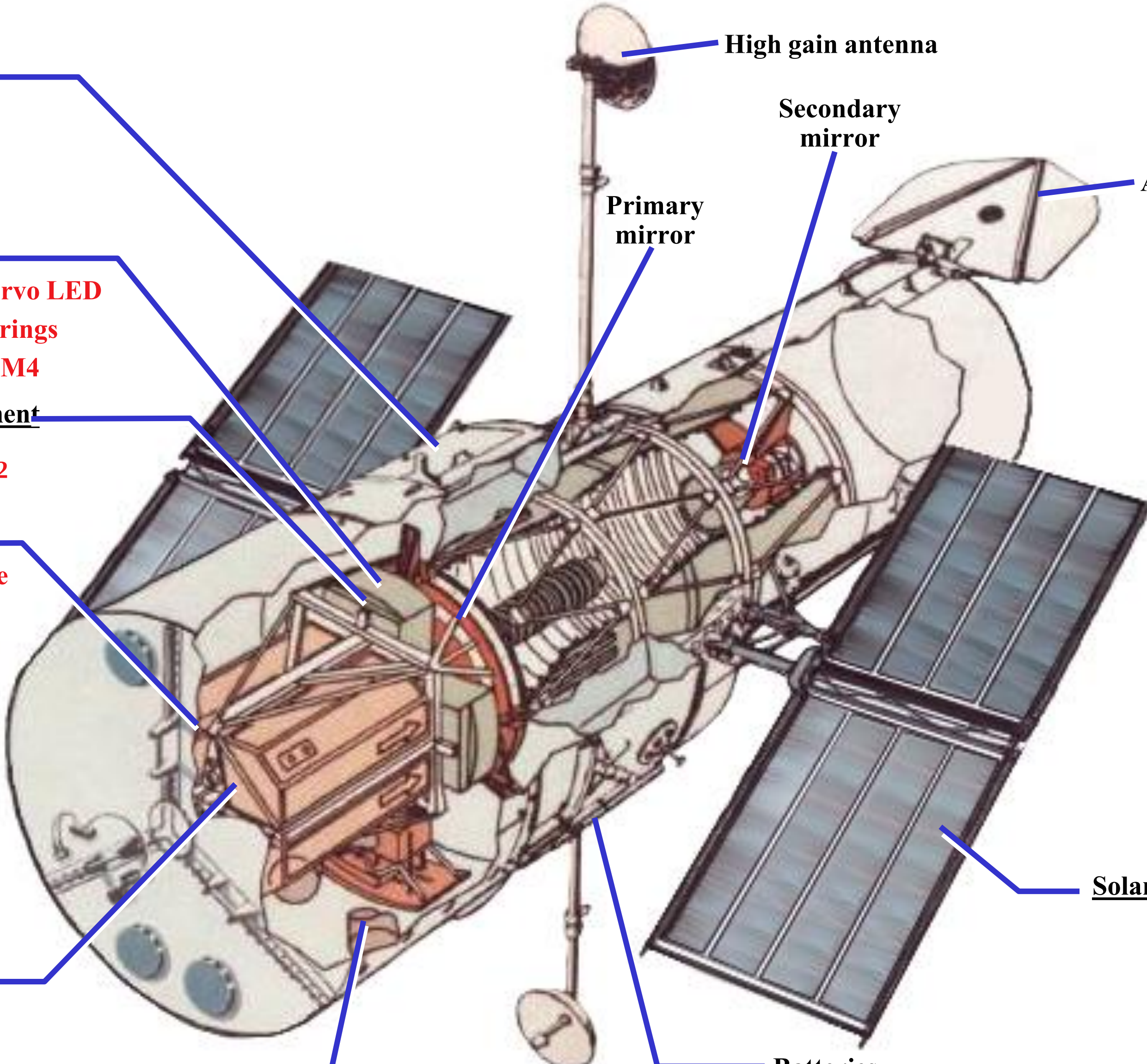
HST Spacecraft Health



Equipment Section
- Degraded MLI: Install NOBLs on Bays 5, 7, 8 in SM4
- Add Over Voltage Protection Kit

Fine Guidance Sensors
- FGS2R: degrading servo LED
- FGS3: degrading bearings

replace one FGS on SM4

Radial Scientific Instrument

-WFC3 will replace WFPC2

Aft Shroud
- Install a Soft Capture Mechanism

Axial Scientific Instruments
- STIS, failed 8/04
- Will be repaired SM4
- COS will replace COSTAR

Rate Sensor Units
- Gyros 3 and 5 failed: replace all 6 gyros on SM4

High gain antenna

Secondary mirror

Primary mirror

Aperture door

Solar Arrays

Batteries
- Charge capacity trending downward; replace all 6 batteries on SM4

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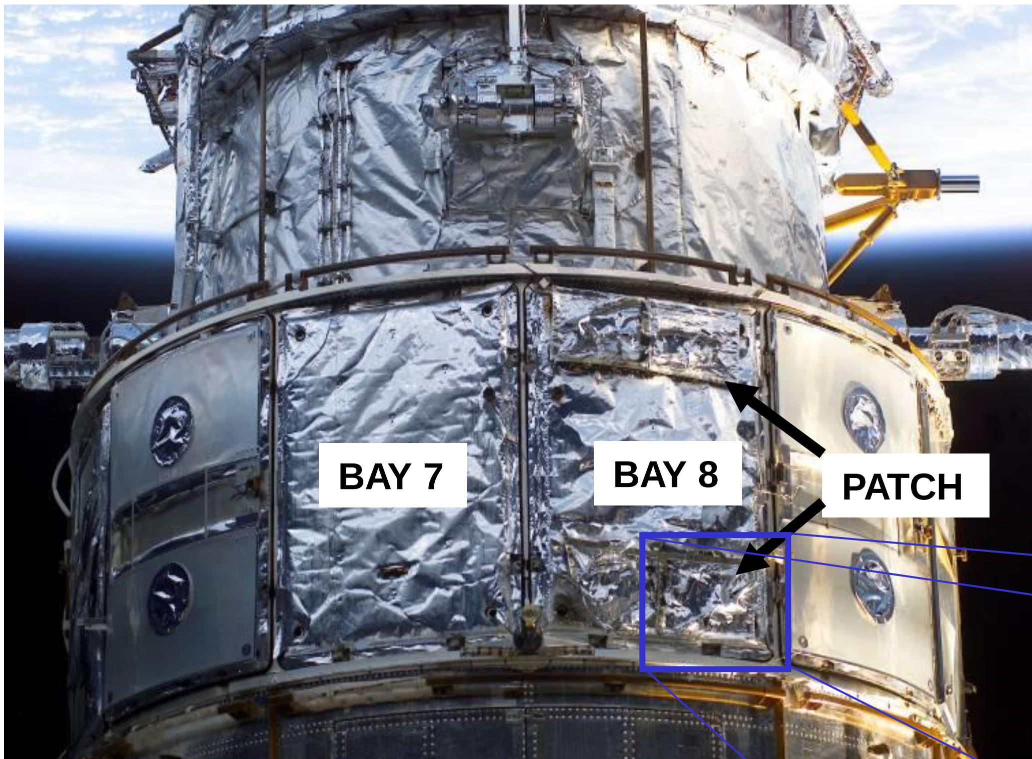
HST's Science and Life Limitations

- **Availability of gyros drives HST science life**
  - Has no impact on ability to service Hubble
  - Switched to Two-Gyro Science operations August 29, 2005
  - Predictions indicate 2-gyro science likely until mid 2008
    - Work initiated on One-Gyro Science Mode
  - For longer missions, the ops concept will evolve dramatically over its lifetime
- **Declining observatory battery system charge capacity drives HST life on-orbit**
  - Determines Hubble availability to be serviced
  - Life extension activities in the area of battery charge management indicate positive results
  - Latest measurements predict battery useful life has increased from late 2009 into mid-2010
- **Degraded MLI on Bays 5 and 8 potentially accelerates aging of critical avionics**
  - SSR and MAT (Bay 5) and PSEA (Bay 8) approach thermal red limits every hot season
    - Understanding the genesis of these numbers is critical
  - Installation of NOBLs on Bays 5 & 8 a priority for SM4
  - Installation of NOBL on Bay 7 is highly desired

Degraded MLI on Bays 5, 7, & 8



S109E5589

Bay 5

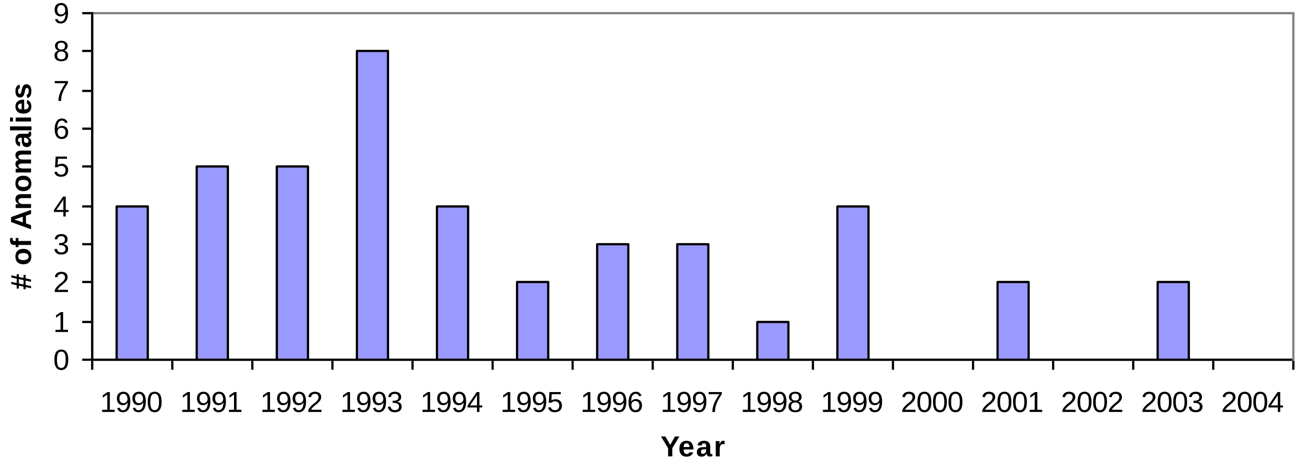
Radiators

(SM3B Survey)

Avionics System

- Hubble is not “dying”
- Hubble contains known wear-out items that need to be replaced from time to time
- The rate of random failures in other Hubble systems (“avionics”) has decreased dramatically since the first 5 years of Hubble’s Mission
- Hubble is well past “infant mortality”, and as repair and maintenance needs have arisen they have been addressed in the prior four Servicing Missions
- Hubble is probably more reliable and robust as a spacecraft than a newly launched observatory could be because (as shown below) all of the infant mortality anomalies have already occurred
- The avionics failure rate during the last 5 years of HST operations is 73% lower than the failure rate averaged over the entire 14.6-year mission (through 2004), and 86% lower than during the first 5 years of operation

HST Avionics Failure History

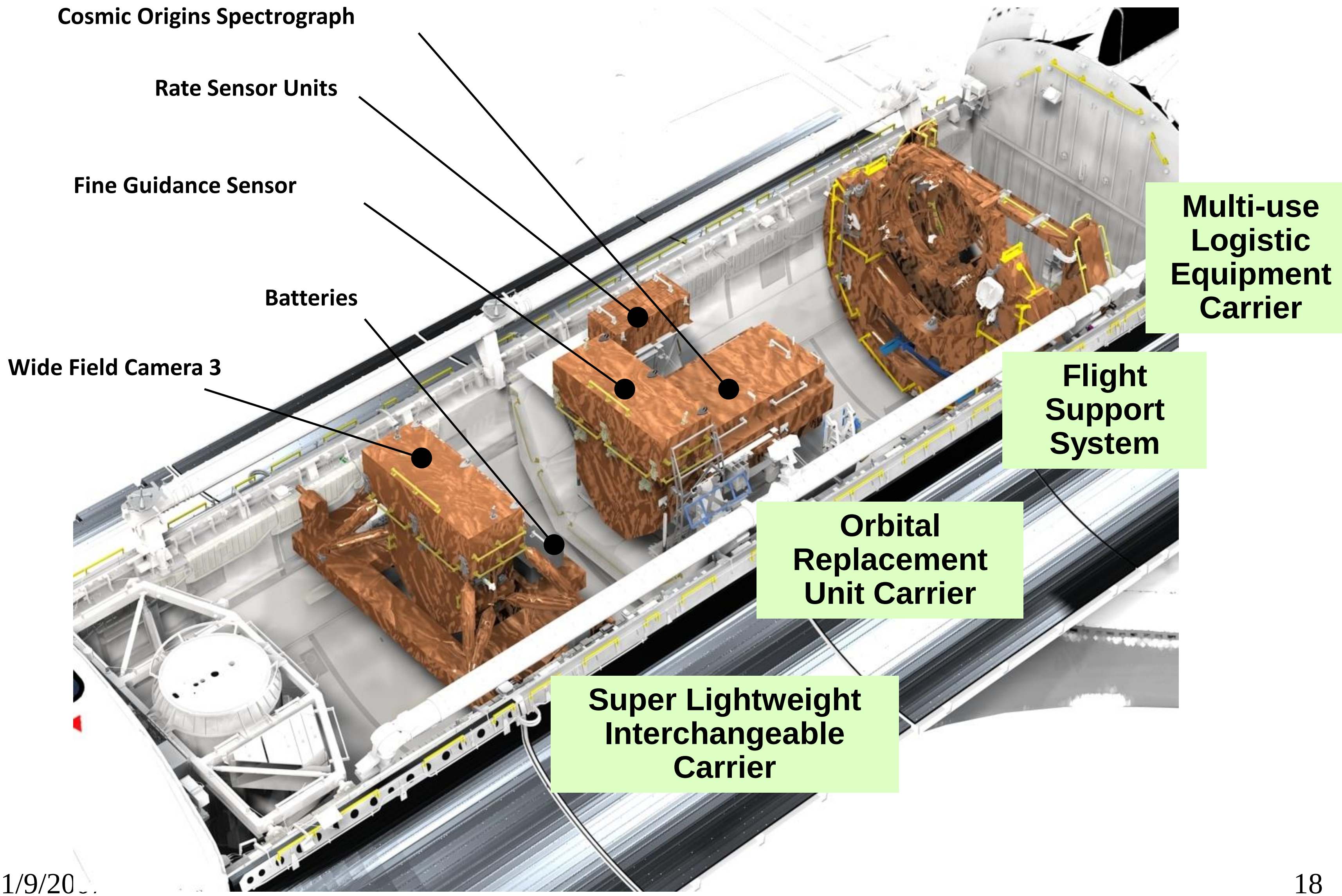


Assumptions for SM4

Program planning for SM4 assume the following:

- **Launch Readiness Date (LRD) is December 6, 2007**
  - Expected to change soon to September 2008
- **Shuttle mission cargo manifest includes**
  - HST life extension hardware
    - Rate Sensing Units (3 RSUs, 6 gyros total)
    - Batteries (2 modules; 6 batteries total)
    - Fine Guidance Sensor (FGS)
    - New Outer Blanket Layers (NOBLs, for Bays 5, 7, and 8)
    - Over-voltage Protection Kit (OVP)
  - HST science upgrades
    - Wide Field Camera 3 (WFC3) (replace WFPC2)
    - Cosmic Origins Spectrograph (COS) (replace COSTAR)
  - Science restoration
    - Space Telescope Imaging Spectrograph (STIS) repair is on a best efforts basis and install hardware to help cool STIS
  - Soft Capture and Rendezvous System
  - Carriers, protective enclosures, and Flight Support System (FSS)
  - Crew Aids and Tools
- **5 EVAs in a 11 days mission with rendezvous at 304 n. mi.**

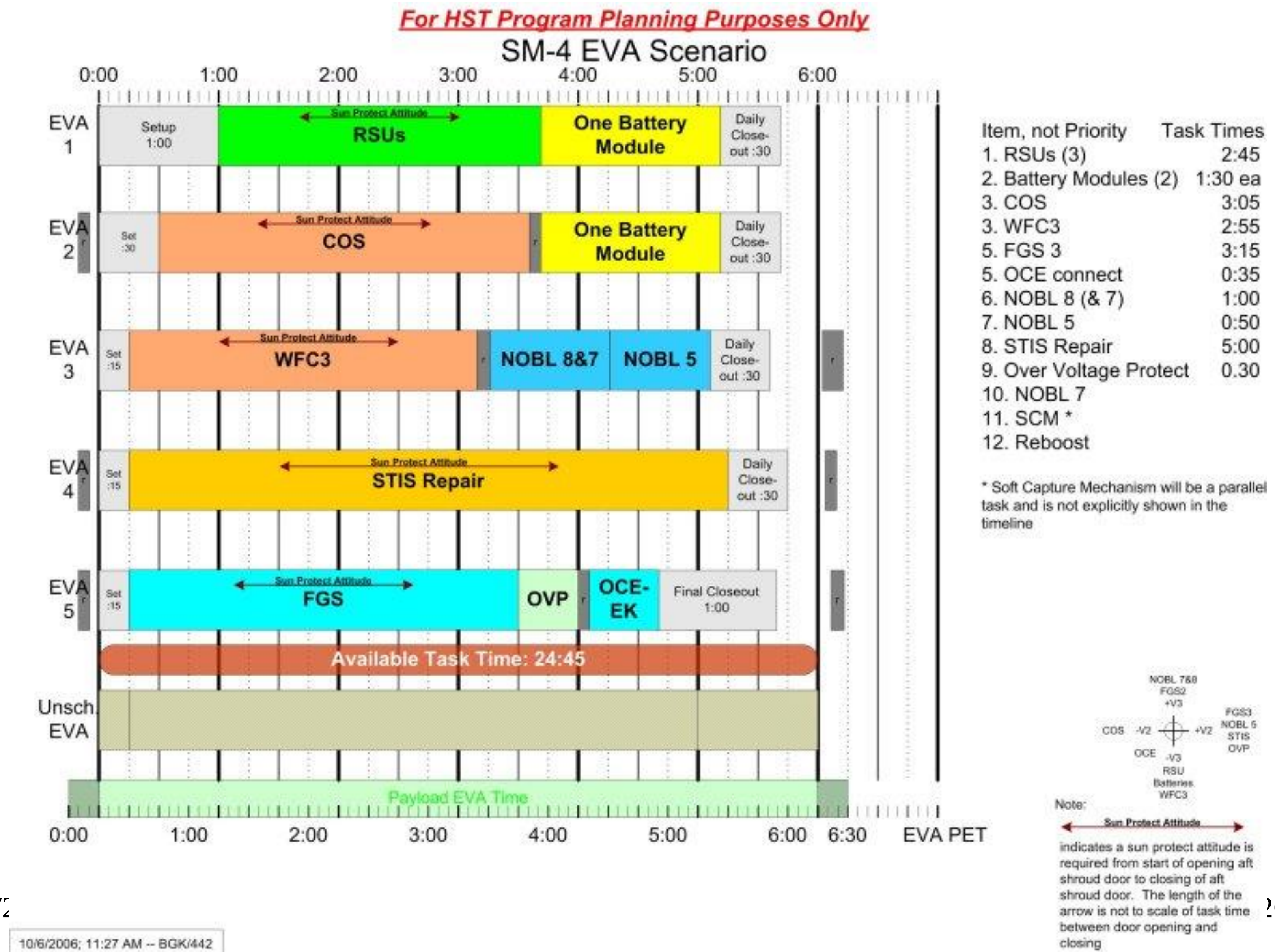
HST Servicing Mission 4 (SM4) Configuration
(Preliminary)



Complexity of the Mission Timelines will vary by the complexity of the mission

- **All missions will require a mission script or timeline**
- **Timeline will synch various activities into a coordinated plan**
  - Spacecraft commissioning plan, communication view periods, critical commands
- **Timelines must be modular**
  - Timelines may not (and probably won’t) follow exactly the initially well-planned and well-rehearsed timeline
  - Team must be well trained to re-arrange the mission timeline
  - Must be exercised during contingency training (more about this later)

SM-4 EVA Scenario
(the top level)



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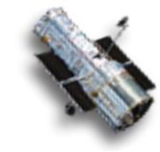
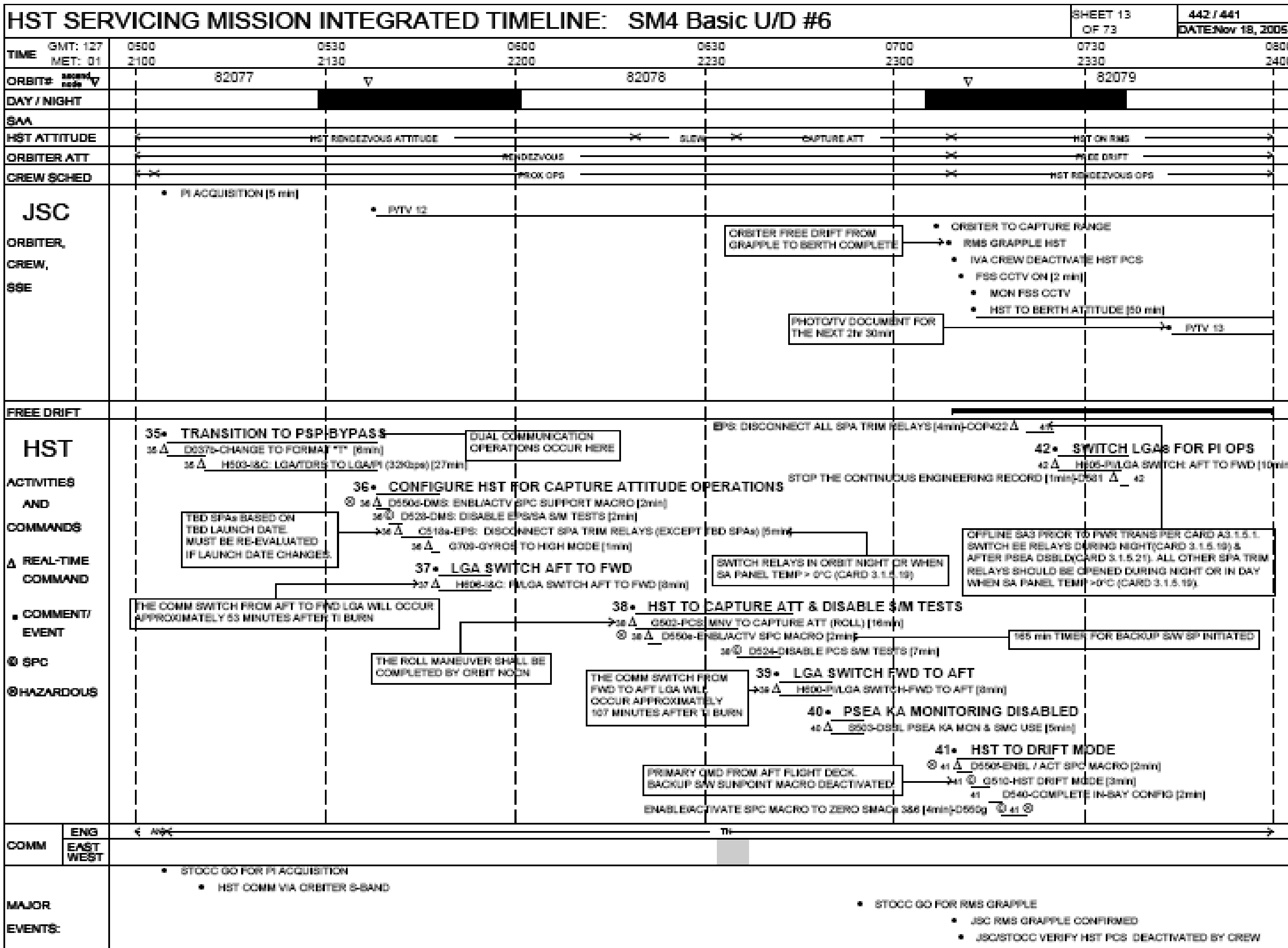


Servicing Mission Integrated Timeline (SMIT)

(the next level down)



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HST Command Plan

(the lowest level)

SEQUENCE # 41
MET: 01:23:10
DURATION: 14min
SEQUENCE TITLE: HST TO DRIFT MODE

HST FOURTH SERVICING MISSION COMMAND PLAN
MAY 5, 2005 SM4 BASIC UPDATE #4
RELEASED OCTOBER 3, 2003
Revised 09/26/03

TIME COMPLETE	STEP#	PROC	ACTION	TLM	ΔTIME (min)	AD	DESCRIPTION
			NOTE: IF RMS GRAPPLE IS SUCCESSFUL, THE SHUTTLE CREW WILL SEND AN AFT FLIGHT DECK COMMAND TO PLACE HST IN DRIFT MODE. IF THE AFT FLIGHT DECK COMMAND FOR DRIFT MODE IS SUCCESSFUL THERE WILL BE NO NEED FOR STOCC TO ENABLE HAZARDOUS CMD GROUP 6 OR IMPLEMENT CCL PROC "XSERMSPC 7". NOTE, STOCC WILL STILL PERFORM VERIFICATION FOR HST TO DRIFT MODE.				
BACKUP-->	*41-1*	--	*PAYLOAD OFFICER TO STOCC OPS: GO/NOGO FOR COMMAND HST TO DRIFT MODE* *STOCC CONTROL TO HOUSTON DATA : ENABLE HAZARDOUS COMMAND GROUP 6 FOR UPLINK*	*TN*		*D550f*	
BACKUP-->	*41-3*	*XSERMSPC 7* **** HAZ CMD GRP 6 **** *(THIS STEP IS OPTIONAL)*	*DMS: VERIFY TIMED PROCESSOR ACTIVATED FOR EXECUTING COMMANDS TO PLACE FSW AND PCS IN DRIFT MODE.* *P D486, TAB D2: D4CNXT1 = NOT EQUAL TO 0 DTIMSPCL = ACTV DTIMSPCR = NO WAIT*	*TN*		*D550f*	*HST DRIFT MODE IS COMMANDED VIA NOMINAL AFD OR BACKUP STOCC COMMAND, JUST AFTER RMS GRAPPLE INITIATING TSPC MACRO EXECUTION. DRIFT MODE SHOULD NOT BE COMMANDED PREMATURELY, ELSE UNDESIRABLE VEHICLE RATES COULD RESULT DUE TO ENVIRONMENTAL TORQUES. CONVERSELY, DRIFT MODE SHOULD BE COMMANDED SHORTLY AFTER RMS GRAPPLE; HOWEVER EXCESSIVE WHEEL SPEEDS COULD RESULT AS THE RWA'S ATTEMPT TO TORQUE IN OPPOSITION TO THE RMS, IF DRIFT MODE IS NOT COMMANDED.*
BACKUP-->	*41-4*	--	*STOCC CONTROL TO HOUSTON DATA : DISABLE HAZARDOUS COMMAND GROUP 6.*	*TN*		*D550f*	
	41-5	--	STOCC OPS TO SMM AND PAYLOAD OFFICER: BACKUP S/W SUNPOINT MACRO HAS BEEN DEACTIVATED.			G510	

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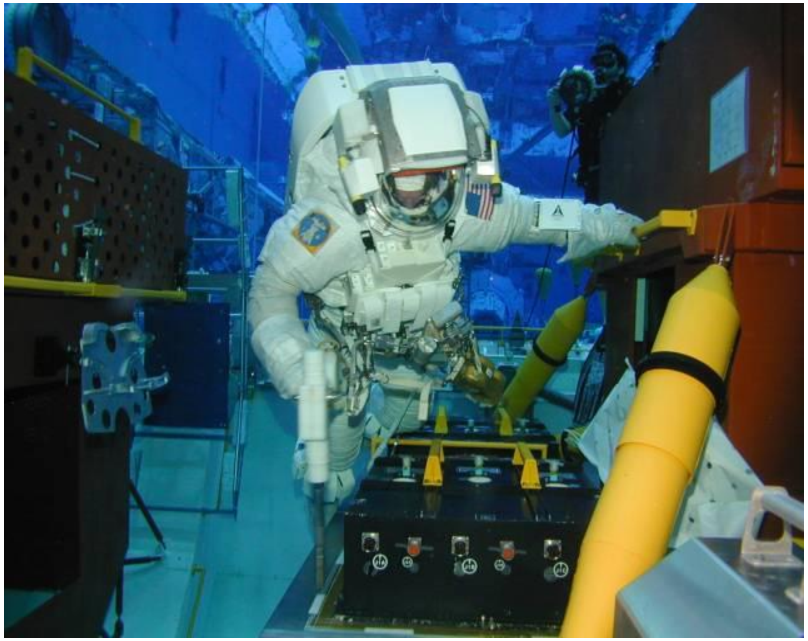
Timeline needs to drill down to the level of commanding!

HST Servicing Provides Capabilities to HST and Challenges

- **Both of the original battery modules will replaced on the next Servicing Mission**
- **Due to scheduling limitations, one module will be replaced on each of the first 2 days**
- **Batteries will receive their final charge on the pad prior to launch**
  - State of Charge (SOC) will gradually drop
  - Batteries will be recharged once on orbit and installed
- **Team must still protect for a rapid deploy scenario, regardless of the SOC and battery configuration**
  - Flight rules and contingency procedures are required to protect for the various



Removing the new batteries from the Orbiter in the NBL

COS Overview

- **The Cosmic Origins Spectrograph (COS) is a fourth-generation instrument to be installed on the Hubble Space Telescope (HST) during Servicing Mission 4**
- **COS is designed to perform high sensitivity, medium- and low-resolution spectroscopy of astronomical objects in the 1150-3200Å wavelength range**
- **Science Goals:**
  - Large-structure, the Intergalactic Medium, and origin of elements
  - Formation, evolution, and ages of galaxies
  - Stellar and planetary origins and the cold interstellar medium

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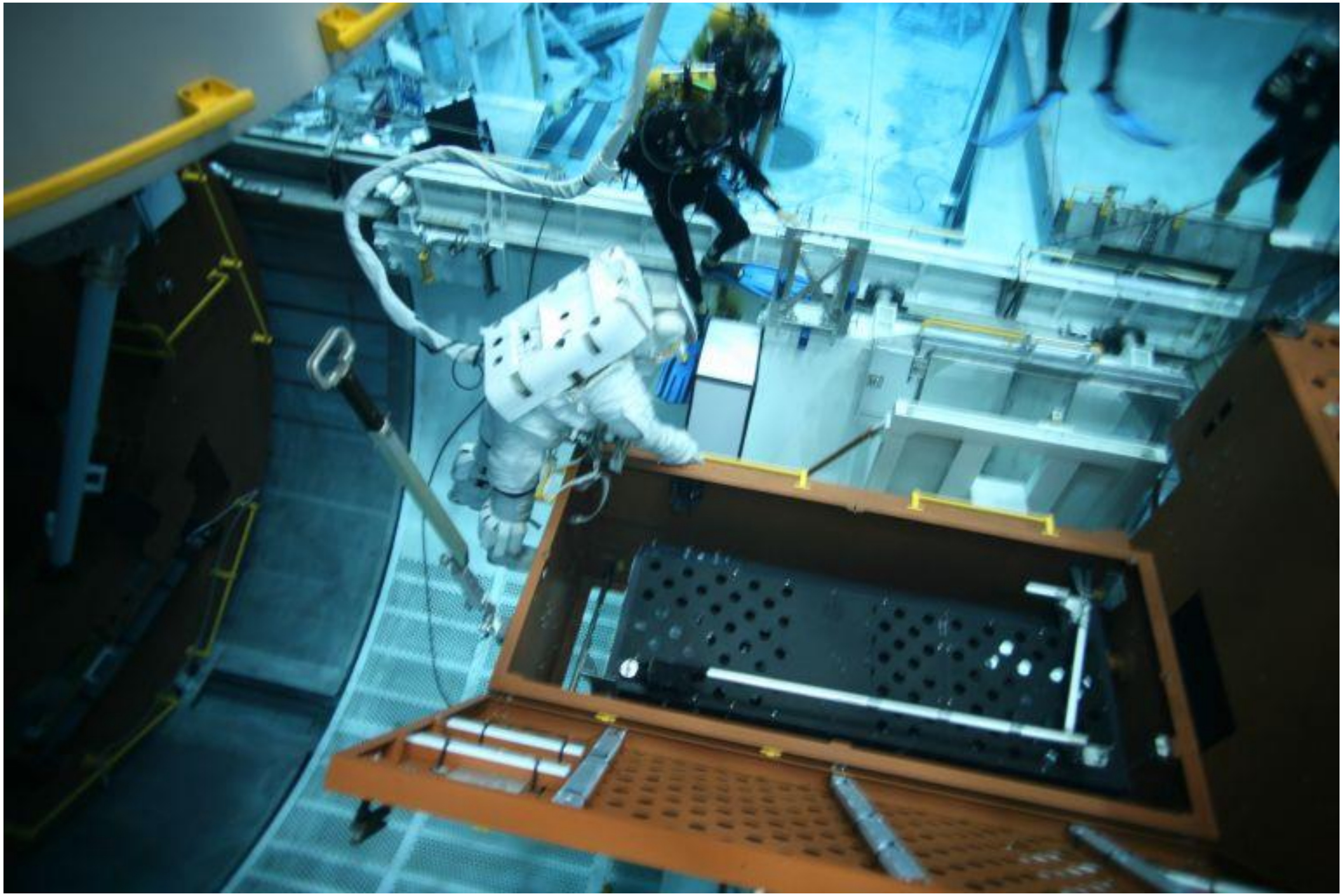
COS Installation



Astronaut opening the carrier lid to gain access to COS

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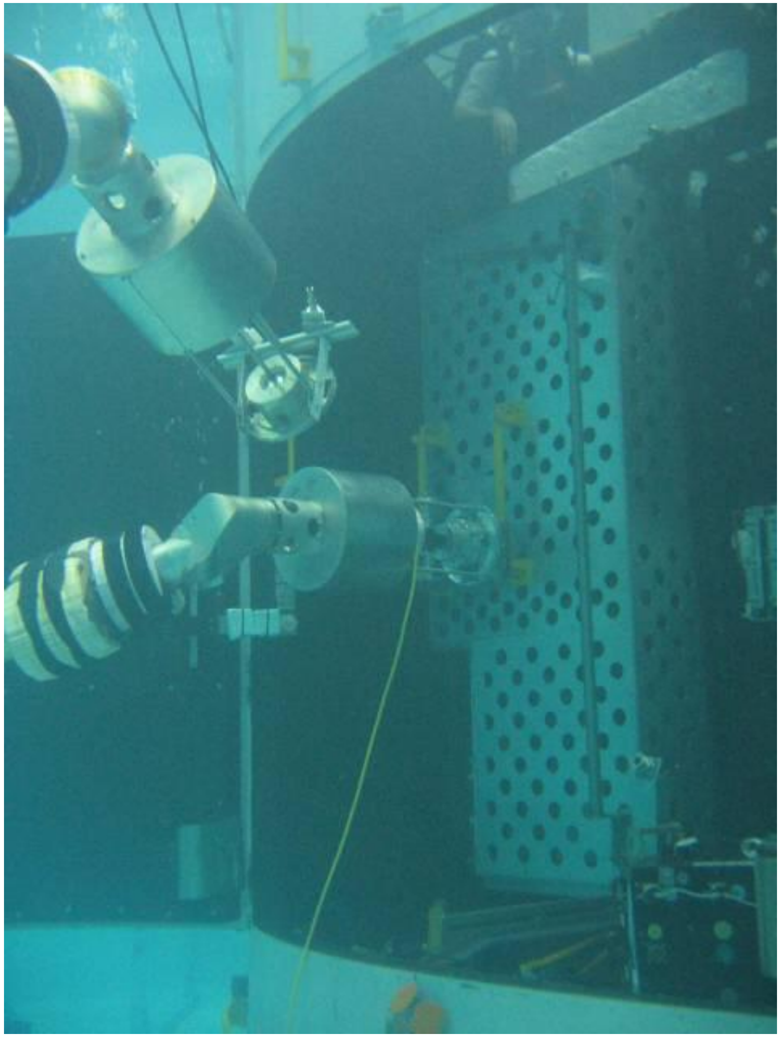
You Never Know Where Systems Engineering and Operations Will Take You

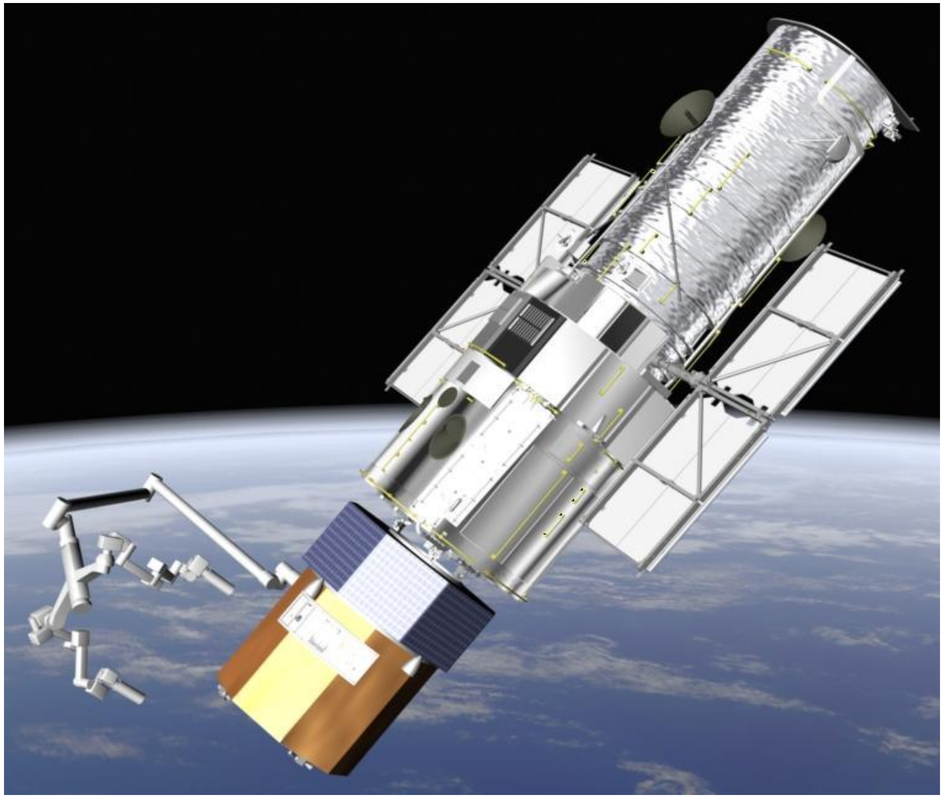
- **HST Project assessed conducting a robotic servicing mission**
- **A robotic servicing mission presents unique challenges**
  - Interfaces were designed for human compatibility
  - Delays and variability in transmission time for robotic operators
  - Lighting is uncertain
  - Time scale of operations is dramatically different
  - The realm of contingency issues is much larger
- **With the maturing of robotic technology, robotic missions will play a greater role in the future**



Robotic Installation of COS

Always need to look for the future

- **Each ORU (orbital replacement unit) or ORI (orbital replacement instrument) is a microcosm of the larger mission**
  - Requirements need to be defined
  - Operational concept required. Need to assess:
    - Impact on the Servicing Mission
    - Impact on nominal operations
    - Impact on safing operations
  - Impact on future missions (HST still must be deorbited)



Concept of Hubble Robotic Servicing Mission

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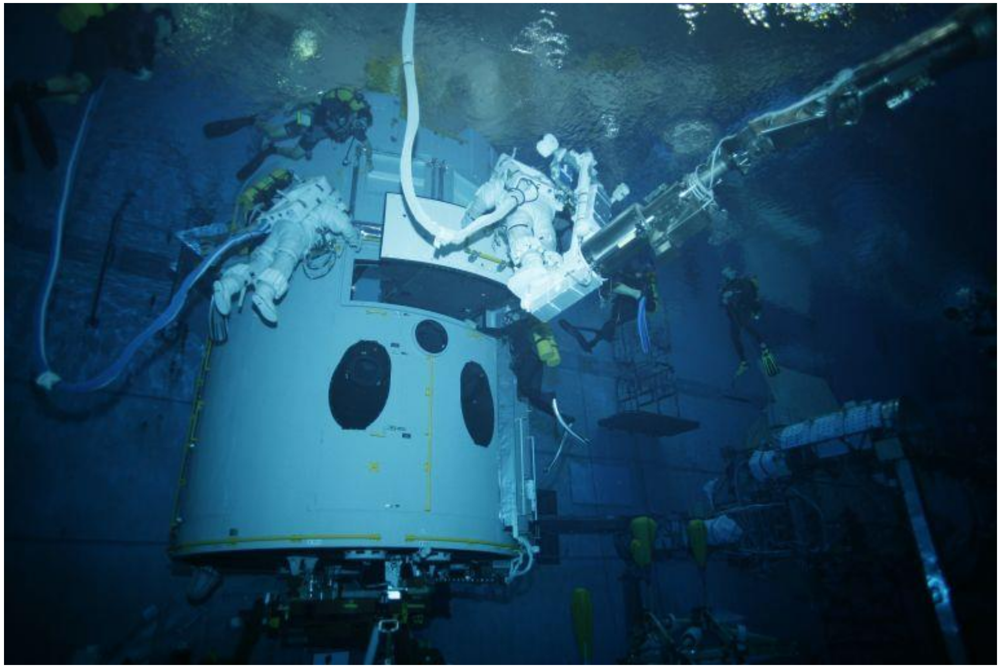
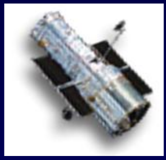
WFC3 Changeout

- **WFC3 will ensure an imaging capability through end of HST mission**
  - Replaces WFC2 and is complementary to ACS
  - Provide panchromatic coverage over a wide field
    - Widest spectral coverage of any HST instrument
    - 200-1000 nm in UVIS channel and 850-1700 nm in IR channel

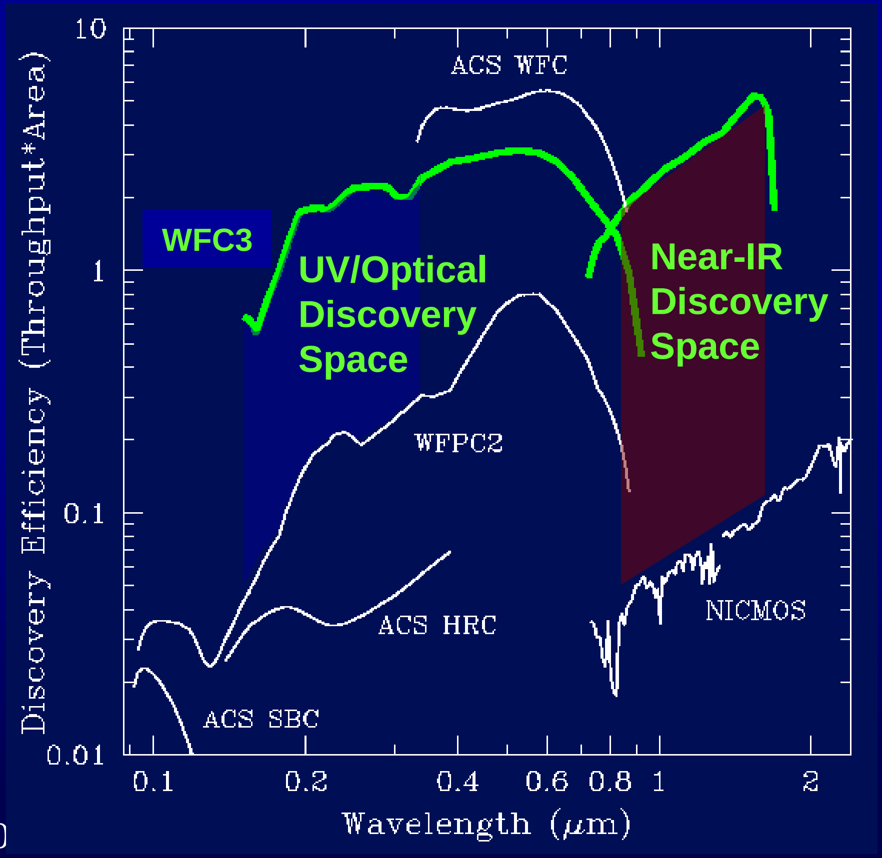


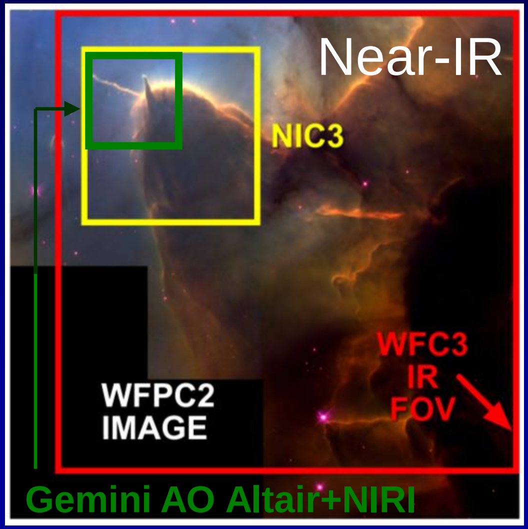
Installation of WFC3 at NBL

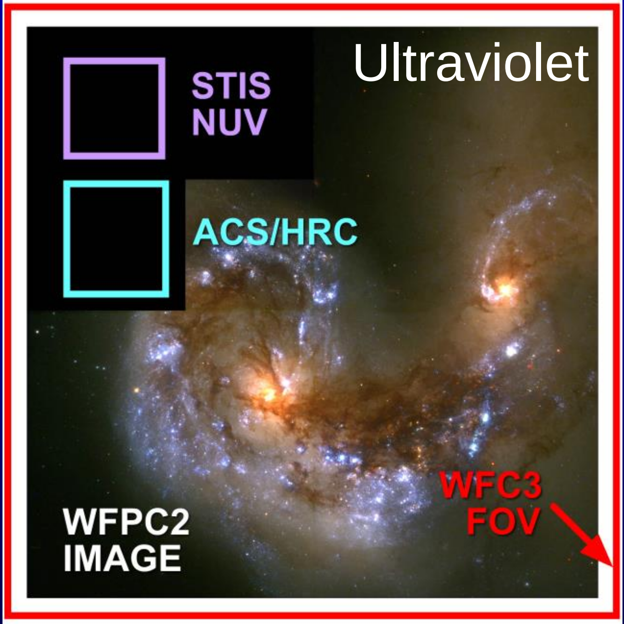
Wide Field Camera 3



- Capabilities
  - **Imaging from 2000 Å to 1.7 μm**
  - **Slitless spectroscopy**
- Huge improvement in near-UV, near-IR imaging







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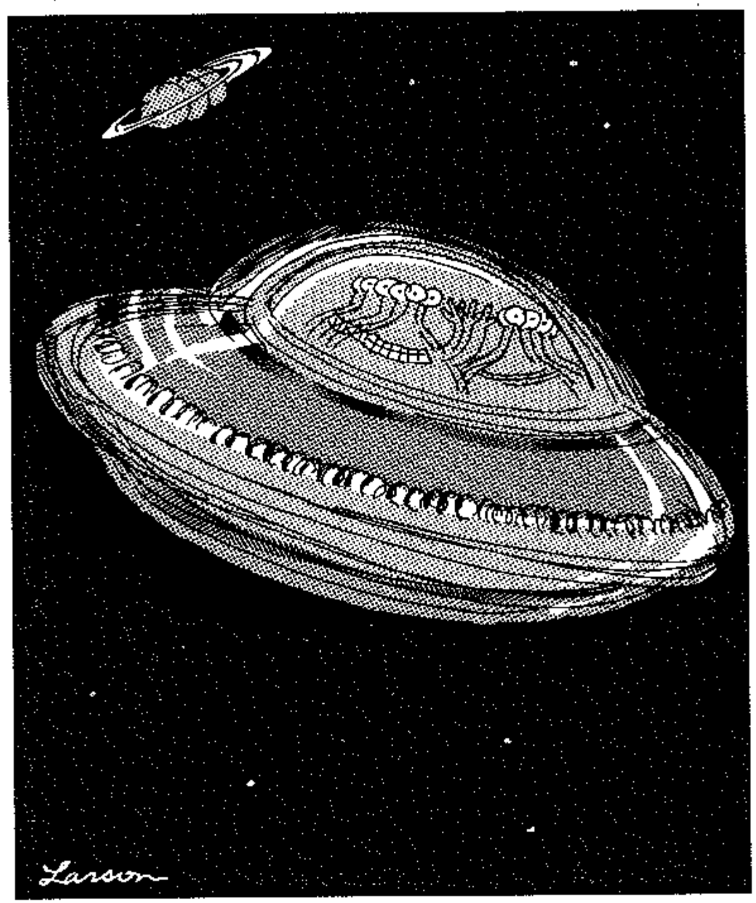
Original Hubble Optics Although Excellent Still Needed to Be Corrected



Another photograph from the Hubble telescope

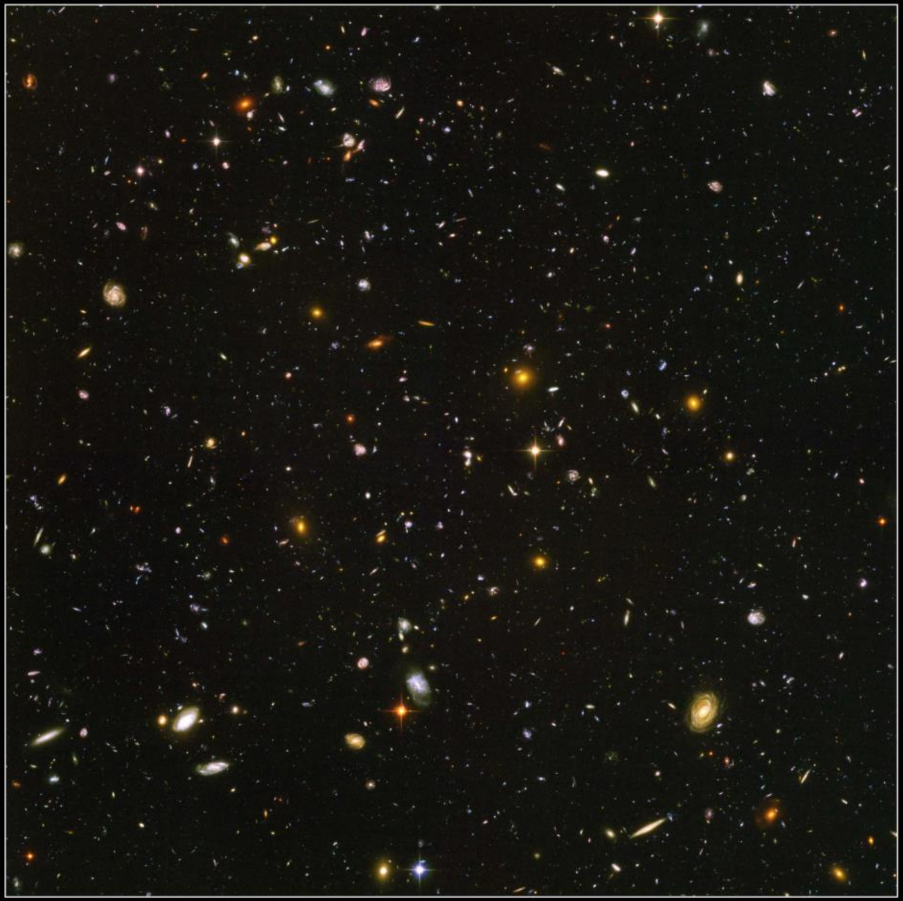
THE FAR SIDE

APRIL

8

THURSDAY

Hubble Ultra Deep Field Survey



Hubble Ultra Deep Field
Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, S. Beckwith (STScI) and the HUDF Team   STScI-PRC04-07a

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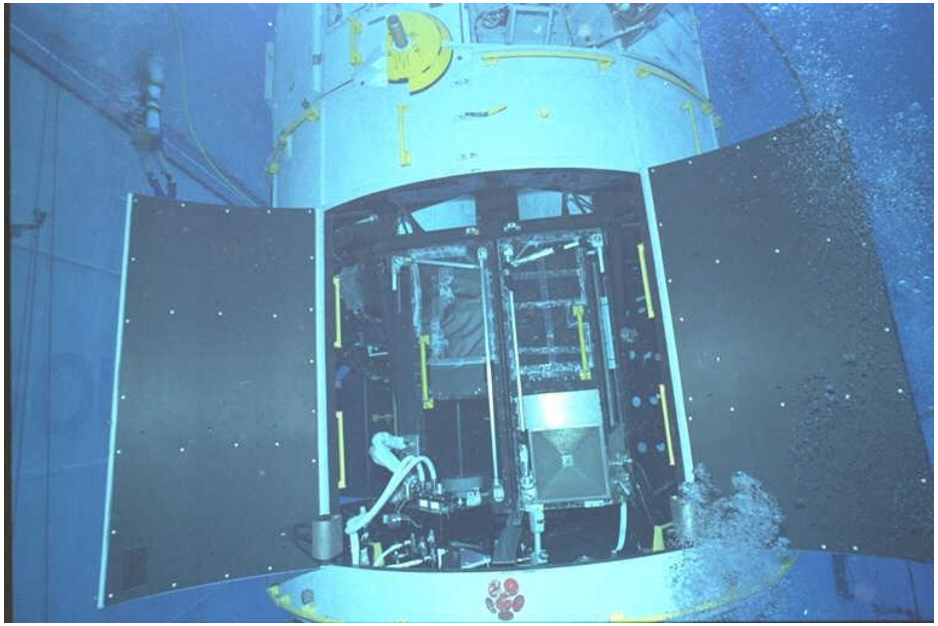
STIS Repair

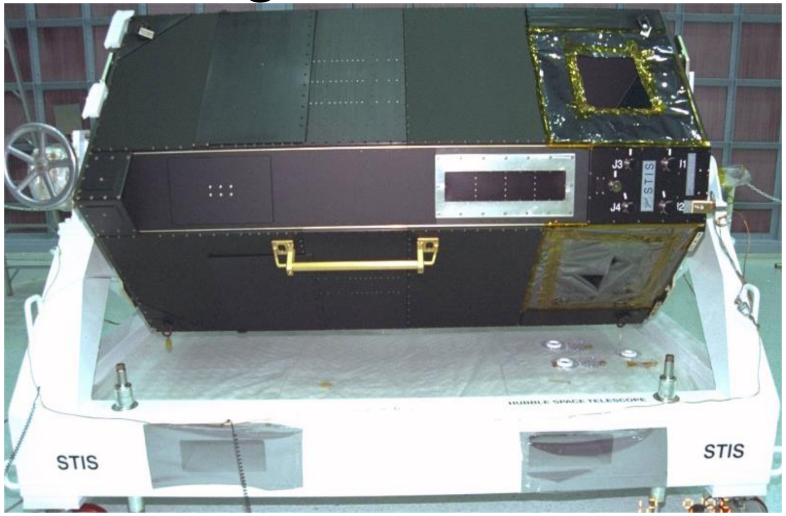
- **Objective is to regain full ultraviolet and visible spectroscopy capabilities of HST Space Telescope Imaging Spectrograph (STIS) instrument**
  - Spectroscopy is a fundamental tool of astronomy
  - STIS is a powerful general-purpose spectrograph suitable for investigating the full range of astronomical phenomena
  - STIS has had a great track record of scientific productivity
  - If returned to service, STIS will continue to provide that high scientific return for the astronomical community into the future



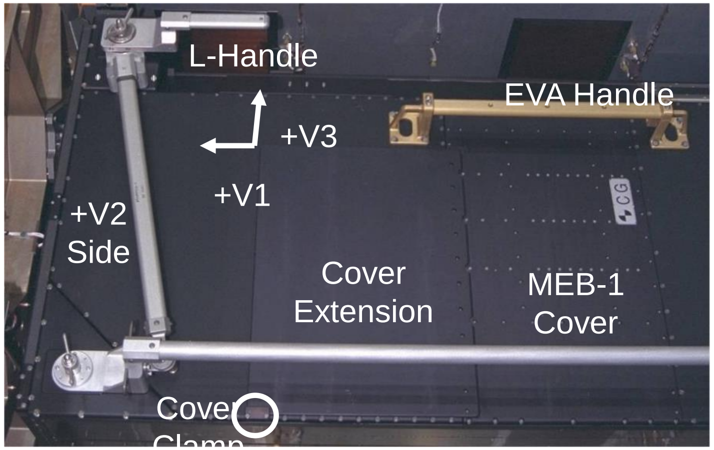
+V2 View of NCS and STIS (on right)

New Challenges for System Engineers

- **Side 1 suspended operation in May 2001**
  - Most probable cause is a shorted capacitor in a power lead
- **Side 2 suspended operations in August 2004**
  - FRB concluded fault resided in +28V to +5V DC/DC Converter
- **STIS was never designed to be serviced**
  - Cover contains 117 non-captive fasteners
  - CG label covers two of the fasteners!



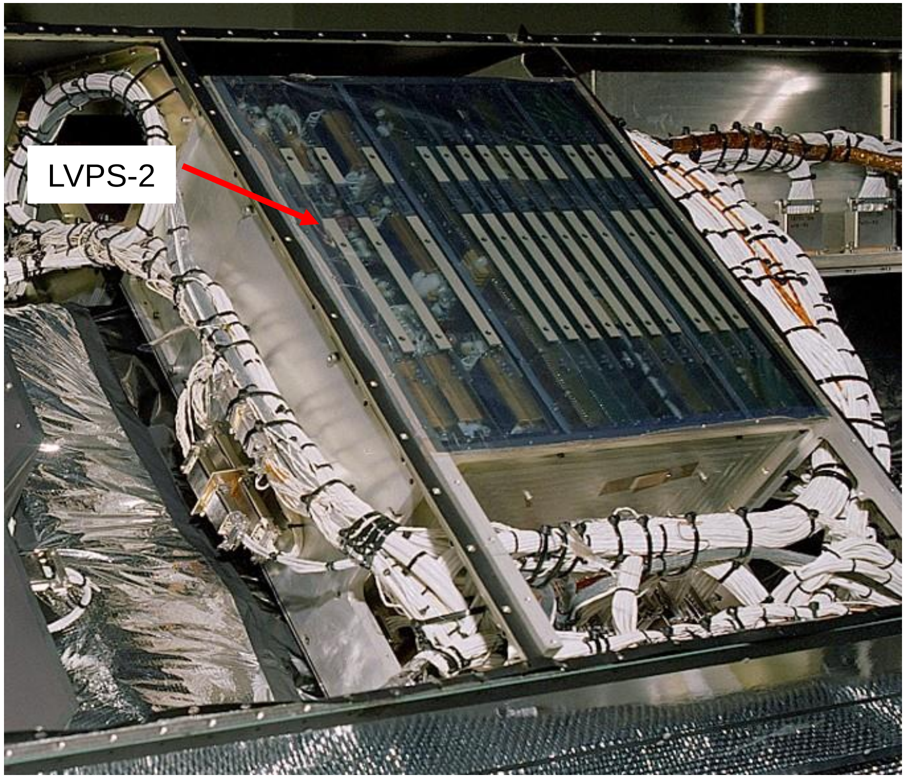
Flight STIS Instrument



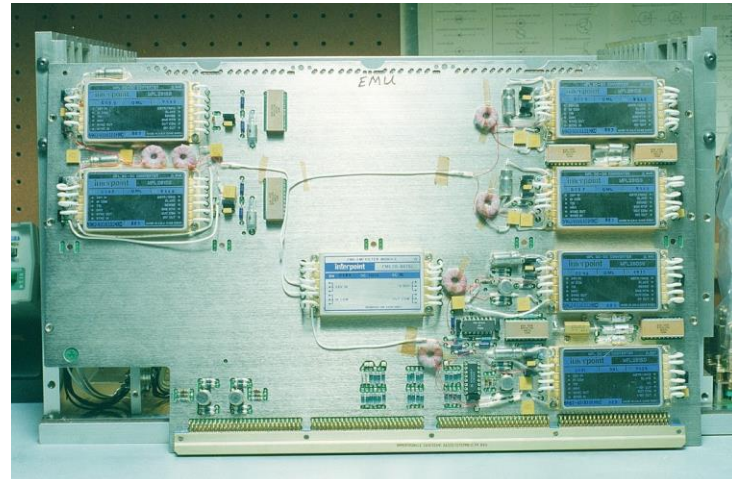
STIS Closeup

STIS Main Electronics Box (MEB)

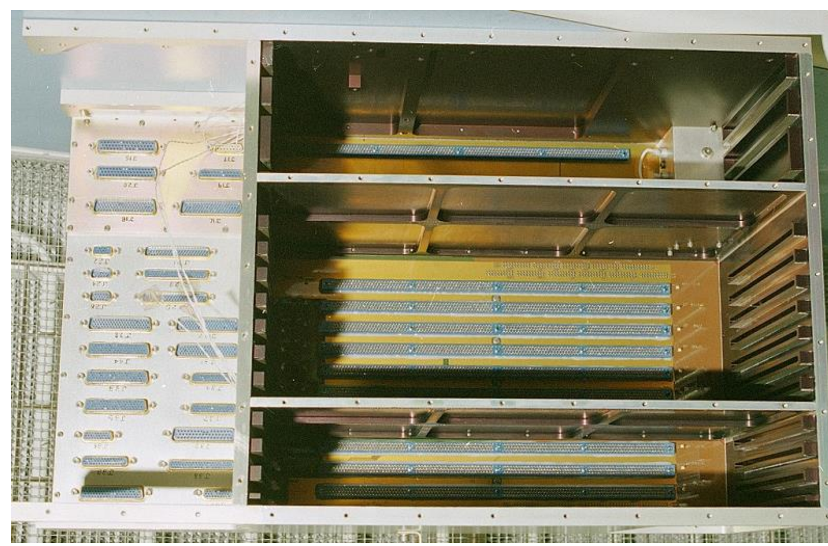
MEB-1 Cover Removed



LVPS-2 Board (Engineering Unit)



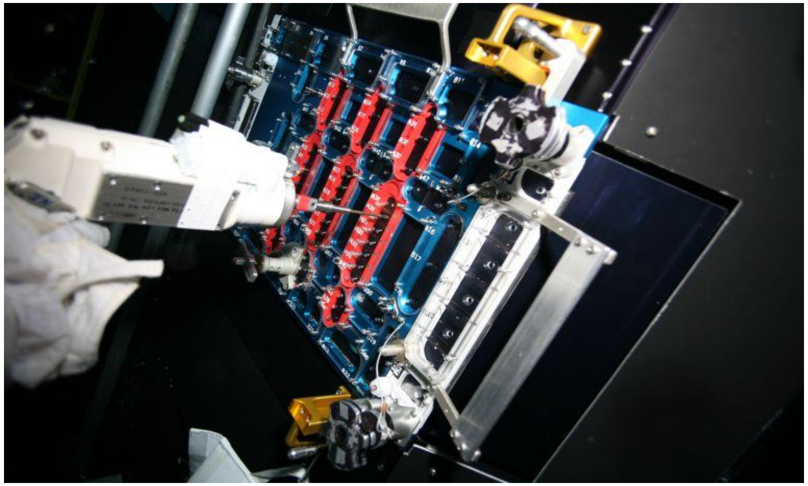
MEB Structure (non-flight)



STIS Repair Concept Still Being Perfected

- **HST System engineers are working with the crew to define the correct:**
  - Tools
  - Procedures
    - Nominal
    - Contingency
  - Timelines

- **Remember the role of the system engineer is incredibly diverse**



Fastener removal in NBL

STIS radiator installation in NBL

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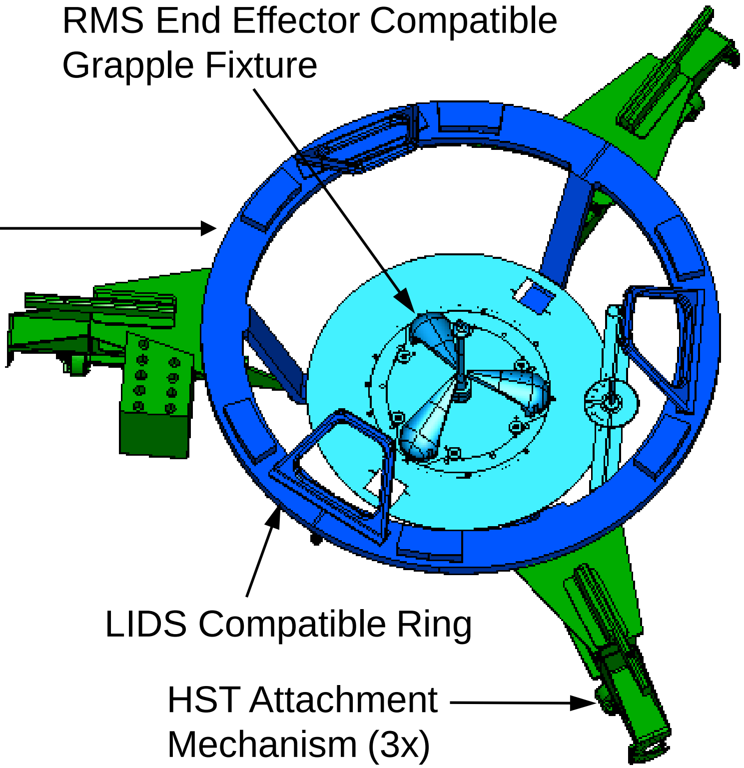
Operational Planning Must Remain Flexible

- **Both FGS2R and FGS3 exhibit life limiting degradation modes**
- **One flight spare unit is available**
- **Decision of which unit to change out will be made before the Cargo Integration Review**
- **FGS3 baselined for planning purposes since it is the more difficult (EVA and IVA)**
  - Requires manipulation of the HST scuff plate
  - Requires installation of the Optical Control Electronics - Enhancement Kit (OCE-EK)
- **Timelines must be flexible enough to accommodate either option**

Changeout of FGS 2 on SM3B

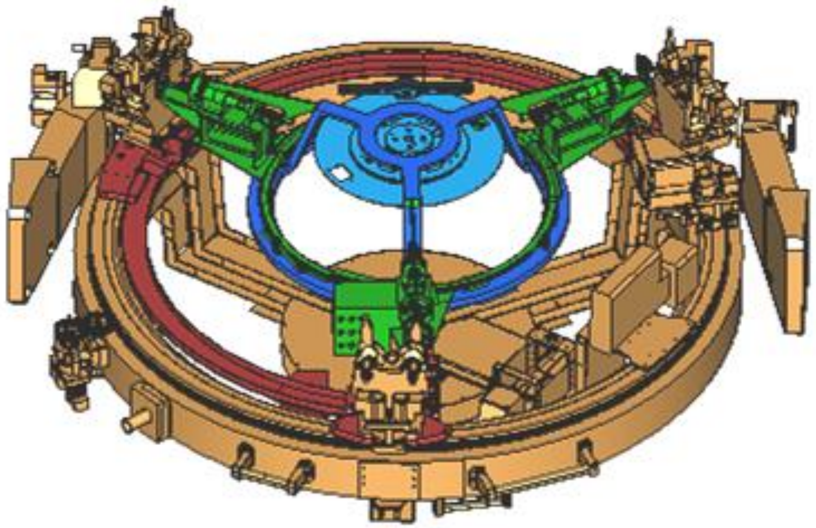
SCRS Will Aid a Future Rendezvous

- **One of the most challenging issues for the robotic mission was ability for a vehicle to grapple a potentially uncooperative HST**
- **The Soft Capture Rendezvous System (SCRS) addresses this issue**
- **The SCRS shall enable/assist the safe end-of-life deorbit of the HST Observatory.**
  - Soft Capture Mechanism system (SCM):
    - The SCM is a compact device which attaches to the HST Aft Bulkhead
    - It is designed to make HST a "friendly and cooperative" passive target for future rendezvous and capture operations.
    - Additional optical targets will be mounted.
  - Relative Navigation Sensor system (RNS):
    - The RNS is the SCRS imaging system consisting optical and navigation sensors; and supporting avionics and processes.
    - RNS will obtain data of the HST Observatory during SM-4 capture and deploy events

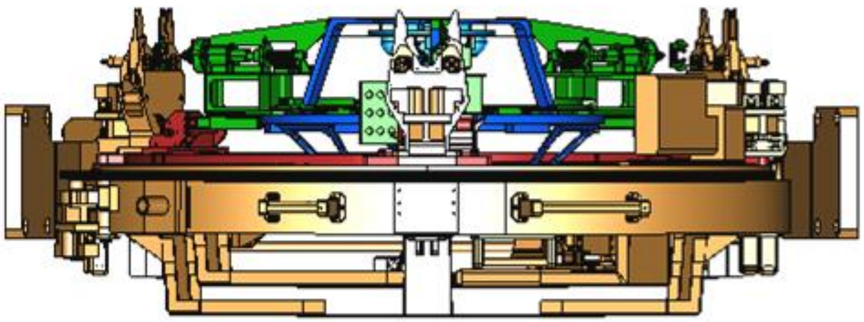


SCM Requirements for FSS Compatibility

- The HST/SCM stack shall have the capability to be re-attached to the FSS after it has been released from the FSS latches
- The SCM shall not interfere with any FSS operations and/or contingencies at any time
- SCM can not be attached to both the HST and the FSS (and hence Orbiter at the same time)

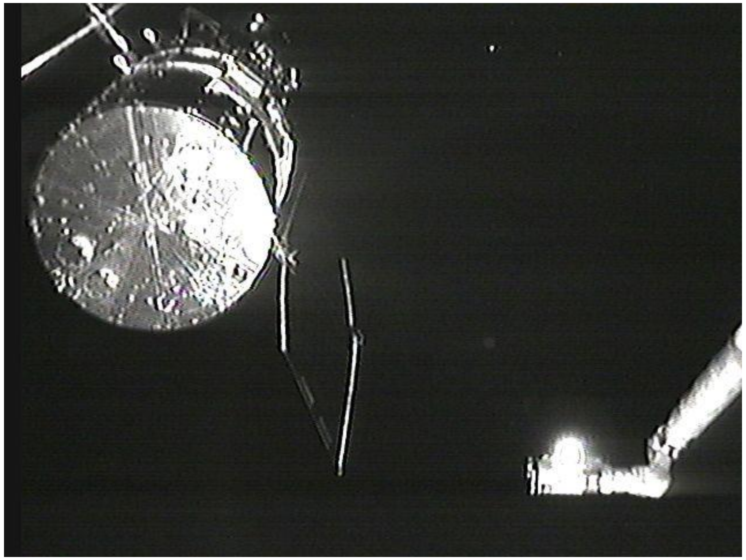


SCM Launch Configuration (attached to FSS)

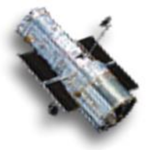


RNS Requirements

- **The Relative Navigation Sensor (RNS) system shall obtain and store high resolution optical imaging and GPS range data**
  - Rate, resolution, and signal-to-noise level to be sufficient to support future rendezvous and docking navigation
- **The RNS shall remain with the SSE for earth return and post-mission data processing**
  - Mounting, alignment, and focus to be pre-set during Shuttle Payload Integration operations at KSC, prior to launch



Orbiter approach to HST on SM2



Once again, flexibility is required in systems engineering for RNS

- **Skills needed for an RNS systems engineer**
  - Standard sub-system knowledge (thermal, power, mechanical, etc.)
  - Understanding the effects of lighting
  - Pattern recognition issues
  - Mission operational impacts
  - Human spaceflight requirements and restrictions

- **Don't have to be an expert in all areas, but need to understand how these issues and many others will affect the success of your system and surrounding systems**

Contingency Procedures Need to be Defined and Exercised

- **Contingency procedures need to be developed and exercised during simulations**
- **Number of procedures developed will vary depending on the type of mission**
- **Typically for nominal non-human missions, only a handful will need to be developed for immediate action**
  - e.g., (For SoHO, a billion dollar mission, the FOT required less than 10 "immediate" procedures)
- **For the HST Servicing Mission hundreds of procedures are needed!**

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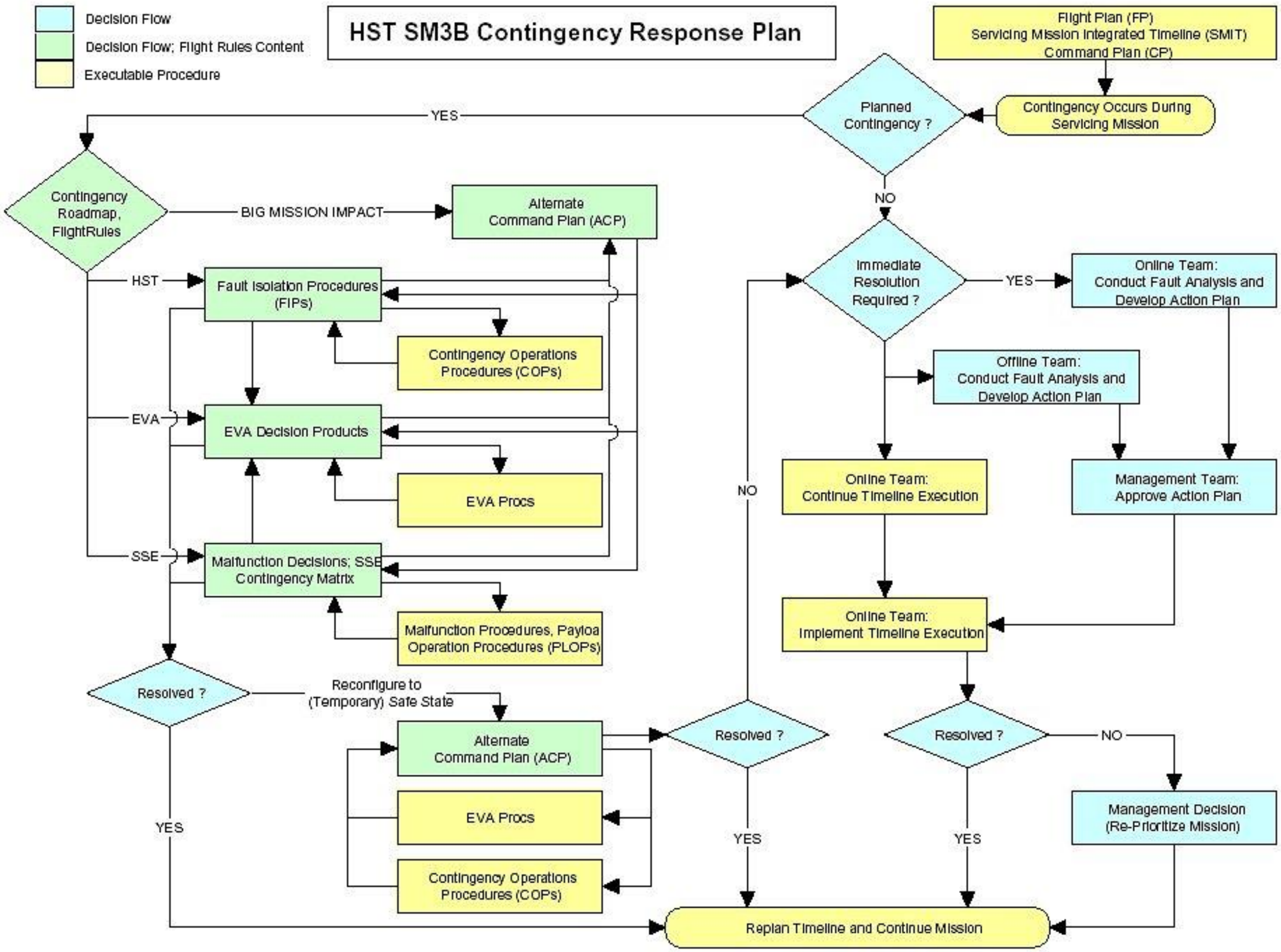
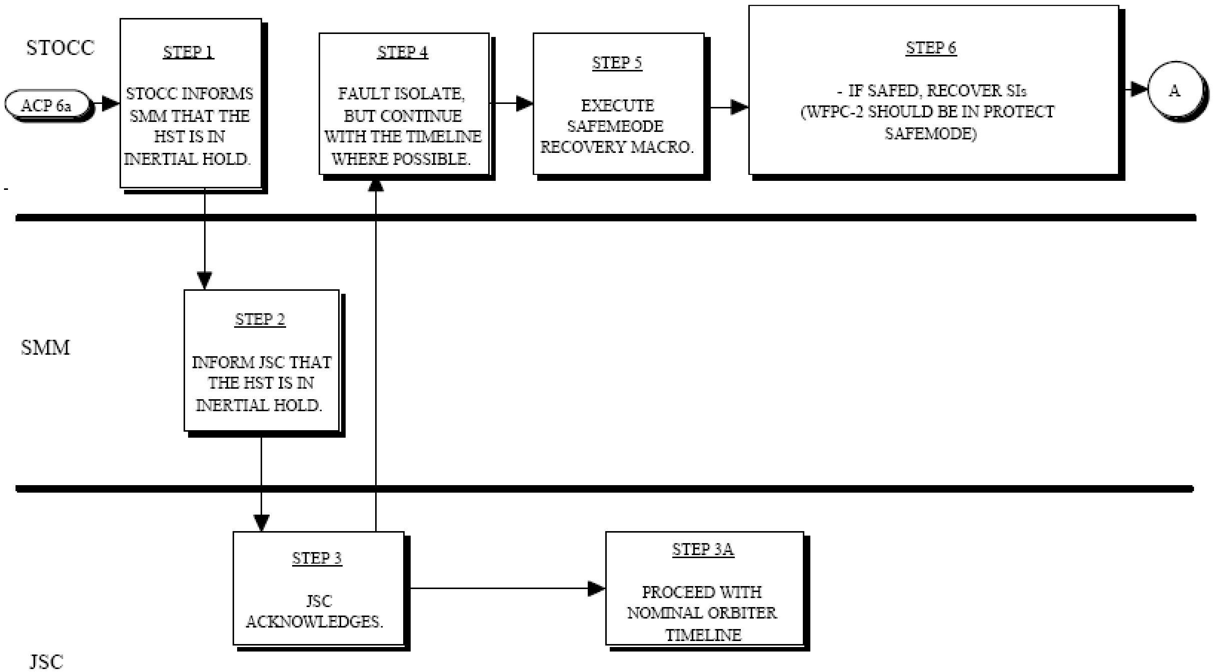
Elaborate Pre-Mission Contingency Planning is Critical



HST Contingency Procedures are Numerous and Diverse

- **Alternate Command Plan (ACP): Supplants nominal command plan due to a major anomaly**
  - Developed to support anomalous situations that require rapid reaction of the entire team
  - (e.g., HST falls into inertial hold prior to rendezvous)



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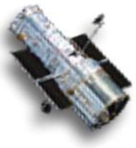


Detailed Procedures are Available for Immediate Implementation

ACP 6a
HST IN INERTIAL HOLD PRIOR TO RENDEZVOUS (SERVICING MISSION 3B)

Revised 10/25/00

SEQUENCE # 2

MET: 00:00:02

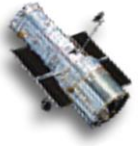
DURATION: 107min

SEQUENCE TITLE: SI RECOVERY AND I&C CONFIGURATION

SEQUENCE DESCRIPTION: MANAGE COMMUNICATIONS LGA DIRECT TO TDRSS, RECOVER SAFED SIs, DUMP RECORDER IF NEEDED, COMMAND SSA INHIBITS, TURN ON GEA'S, TURN ON HGA CONTROL LAW AND HGA TORQUE TEST, UPLINK COMMAND LOAD TO SLEW HST AND SET POINTER, PROCEED WITH NOMINAL COMMAND PLAN.

INITIAL CONDITIONS: HST IS IN INERTIAL HOLD.

TIME COMPLETE	STEP#	PROC	ACTION	TLM	ΔTIME (min)	AD	DESCRIPTION
* NOTE: PROCEED WITH NOMINAL ORBITER TIMELINE. *							
	2-1	--	EXECUTE COP 5.10A - COMMUNICATIONS DURING SAFEMODE.	AN	4	CP06a	MANAGE COMMUNICATIONS DIRECT TO TDRSS THROUGH LGA'S.
	2-2	--	EXECUTE COP 18.10 - STIS SAFEMODE RECOVERY. (IF REQUIRED)	AN	20	CP06a	RECOVER STIS IF NECESSARY.
* NOTE: IF WFPC-II IS IN PROTECT SAFEMODE, SKIP THE FOLLOWING STEP. *							
	2-3	--	EXECUTE COP 17.14 - WFPC-II REAL-TIME SAFEMODE RECOVERY. (IF REQUIRED)	AN	15	CP06a	RECOVER WFPC-II IF NECESSARY.
	2-4	--	EXECUTE COP 19.10 - NICMOS SAFEMODE RECOVERY. (IF SAFED)	AN	20	CP06a	RECOVER NICMOS IF NECESSARY.



HST Contingency Procedures (cont)

- **Fault Isolation Procedure (FIP): Logic flow used to help isolate the cause of an HST anomaly and a workaround**
- **Contingency Operations Procedure (COP): Detailed procedures from the STOCC which reference the actual command sequences required to reconfigure hardware**
- **EVA Contingency Procedures: Specific steps to resolve or troubleshoot an anomaly without requiring ground inputs for each EVA interface**
- **SSE Contingency Matrix: Identify and isolate the cause of the anomaly and identify the potential solution for the SSE**
- **SSE Malfunction Procedures: In flight trouble shooting procedure used by crew**

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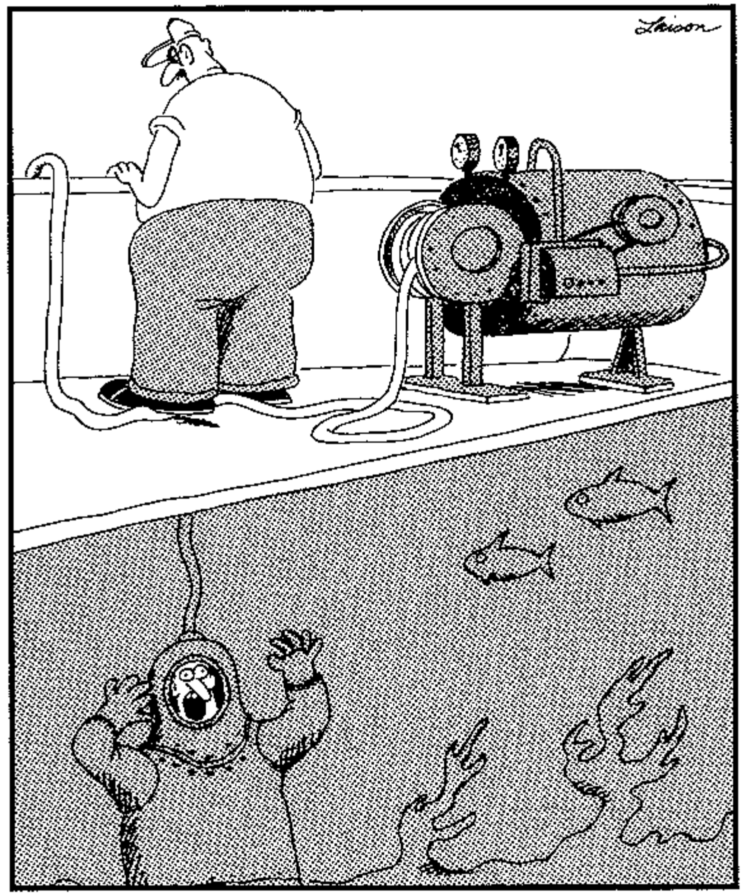
Of course the contingency that occurs will not have been defined



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LAST IMPRESSIONS
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Tuesday 28

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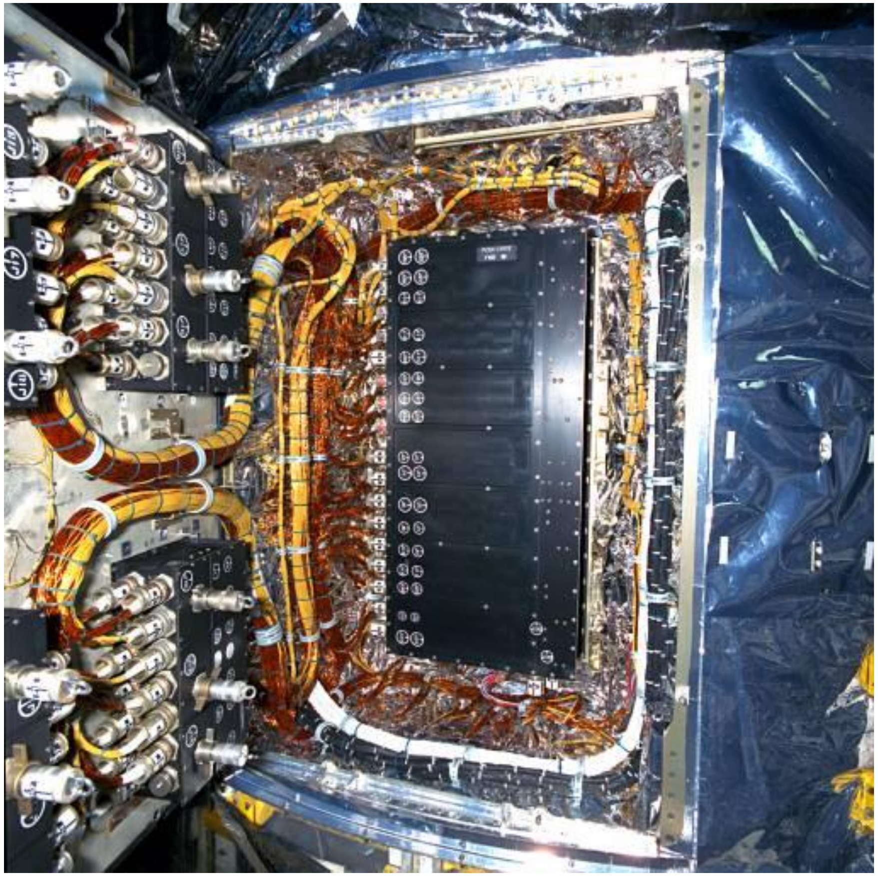
A major anomaly almost interrupted a critical Servicing Mission Activity

- **On SM3B, astronauts changed out the power control unit (PCU)**
- **Replacing the PCU entailed powering off the entire HST**
  - Required hours of preparation (pre-heats, safing interfaces)
- **Shortly before egress, a water leak in the cooling line developed with John Grunsfeld's suit**
- **Team had to quickly assess a replanned timeline**
- **Astronauts resolved the issue and egress was delayed 2 hours, but it could have caused a major issue**
- **Training and discipline of the team allowed an orderly analysis of the problem**



HST Power Control Unit

Simulations are critical for team readiness

- **Depending on the complexity of the mission, various amounts of simulations will be required pre-mission**
- **Smaller missions may only need a few simulations**
  - Simulations are supplanted by many hours of preparation by the FOT and system engineers in other activities (e.g., thermal vac)
- **HST conducts 18-20 major simulations**
  - 12 internal simulations among the GSFC team
  - 6-8 Joint Integration simulations including the team at JSC
  - 1 JIS is a “wet” JIS where the crew is supporting in the NBL
- **Simulations need to exercise a combination of nominal activities and anomalies**
  - Don’t go overboard on anomalies. Team needs to be familiar with nominal operations also
  - Processes are as important as the technical issues
- **Add the simulations to the project schedule!!!!**

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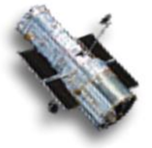
Is it Art or Science?

Summary

- **Enjoy what you're doing**
  - Operations provides an incredible opportunity to learn about new disciplines



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Summary

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  - Operational personnel will be relying on them for years
- **Bring in operational personnel early as part of the mission design**
  - Ops personnel can provide a unique perspective based on their experiences
  - Ops personnel have a long-term vested interest (they'll be on console on Christmas Eve when something goes wrong)
- **It's a tremendous feeling of accomplishment when your missions begins returning science data, knowing you've played your part**

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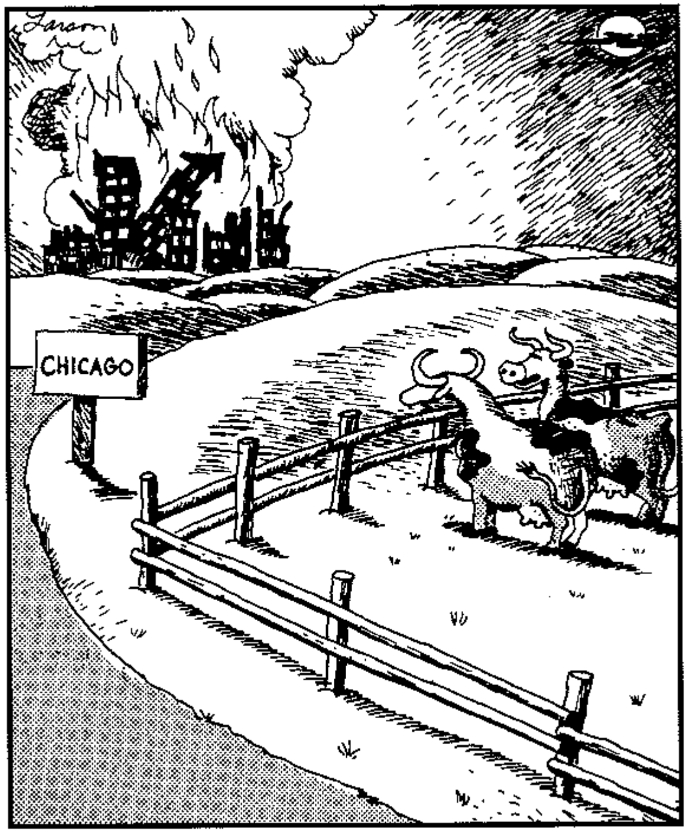
Mission Success is a Phenomenal Accomplishment



"It seems that agent 6373 has accomplished her mission."

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