Designing for On-Orbit Assembly and Servicing

Design Guidelines for Future Space Telescopes

Mirror Tech/SBIR/STTR Workshop 2015
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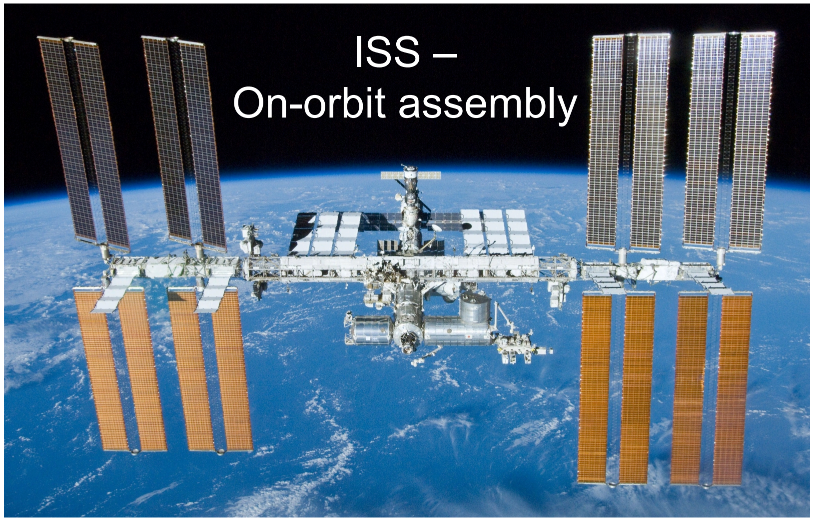
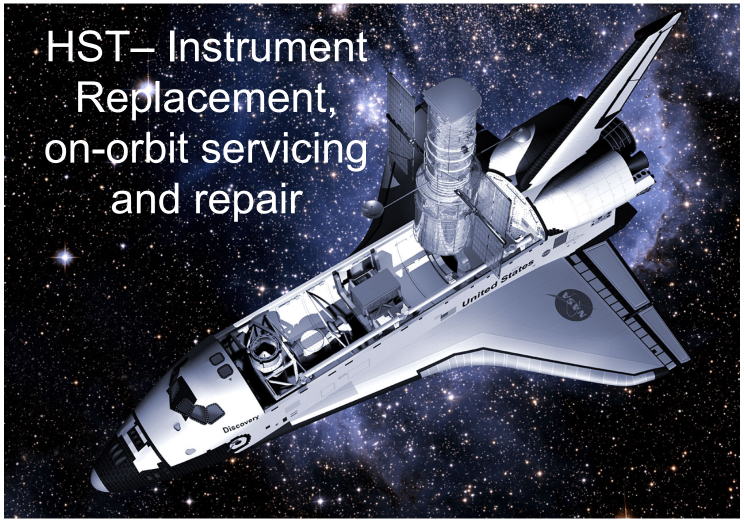
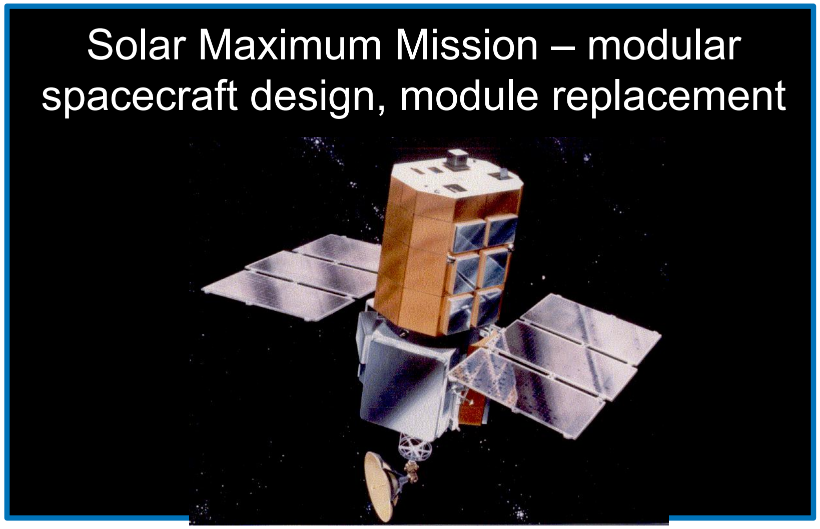
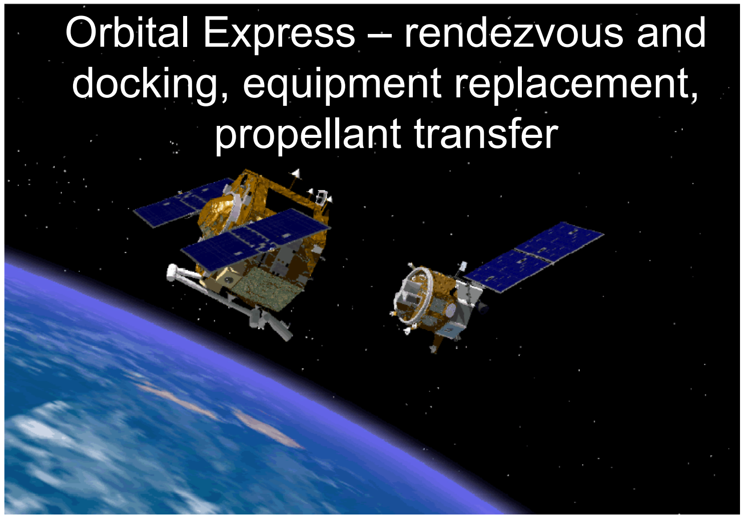
Existence Proof









- Most required technologies already demonstrated on orbit and are now at Technology Readiness Level (TRL) 9

Design for Servicing

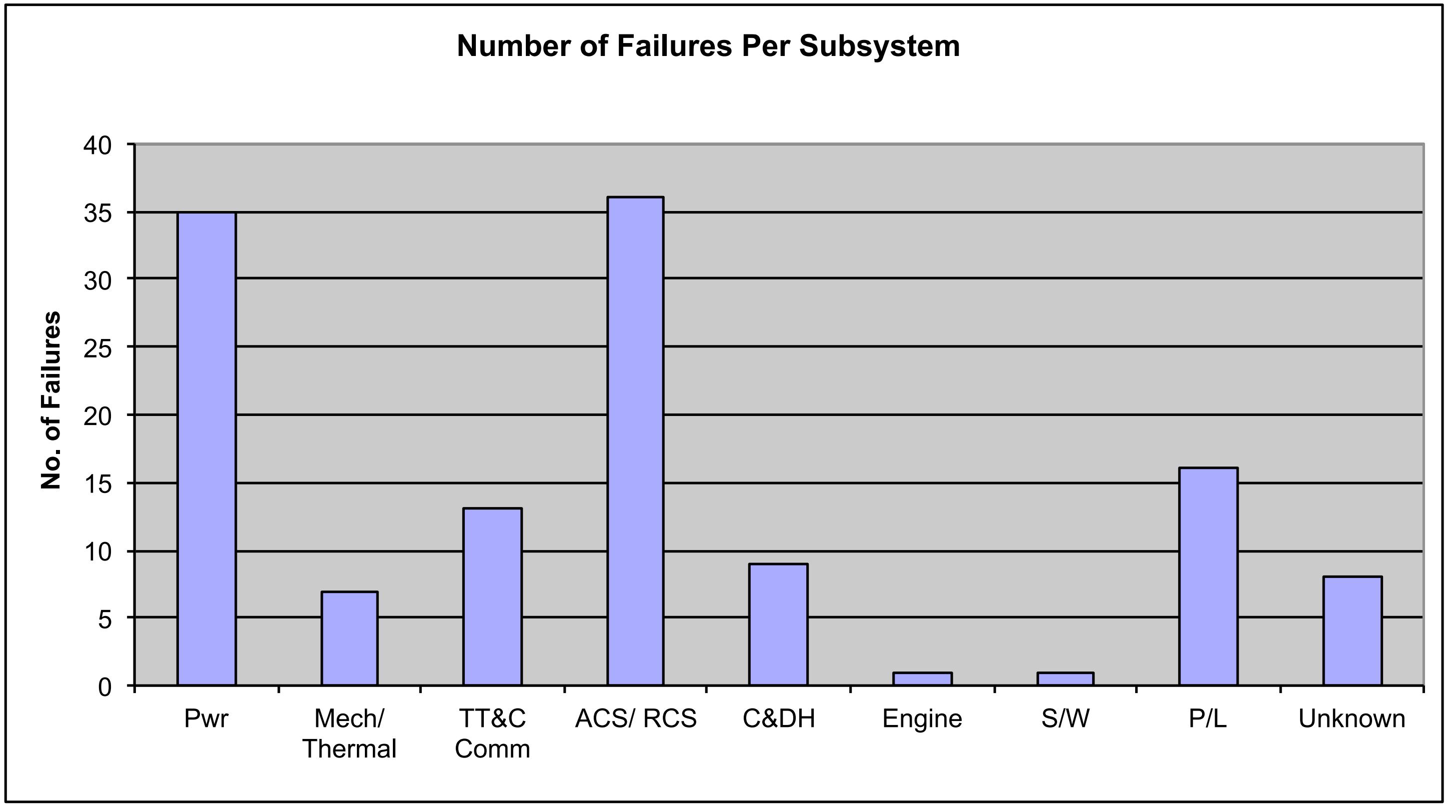
- Future space observatories should be designed to enable on-orbit assembly and servicing to:
  - Add additional components to increase capability
  - Add components with newer technology to increase performance
  - Replace degraded or failed components
  - Replenish expendables to extend mission life
- Guidelines include:
  - Design for servicing from the beginning
    - Standard interfaces with kinematic mounts, blind mating connectors
    - Ease of access with external mounting or easily opened panels
    - Grapple fixtures, handholds and foot restraint fittings for EVA servicing
    - Fittings for propellant replenishment
  - Create modular designs
    - Package subsystem components together where possible
    - Replace at subsystem and/or component level
    - Orbital Replaceable Units (ORU's) for units most likely to wear out or fail
    - Parts kits to allow other units to be fabricated if necessary (CRU's)

Replaceability Options

- Replace Entire Bus
  - Pro: Ability to update all systems with future technology
  - Con: Requires new bus to fix one component
- Replace individual subsystems
  - Pro: Lower cost, Spare selection based on statistical failure modes
  - Con: Inability to update all systems with future technology
- Replace individual components
  - Pro: Maximum flexibility
  - Con: More ORU attachment componentry
    - Requires more sophisticated replacement robot
- Carry Replacement components on only flight
  - Pro: No service vehicle needed
  - Con: Unable to update systems with future technology, higher mass, limited lifetime extension

Subsystem Failure Statistics

- Data below is from every satellite launched from Earth between 1990 and 2008

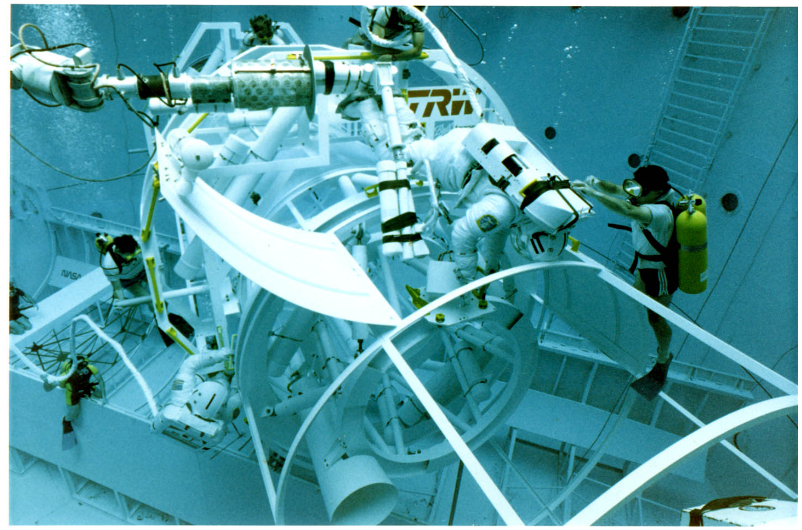


Trade Evaluation Criteria

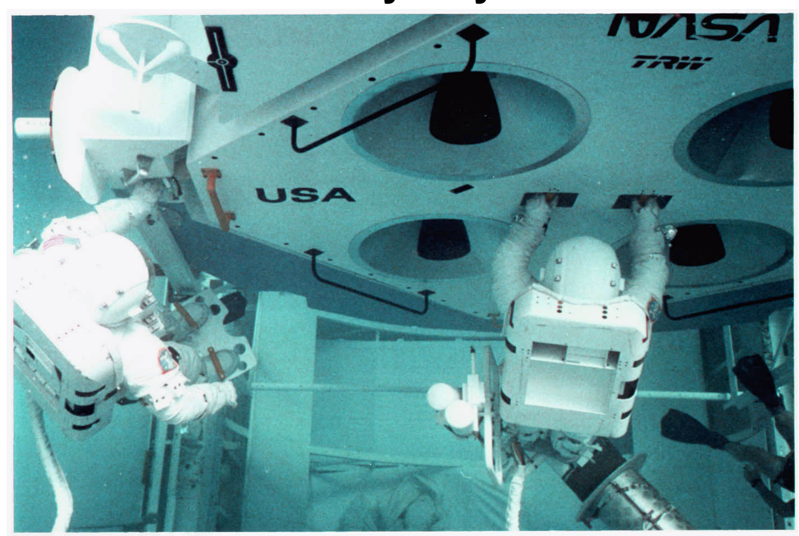
- Impact of number of replaceable units on Cost and Mass
  - More units = more ORU interfaces
  - How should we include servicing vehicle and future launch cost?
- Statistical evaluation of unit spare philosophy
  - Redundancy vs. Replaceability
- Servicing approach and location location
  - Robotic, EVA or Crew Assisted
  - Cis-Lunar (EM L1) or Sun-Earth L2

The Necessary Technologies

- Access to space
  - Launch Vehicles
  - Manned Spacecraft
- Rendezvous and Docking
  - Proximity operations
- EVA Capability
  - Spacesuits
  - Tools and crew aids
  - Work platforms
  - Crew Training facilities
- Robotics
  - Remote manipulator systems
  - Dexterous manipulators
  - Machine vision
  - Autonomous Operations
- Telerobotic
- On-Orbit Servicing Facilities



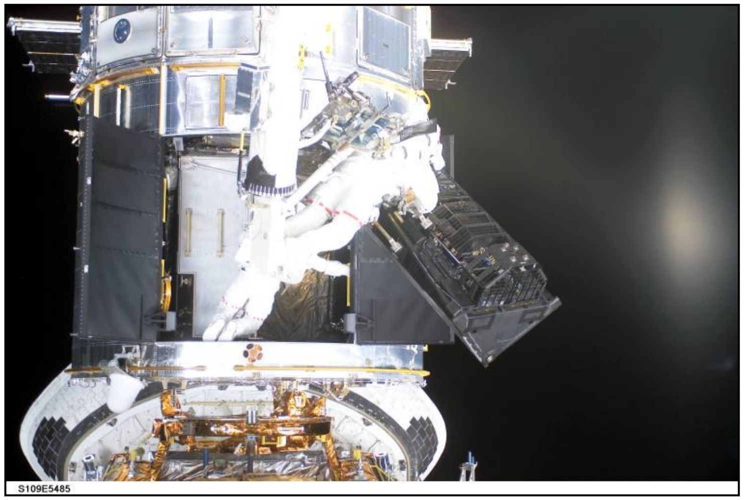
AXAF Neutral Buoyancy Tests at MSFC



OMV Servicing

Servicing the Hubble Space Telescope

- EVA servicing missions for HST have clearly demonstrated the ability of on-orbit to repair, maintain and enhance observatory performance
- The four servicing missions conducted to date have
  - corrected the optical performance of the telescope,
  - replaced failed components,
  - increased the wavelength coverage of its instruments and
  - increased the observatory’s productivity by several orders of magnitude.



Removing the Faint Object Camera

Power Control Unit Replacement

Compton Gamma Ray Observatory (CGRO)

- Like the the Solar Maximum Mission (SMM) launched in 1980, Landsat 4 and Landsat 5 launched in 1982 and 1984, the Upper Atmosphere Research Satellite (UARS) launched in 1991, and the Extreme Ultraviolet Explorer (EUVE) launched in 1992, the Compton Gamma Ray Observatory (CGRO) launched April 5, 1991, incorporated GSFC provided replaceable ORUs derived from GFDC's Multi-mission Modular Spacecraft (MMS)
- It was, however; never serviced and was deorbited on June 4, 2000 after a gyro failed in December 1999

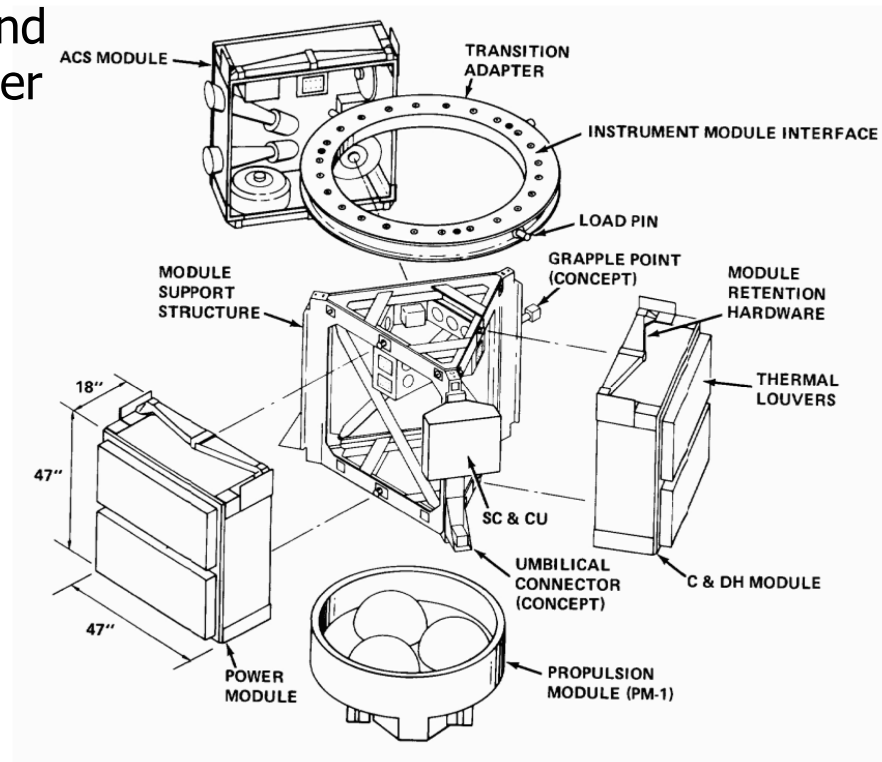
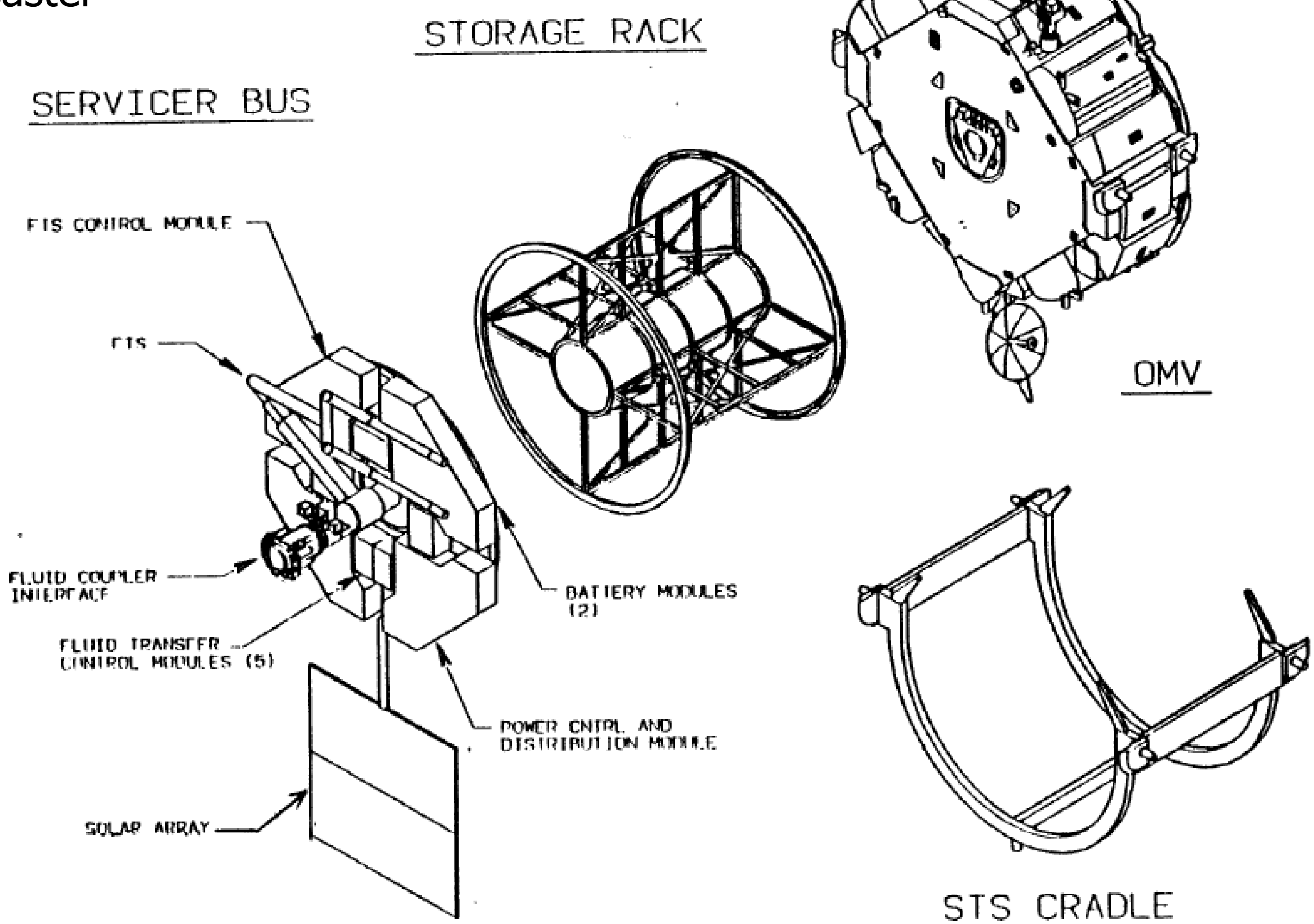


Figure 1. MMS Components

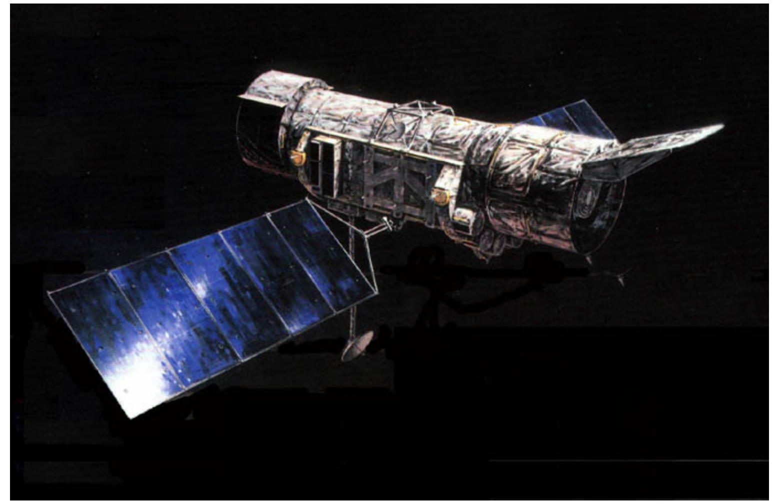
Orbital Maneuvering Vehicle (OMV)

Phase D NGST (TRW) study circa 1985, program cancelled post shuttle disaster

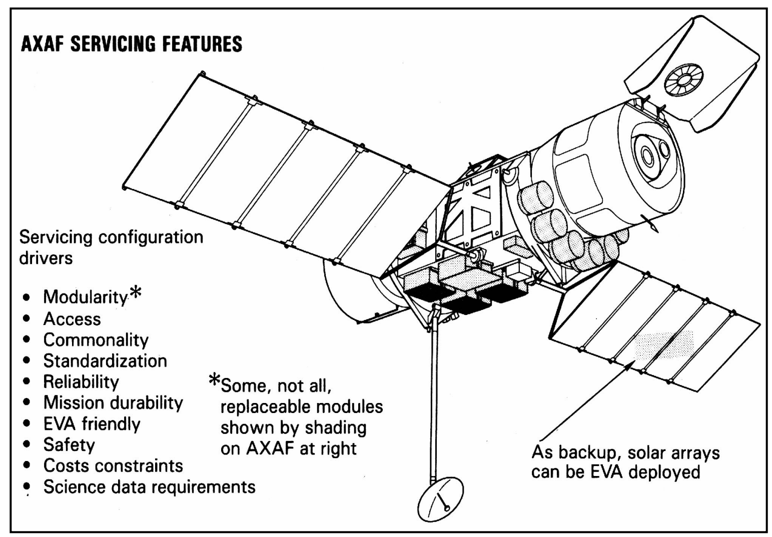


The Advanced X-Ray Astrophysics Facility (AXAF)

- AXAF (now the Chandra X-ray Observatory) was originally designed in the 1980's as a serviceable Great Observatory, like HST, in Low Earth Orbit
- Components likely to wear out were housed in easily accessible Orbital Replacement Unit, i.e.:
  - Avionics modules on the bottom of the observatory
  - Solar arrays
  - Cylindrical reaction wheel containers at the front of the observatory.
  - Science instruments at the rear of the observatory



Low-Earth Orbit Version of AXAF

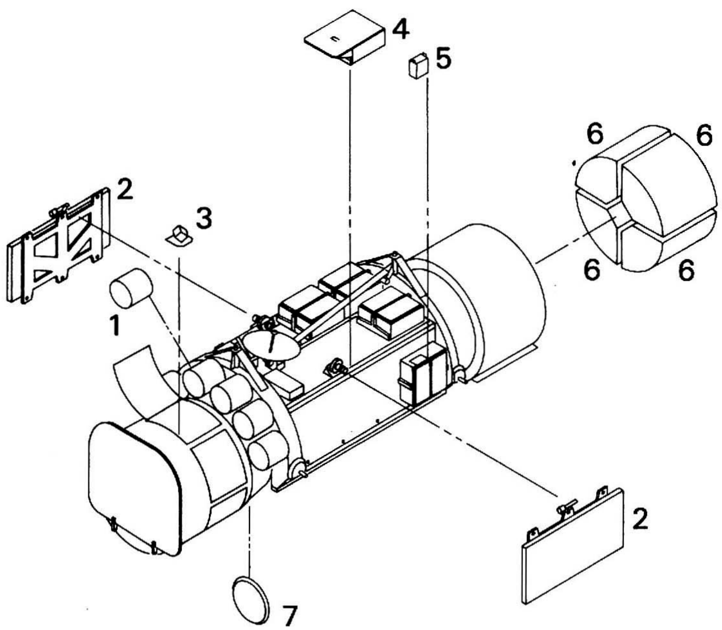


AXAF Servicing Features

AXAF Servicing Concept

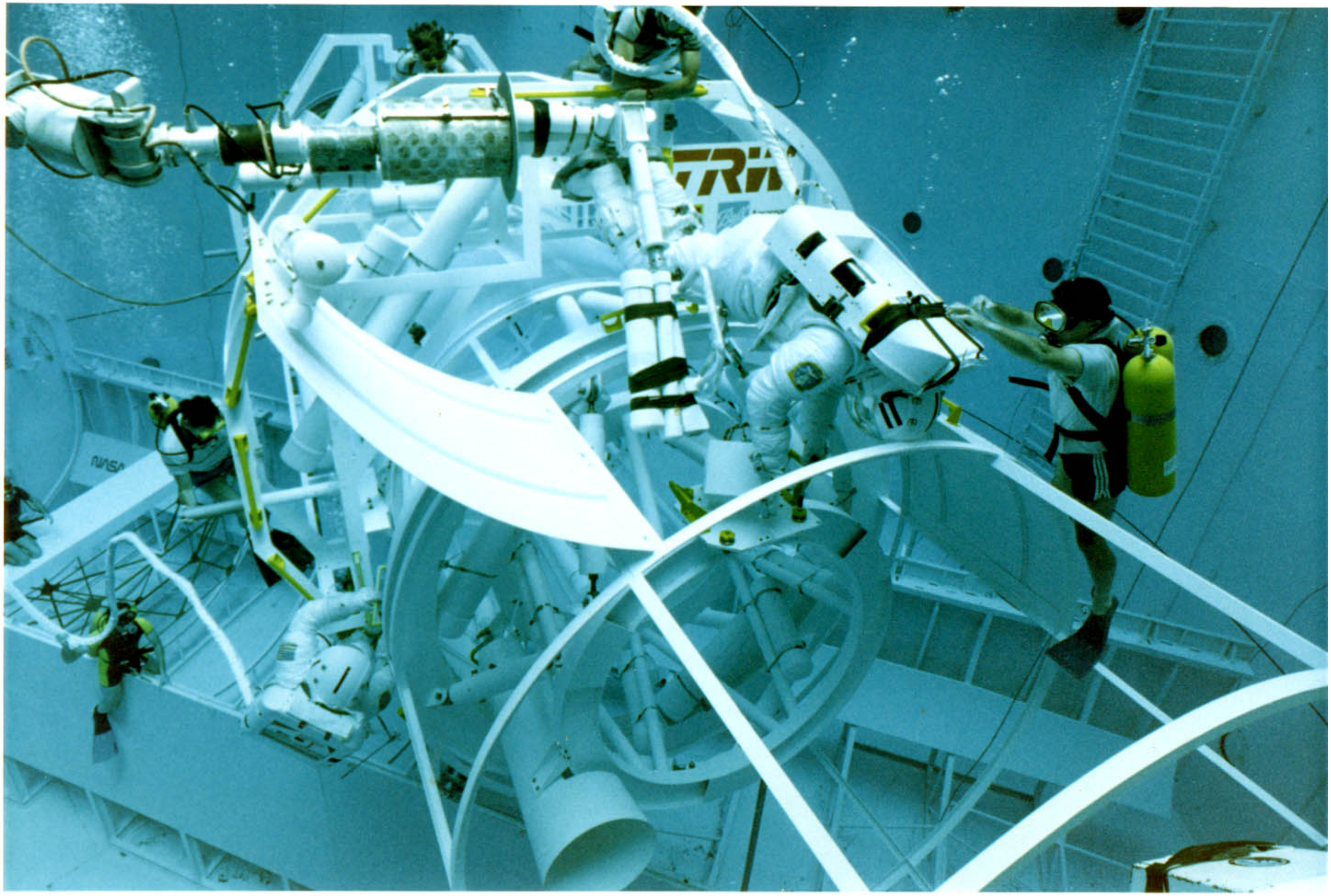
- Concept circa 1989 for servicing with the shuttle or at the space station customer servicing facility

DESIGNED FOR SERVICEABILITY, AXAF ORUs, CRUs ARE LOCATED FOR EASE OF ON-ORBIT SERVICING



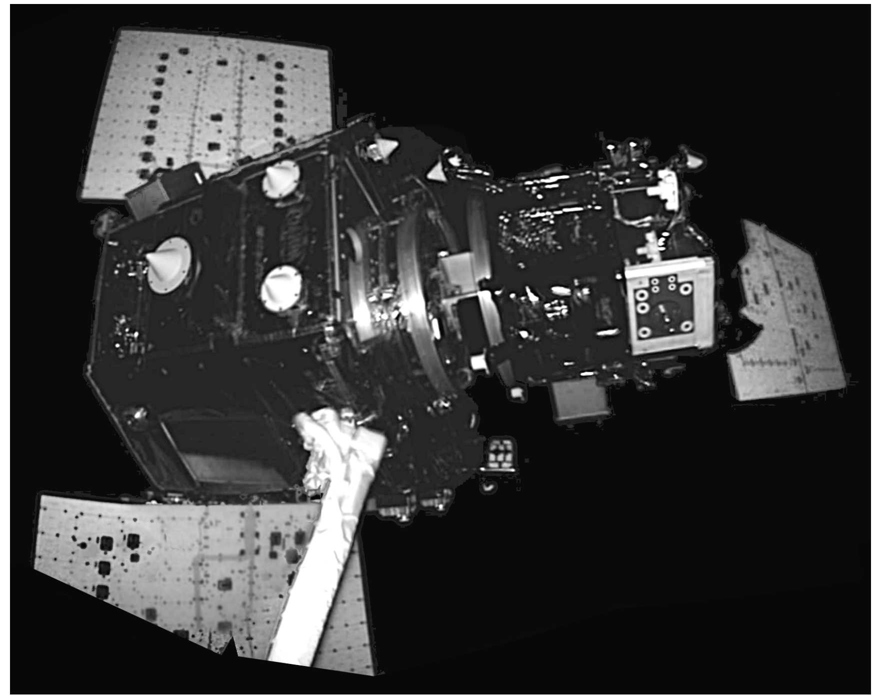
DESCRIPTION		QUANTITY ON SPACECRAFT	SPARES
ORUs	1. Reaction wheel assembly	6	3
	2. Solar array wings	2	2
	3. IRU (gyros)	2	1
	4. Battery module	1	1
	5. Tape recorder	2	2
SIs	6. Focal plane experiment	4	—
	7. Objective transmission grating (OTG)	2	—
Typical CRUs	1. Aspect camera	1	—
	2. Power supply electronics module (MMS type)	3	—
	3. Solar array switching unit (SASU)	2	—
	4. Electronic integrating assembly (EIA)	1	—
	5. Instrument switching unit (ISU)	1	—
	6. CDM module (MMS type)	1	—
	7. Drive electronics assembly (DEA)	2 (redundant units)	
	8. Attitude control electronics (ACE)	2 (redundant units)	
	9. Reaction wheel electronic assembly (RWEA)	6	—
	10. HRMA actuators and related electronics	6	—
	11. HGA dish	1	

AXAF Mockup in MSFC's Neutral Buoyancy Facility



Orbital Express Overview

- DARPA demonstration program to advance technologies for satellite servicing
  - Rendezvous and Docking
  - Fluid Transfer (propellant re-supply)
  - ORU (orbital replacement unit) Transfer
- General Program
  - ~5 years from program award to end of flight operations
  - NGAS provided the Fluid Transfer and Propulsion Systems to Boeing/Ball
  - Class C+ (limited redundancy)

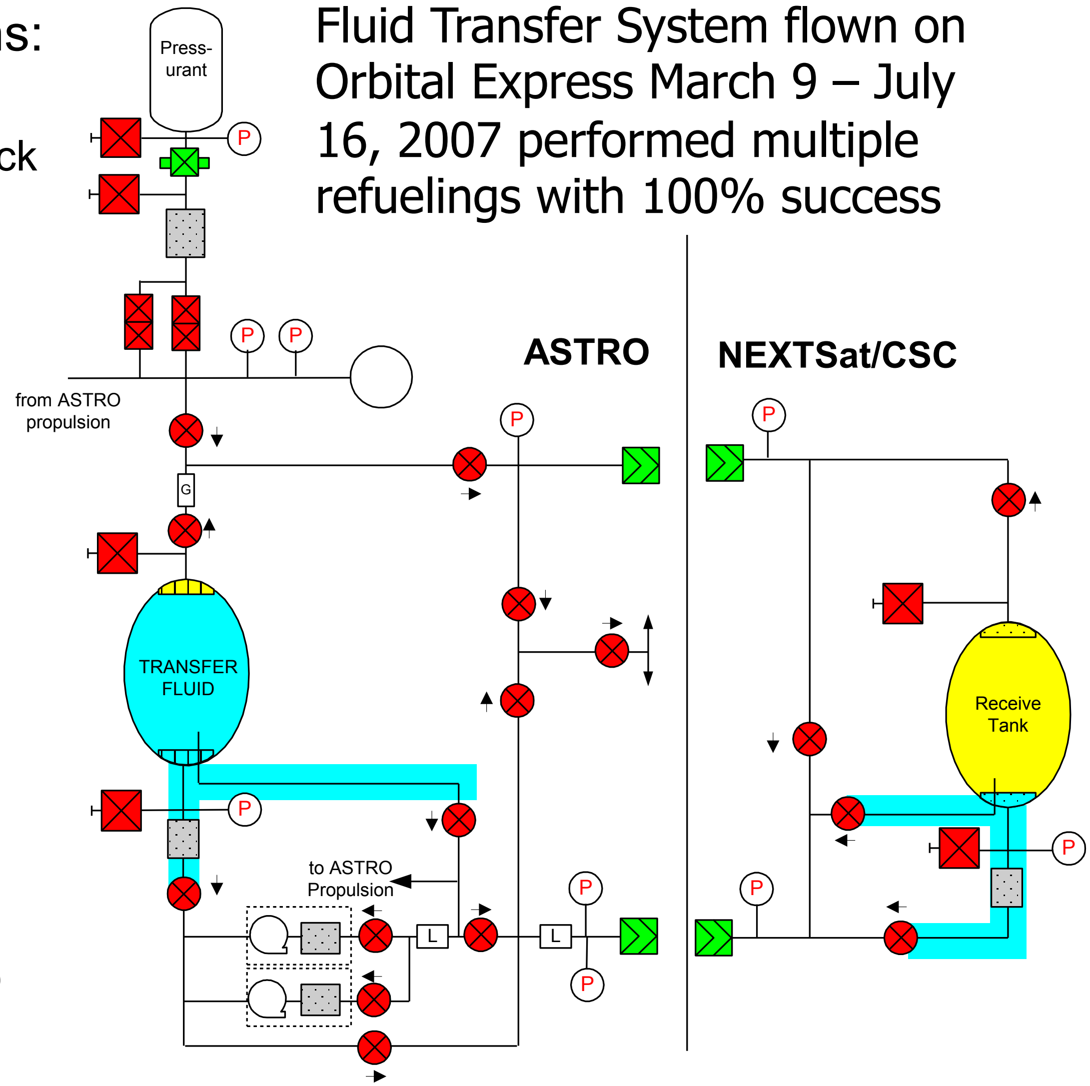


Self portrait of the two docked vehicles (ASTRO servicing vehicle on left; NextSat client/ commodities spacecraft on right)

Fluid Transfer Demonstration System

- Key on-orbit demonstrations:
  - Closed loop transfers - propellant in, pressurant back using fluid pump
  - Ullage recompression - no pressurant exchange using pressure supply
  - Fluid gauging - multiple methods
  - Autonomous fluid transfer operations
- Future Client Impacts:
  - 1 to 3 additional valves and two pressure transducers
  - Addition of a passive side coupling and passive side capture system (not shown)

Fluid Transfer System flown on Orbital Express March 9 – July 16, 2007 performed multiple refuelings with 100% success



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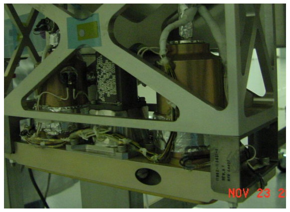
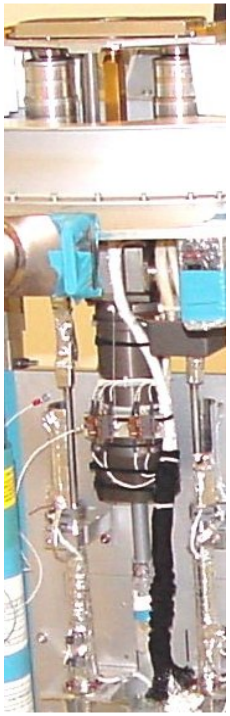
Development Hardware

Component	Innovation
Variable speed hydrazine (N2H4) pump (0.23 lbm/sec)	Motor-driven adaptation of turbine Shuttle APU pump
Fluid coupling/bellows Assembly	2-path/redundant seal couplings with ~4" travel, rotating-cover thermal protection, axial/ lateral misalignment tolerance
Propellant/fluid transfer tanks	Surface tension ullage gas bubble positional control to 95% fill fractions
Flow sensors	Passive fluid flow measurement
Non-propulsive catalytic vent	Operates from 100% liquid to 100% gas along with any combination in-between

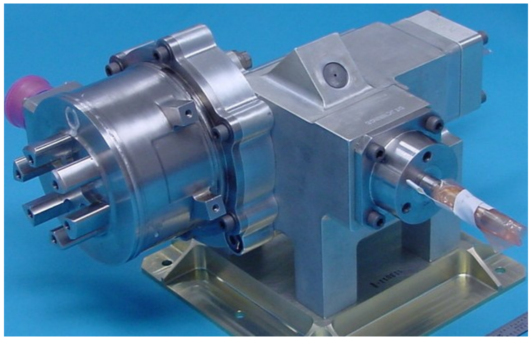
Coupling





Tank PMD

Flow Sensor



Pump

Propellant Resupply Benefits

- Early mission: reduced launch weight
  - Launching without mission propellant load could allow an extra spacecraft or more payload to be launched
- Mid-life: generally life extension, system efficiency, contingency refuel, and maneuverability. Maneuverability can have mission-improving and mission-enabling benefits, including:
  - Increased coverage, threat avoidance, unpredictability, and imagery resolution (i.e., orbit shifting, reduced perigees)
- End-of-mission: reduced launch weight, system efficiency (reduced mission weight)
  - Particularly for those missions with orbits below 2000 km requiring end-of-life disposal, the savings in propellant mass and tank volume can be substantial

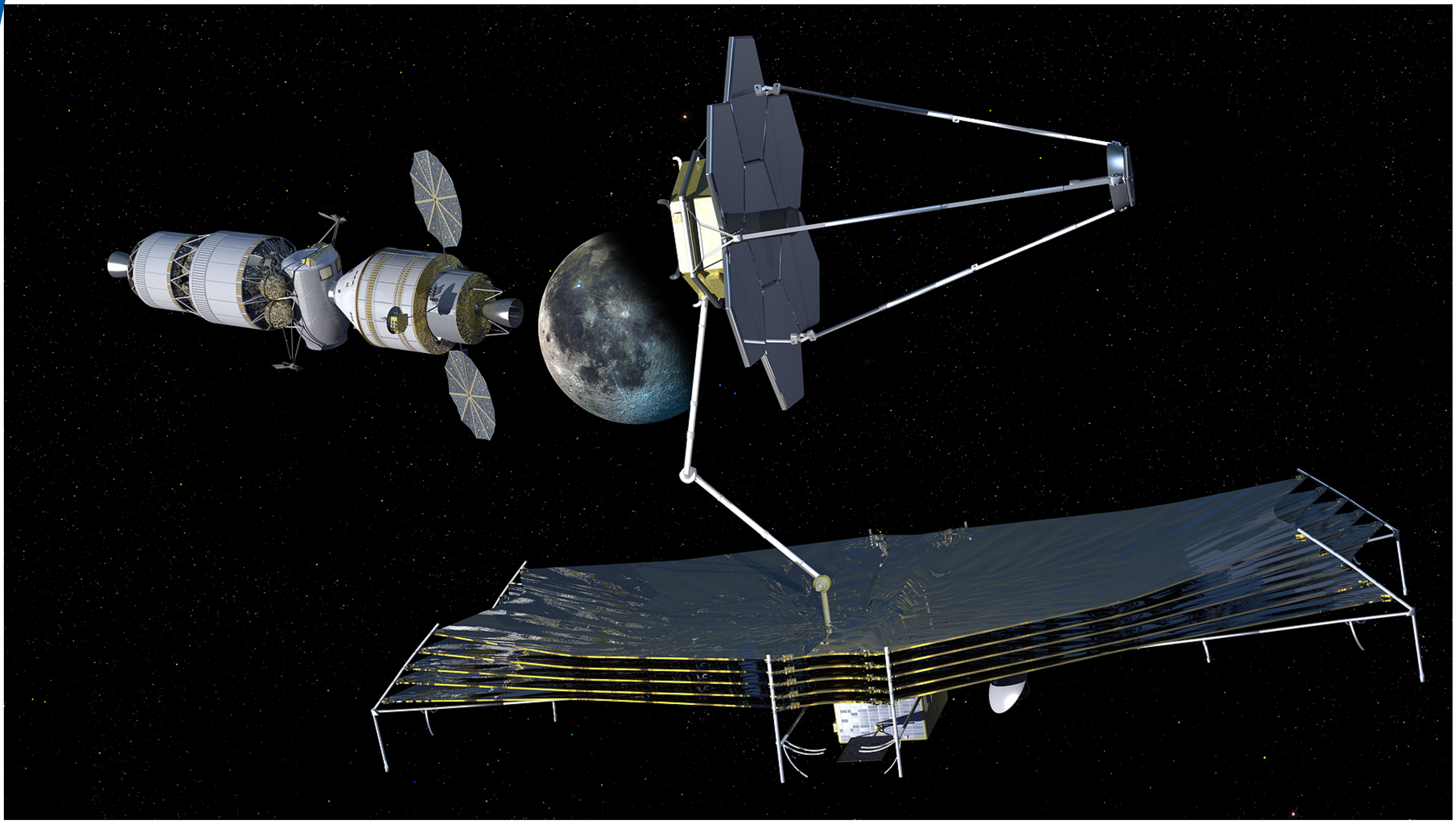
OE has laid the groundwork for future mission planners to evaluate the benefits of propellant re-supply for a variety of mission needs

Hubble Robotic Servicing Vehicle

- The HRSV consists of an Ejection Module (EM) and Deorbit Module (DM)
  - The EM holds the robot arm, ORUs, new instruments and servicing tools
  - The DM contains the propulsion system that will be used to deorbit HST
  - The "skirt" at the bottom of the EM is made up of solar panels that provide electrical power to the vehicle.

- The key element of this design is servicing arm tipped with a flight qualified robot developed for the International Space Station.
  - "Dextre" (the Special Purpose Dexterous Manipulator) has 7-degrees-of-freedom in each of two arms, and a 23-foot total arm span.
  - In tests at GSFC it has demonstrated its ability to perform the servicing tasks scheduled for SM4 autonomously and/or telerobotically.

Manned Servicing Concept



- Servicing in Cis-Lunar Space with an ORION/CEV based servicing vehicle

NASA Current and Planned Activities

- Robotic Refueling Mission
  - International Space Station experiment demonstrating robotic technologies, tools and techniques for on-orbit satellite servicing
- Remote Robotic Oxidizer Transfer Test
  - A multi-Center, remotely controlled test of new technologies that would empower future space robots to transfer hazardous and corrosive satellite oxidizer into the propellant tanks of spacecraft in space today.
- Raven: Demonstration of a Real-Time Relative Navigation System
  - International Space Station demonstration of a real-time relative navigation system that would enable future spacecraft to autonomously rendezvous with both prepared vehicles and those not designed for servicing.
- Release of Cooperative Servicing Aids List
  - Suggested features that could be incorporated into new satellites to facilitate servicing in the future.
- Notional Robotic Servicing Mission Study
  - Examining the parameters of robotic satellite servicing and the technologies needed to achieve them.
- Cryogenic Propellant Storage and Transfer (CPST)
  - Project to assess performance of numerous technologies for cryogenic propellant transfer, such as vapor cooling, multilayer insulation, gauging and analytical models.

Summary

- ISS on-orbit assembly clearly demonstrated the feasibility of assembling large structures in orbit
- HST servicing missions demonstrated the feasibility of on-orbit servicing, and need for NASA's EVA capabilities
- The Orbital Express robotic servicing mission demonstrated the feasibility of autonomous rendezvous and docking, fluid transfer, and equipment replacement.
- Many options for human and robotic servicing are now available and should be incorporated in the design of future space observatories.
  - Modular design of components (ORUs and CRUs)
  - Orbital Express and Hubble Robotic Servicing Vehicle derivative vehicles
- Assembly and servicing of observatories at L2 or the EML1/L2 point will extend their operational lifetime and enhance their performance
  - Instrument replacement will enhance performance and science return
  - Propellant replenishment will greatly extend the observatory lifetime

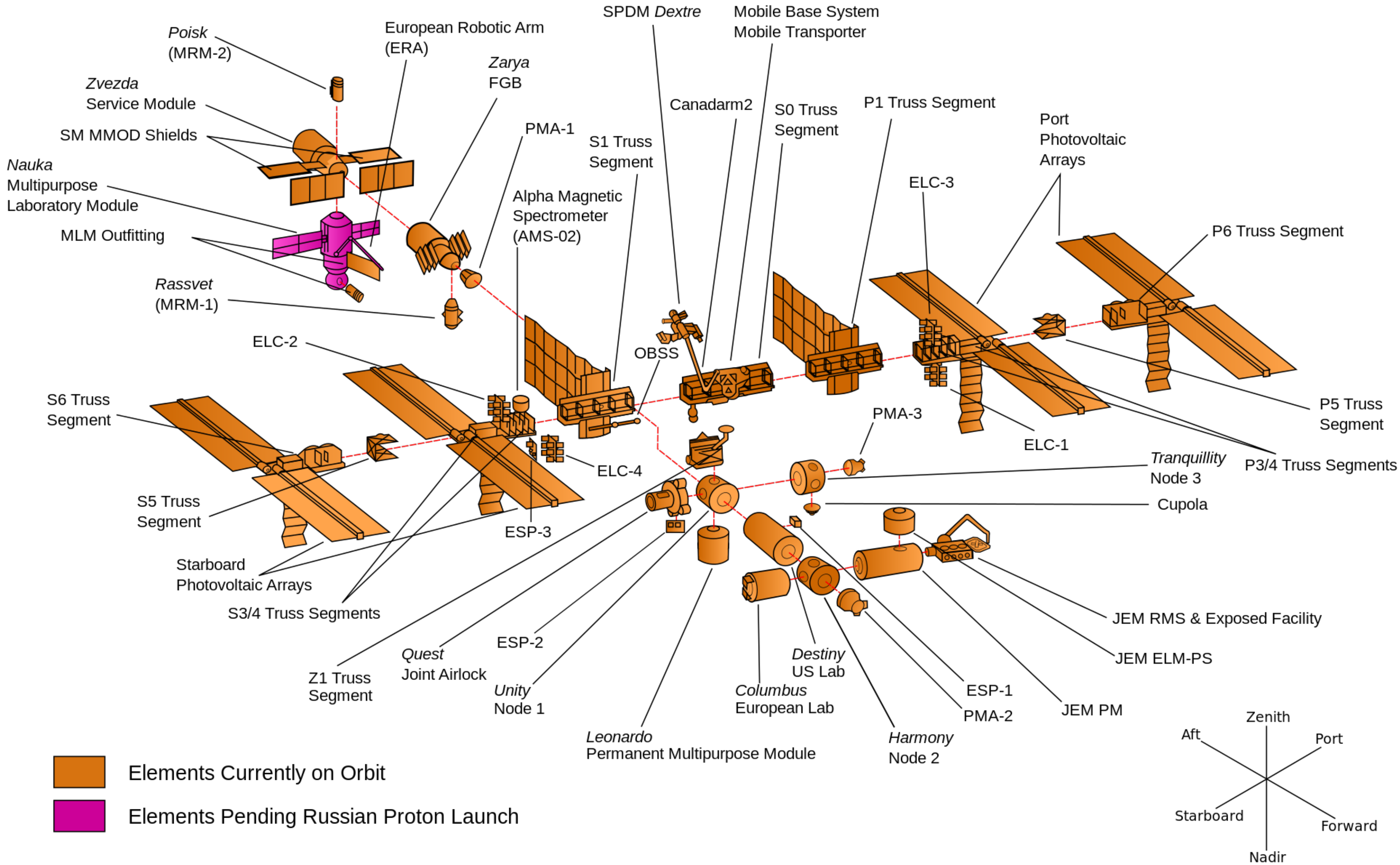
Thank You

Comments and Questions

Backup Charts

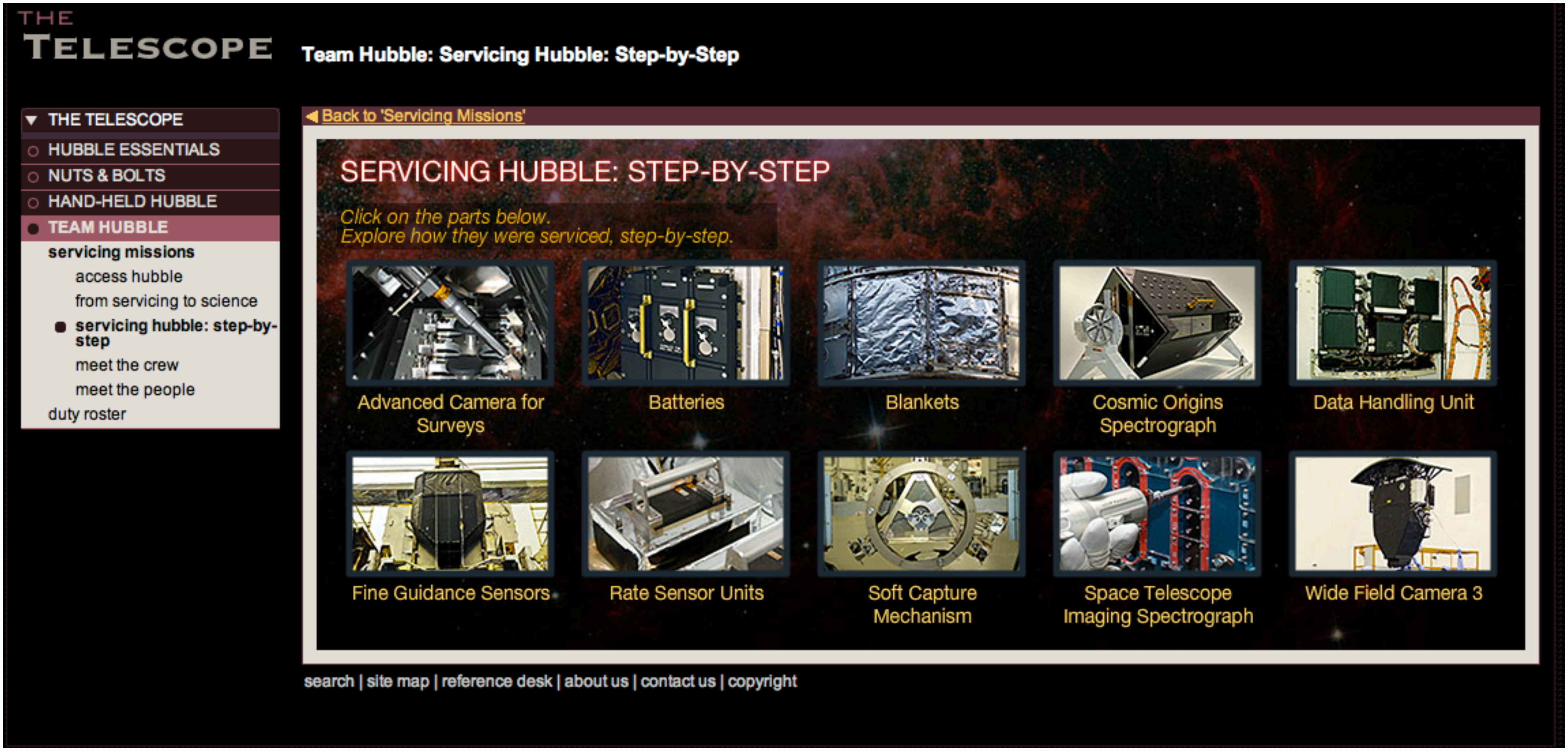
ISS Configuration

As of May 2011 (ULF6 - STS-134)



Servicing Hubble

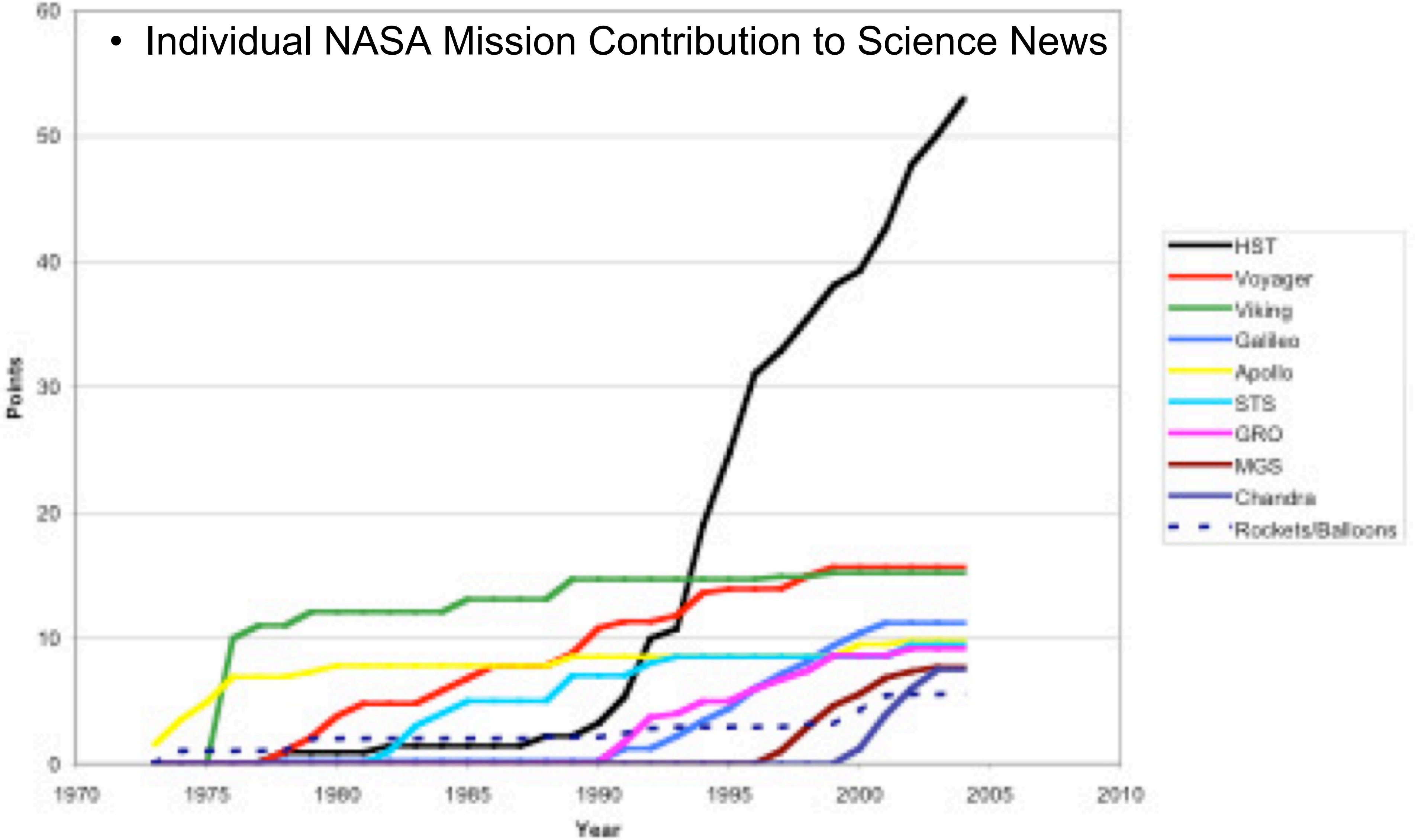
- Between December 1993 and May 2009, 5 Hubble Servicing Missions successfully corrected flawed optics, replaced degraded and failed components and installed new instruments that extended the observatories lifetime, improved its performance, and extended its scientific capability by orders of magnitude, producing a new and improved observatory after each mission.

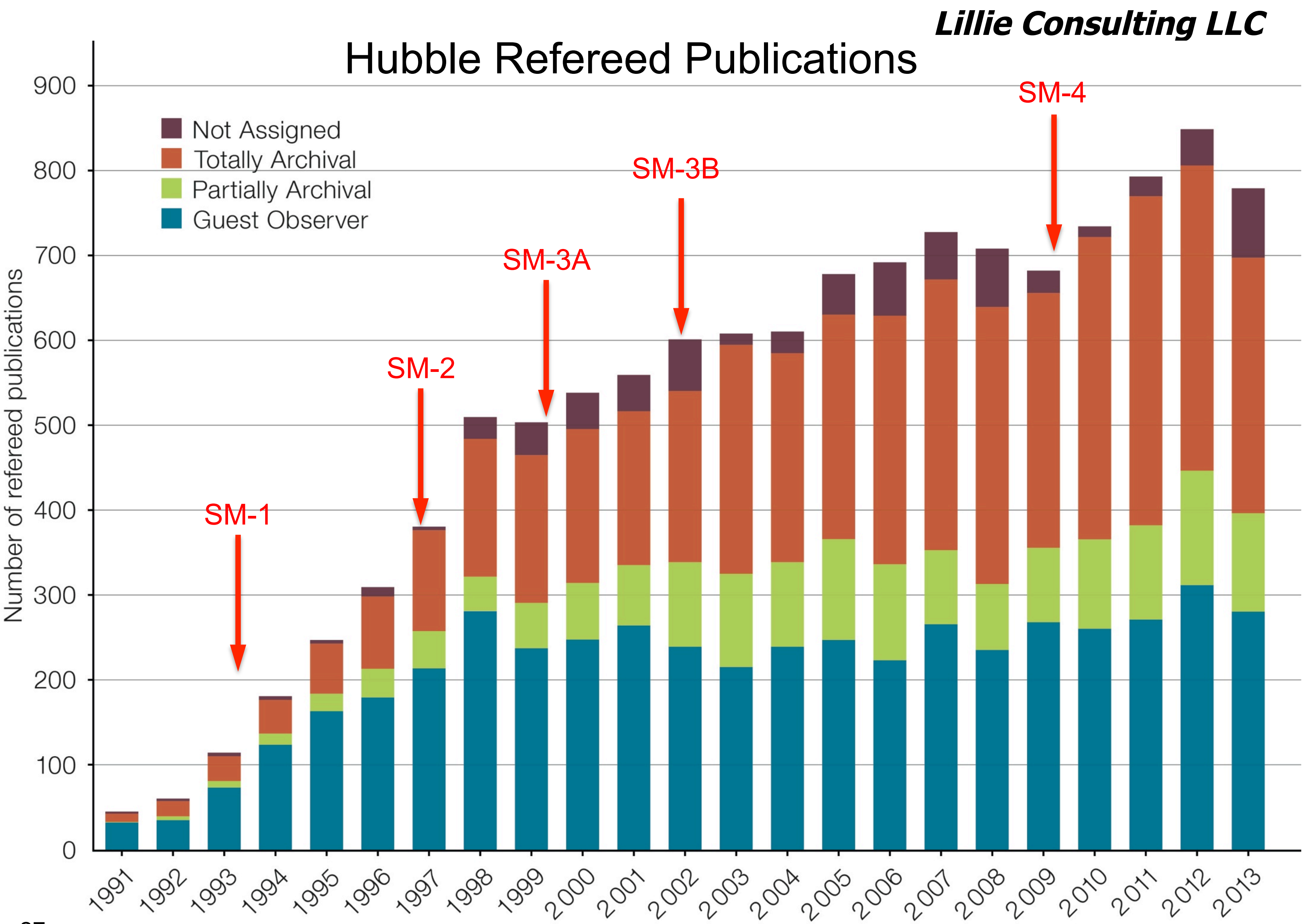


http://hubblesite.org/the_telescope/team_hubble/sm4/servicing-hubble

Science News Metric

- Individual NASA Mission Contribution to Science News

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Hubble Refereed Publications
Not Assigned
Totally Archival
Partially Archival
Guest Observer
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SM-2
SM-3A
SM-3B
SM-4
Number of refereed publications
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