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The Hubble SM4 Repair Mission

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Planetary nebula Kohoutek 4-55 (or K 4-55). The Hubble community bade farewell to the soon-to-be decommissioned Wide Field Planetary Camera 2 (WFPC2) onboard the Hubble Space Telescope taking this final "pretty picture." Credit: *NASA/ ESA/ Hubble Heritage Team (STScI/NASA).*

Between May 14 and 18, 2009 astronauts aboard the space shuttle Atlantis successfully carried out a major set of upgrades and repairs to the venerable Hubble Space Telescope (affectionately known as HST to astronomers), designed to prolong its useful scientific life for another decade. All in all, two new instruments were installed (the Wide Field Camera 3 and the Cosmic Origins Spectrograph), two old and defunct instruments were repaired (the Advanced Camera for Surveys and the Space Telesope Imaging Spectrograph), a backup for the essential Control and Data Handling computer was installed, one of the two Fine Guidance Sensors was replaced with a refurbished unit, and all of the Observatory's gyros and batteries were replaced. In addition, 3 sets of thermal blankets were replaced as well as installing several door latches and a new "soft capture mechanism". As I write this, the astronauts are awaiting clear weather in Florida for their return.

May 11, 2009, 2:01 p.m. (EDT). Space Shuttle Atlantis and its seven-member crew head toward Earth orbit and rendezvous with NASA's Hubble Space Telescope. Onboard were astronauts Scott Altman (commander), Gregory C. Johnson (pilot) and Michael Good, Megan McArthur, John Grunsfeld, Mike Massimino and Andrew Feustel. Credit: *NASA.*

In the Payload Hazardous Servicing Facility at NASA's Kennedy Space Center in Florida, technicians attach straps from a crane in order to lift the Science Instrument Control and Data Handling Unit, or SIC&DH, which was installed by astronauts John Grunsfeld and Drew Feustel on the first day of repairs. Credit: *NASA/Jack Pfaller*.

14 May 2009, fourth day of flight. Astronaut Megan McArthur looks through a window while working controls on the aft flight deck of Space Shuttle Atlantis on the first day of repairs. Credit: *NASA/Hubble Heritage Team (STScI/NASA).*

The following synopsis of what was accomplished in five very busy days on orbit is shamelessly stolen from reports sent to the Space Telescope User's Committee by Hubble scientists Ken Sembach, Helmut Jenkner and Neill Reid.

13 May 2009, third day of flight. An STS-125 crewmember onboard the Space Shuttle Atlantis snapped a still photo of the Hubble Space Telescope following grapple of the giant observatory by the shuttle's Canadian-built remote manipulator system on the third day of flight. Credit: *NASA/Hubble Heritage Team (STScI/NASA).*

Day 1: Wide Field Camera 3 and a new Science Instrument Control and Data Handling unit.

Astronauts John Grunsfeld and Drew Feustel performed the first spacewalks of the mission. After encountering unexpected resistance from the bolt that secures the A-latch of the WFPC2, and after trying several torque settings on the Multisetting Torque Limiter (MTL), Drew was finally able to loosen the latch manually with a ratchet without a torque limit. If that latch hadn't released or had broken, it would not have been possible to remove WFPC2, or to install the new wide-field, panchromatic camera WFC3. WFPC2, a venerable workhorse which has been the main camera on HST ever since the first servicing mission in the mid-1990s, will be returned to Earth. WFC3 has a larger field of view than WFPC2, and newer detectors which will allow it to see into the near-infrared as well as the visible and near-ultraviolet parts of the spectrum.

The astronauts also replaced the Science Instrument Control and Data Handling Unit (SIC&DH), another very high-priority piece of equipment necessary to format data and transfer commands between the science instruments and the hardware that transmits data to the ground. One of these two units failed unexpectedly last October, leading to a 7-month delay in the present servicing mission. By replacing this unit, the astronauts have ensured that there is once

again valuable redundancy in this critical piece of the communications chain within the payload.

Day 2: All new gyros and a set of new batteries.

This day proved every bit as exciting and dramatic as the first one, with astronauts Mike Massimino and Mike Good being on duty. Their first task was the replacement of all six gyros, packaged two each in three so-called Rate Sensing Units (RSUs). The installation of the RSUs has to take place in a fairly inaccessible bay, with the astronauts actually being located inside HST, taking care of neither damaging their suits nor the Fixed Head Star Trackers that are located right there. The installation of the first RSU went smoothly. However, the second RSU refused to get seated properly. The next unit was then tried and it went in place of the second. Finally, the stubborn RSU was attempted to be installed in the third location, but again without any luck. A fourth backup RSU was then retrieved and installed successfully. All these problems put the astronauts about two hours behind their timeline. But as there were no concerns with regard to consumables (e.g., oxygen), it was decided to press on with the battery exchange. The actual exchange then went extremely smoothly and more quickly than planned.

In all, this spacewalk lasted 7 hours and 56 minutes, making it the 8th longest in history.

15 May 2009, fifth day of flight and second of repairs. Astronaut Michael Good onboard the Space Shuttle Atlantis. Credit: *NASA/ Hubble Heritage Team (STScI/NASA).*

15 May 2009. Astronaut Michael Good peers through a window toward Atlantis' crew cabin interior, where his shirt-sleeved support team members busy themselves to aid the flight's second of five sessions of extravehicular activity to perform work on the Hubble Space Telescope. Astronaut Mike Massimino can be seen in the background at work on the port side of the shuttle's cargo bay. Credit: *NASA/Hubble Heritage Team (STScI/NASA).*

Day 3: Cosmic Origins Spectrograph and the repair of Advanced Camera for Surveys.

John Grunsfeld and Drew Feustel were again the spacewalkers on this day. The Cosmic Origins Spectrograph installation proceeded smoothly. The old COSTAR device (originally installed to correct the `myopia' in HST's primary mirror, but no longer needed by the newer instruments) was demated and removed from its bay, COS was installed and mated, and COSTAR was stowed for return to Earth in the same protective enclosure in which COS was carried to orbit. It sounds simple, but was only possible because of all the training and preparations by hundreds of people on Earth ahead of time! COS is designed to study the very faint ultraviolet signatures of the most distant objects in the universe, notably quasars, and to use them to probe the extremely tenuous intergalactic medium.

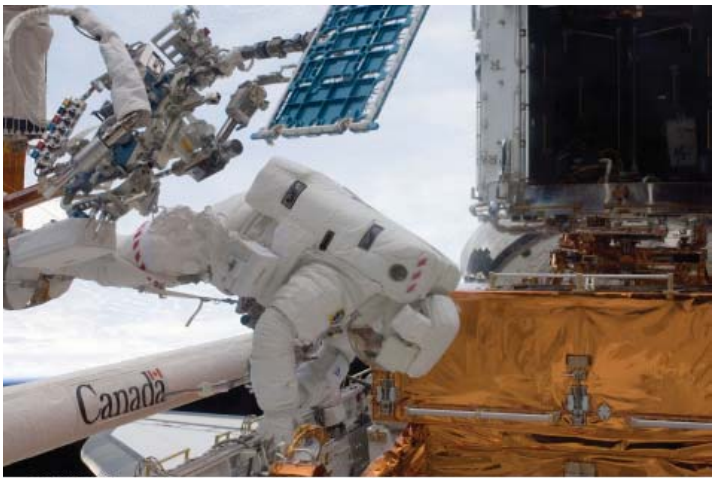
16 May 2009, sixth day of flight and third of repairs. Astronauts Andrew Feustel and John Grunsfeld (partially obscured at bottom) working on refurbishing and upgrading the Hubble Space Telescope. During the six-hour, 36-minute spacewalk, Grunsfeld and Feustel removed the Corrective Optics Space Telescope Axial Replacement and installed in its place the new Cosmic Origins Spectrograph. They also completed the Advanced Camera for Surveys electronic card replacement work, and completed the second part of the ACS repair, installing a new electronics box and cable. Credit: *NASA/Hubble Heritage Team (STScI/NASA).*

The repair of the Advanced Camera for Surveys is the first time a Hubble instrument has been opened on-orbit to replace electronics boards. In the case of ACS, this required several complex tasks. To gain access to the four boards needing replacement, John had to cut an aluminum grid, about as thick as a CD, with a special grid cutter. Then it was necessary to remove the electronics board enclosure cover, which has 32 small screws. A fastener capture plate was installed over the enclosure cover to keep the screws from drifting away. Once the cover was removed and after loosening and extracting four electronics boards, John inserted a replacement unit containing a set of four new boards and an integral replacement cover. The four replacement boards were seated one by one. The task was completed by attaching a new low voltage power supply to the outside of the instrument and routing power and communications cables between the new units and the existing connectors. The repair was completed well ahead of schedule.

Unfortunately, the High Resolution Channel of ACS (the one used primarily for planetary observations) could not be recovered. This result, while very disappointing to some of us, was not completely unexpected. The electrical short that occurred during the June 2006 Side-1 failure turned out to be upstream of the circuitry needed to power the HRC with the new ACS electronics. We learned this only when we tried to power the HRC after the repair. HRC recovery was not a formal requirement of the ACS repair and was done on a best-effort basis.

Day 4: Repair of Space Telescope Imaging Spectrograph.

Day 4 was Mike Massimino's and Mike Good's turn to tackle the STIS repair, considered by many to be the trickiest item on the list. In the early phases of the repair activities, Mike Massimino had to remove a large handhold on STIS that is in the way of the removal of a cover plate. In the process of removing the four bolts that hold that handle, one of the bolt headswas stripped and resisted all further attempts to remove it, in spite of several trips to various storage boxes in the payload bay to retrieve special tools. Finally, the call went up to Atlantis to simply break off the handle, which Mike did in short order. After this little problem, all seemed to be set for removing the cover plate with its infamous 111 screws, just to find out that the Mini-Power Tool ("screwdriver") had an empty battery. More time had to be spent to retrieve the spare from the air lock. After that, things went fairly smoothly. The screws were removed and captured in the so-called Fastener Capture Plate. The old faulty low-voltage power supply electronics board



17 May 2009, seventh day of flight and fourth of repairs. Astronaut Michael Good working on the Space Telescope Imaging Spectrograph. Credit: *NASA/Hubble Heritage Team (STScI/NASA).*

was removed, and the replacement put in. Finally a new cover was put on.

The scheduled replacement of several thermal blankets had to be delayed to Day 5.

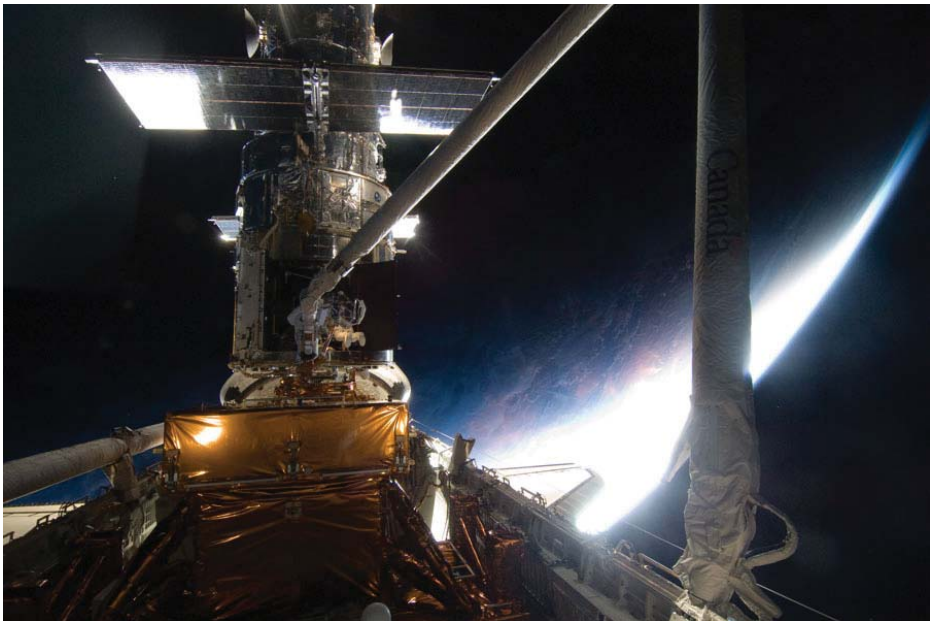
Day 5: Fine Guidance Sensors 2, more batteries and New Outer Blanket Layers blankets.

The final EVA saw John Grunsfeld and Drew Feustel in action again. First, they installed a second set of replacement batteries without any problems. Next came the replacement of one of the Fine Guidance Sensors. A few minor problems occurred while opening the doors, and the so-called A-latch resisted again, similar to what happened during the removal of WFPC2 during EVA-1. After a few tries with increasing torque settings on the power tool, it was again down to a wrench (without torque limiter), John's touch, and a little elbow grease. That did it again, and the A-latch yielded. The rest of the FGS replacement went very smoothly. The twin FGS units are essential for HST to point precisely at celestial targets, and are also scientific instruments in their own right. No FGS has ever failed, but each has been returned to Earth and refurbished at least once.

18 May 2009, eight day of flight and fifth day of repairs. Astronauts John Grunsfeld and Andrew Feustel (out of frame) installed a battery group replacement, removed and replaced a Fine Guidance Sensor and three thermal blankets (NOBL) protecting Hubble's electronics. Credit: *NASA/Hubble Heritage Team (STScI/NASA).*

A technician cuts a piece of aluminum kapton film that became part of a thermal blanket. Credit: *NASA.*

19 May 2009. Astronaut Mike Massimino occupies the commander's station on the flight deck of the Earth-orbiting Space Shuttle Atlantis during flight day nine activities. Earth's horizon and the blackness of space are visible through the windows. Credit: *NASA/Hubble Heritage Team (STScI/NASA).*



Astronaut Michael Good working against the background of the Earth. Credit: *NASA*.

The installation of the insulating New Outer Blanket Layers (NOBLs) over Bays 5 and 8 were the final scheduled tasks of the mission, and were completed with time to spare. So it was decided to do the NOBL installation over Bay 7 as well, which had been lower priority task.

During the clean-up at the end of the EVA, John unfortunately bumped into the aft Low-Gain Antenna and apparently some of its outer shell was damaged. As a last task, just before entering the airlock, John and Drew permanently installed a cover that was used for protection during this Servicing Mission. This was the only accident of the whole mission.

POSTSCRIPT

Preparations for the release of Hubble from Atlantis started early Tuesday morning. First, HST was grappled by the Remote Manipulator arm at 6:48 am EDT. HST was then unberthed from the Flight Support Structure that had held it attached to the orbiter for the previous six days. After slowly maneuvering the telescope to the appropriate release attitude and opening the aperture door, Hubble was finally released at 8:58 am, with Senator Barbara Mikulski watching at the Goddard Space Flight Center. Unlike previous servicing missions, the orbiter was not used to boost the orbit of HST this time.

Next comes the Servicing Mission Observatory Verification (SMOV) period, which will extend over approximately the next three months. During this period, the new and repaired instruments will be checked out in detail and initial calibrations will be performed in preparation for normal science observations. (Preliminary "aliveness tests" have already verified that all instruments are electrically functional and responding to commands from Earth.) SMOV will culminate with the publication of the Early Release Observations to both the scientific community and the public (expected in early September), intended to demonstrate the successful (re)commissioning of the instruments. Stay tuned for some spectacular new multi-color images!

The Hubble repaired. Credit: *NASA*.