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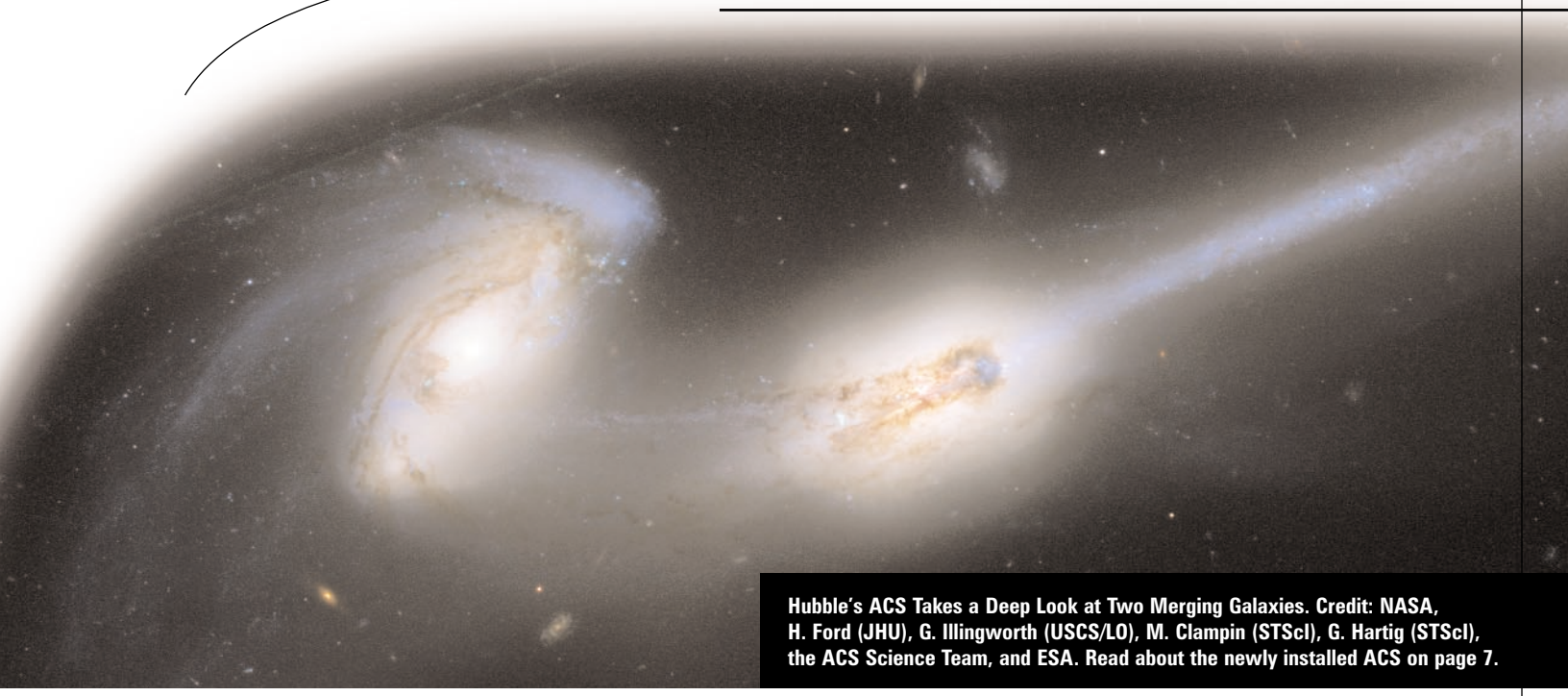
NEWSLETTER

Space Telescope Science Institute



Hubble's ACS Takes a Deep Look at Two Merging Galaxies. Credit: NASA, H. Ford (JHU), G. Illingworth (USCS/LO), M. Clampin (STScI), G. Hartig (STScI), the ACS Science Team, and ESA. Read about the newly installed ACS on page 7.

Lyman-α Emitters as Probes of Reionization

James E. Rhoads, *rhoads@stsci.edu,* & **Sangeeta Malhotra,** *san@stsci.edu*

The searches for high-redshift Lyman-α emitters and for the reionization epoch have had remarkably similar histories. Both were predicted in the 1960s. Both are strongly related to galaxy formation. And both have moved from theoretical concept to observational reality in the last few years. These two parallel strands of observational cosmology are now poised to converge: Lyman-α emitters can provide a new and robust test of the reionization of the intergalactic medium.

The conclusion that the intergalactic medium (IGM) is ionized followed closely the discovery of quasars. If the IGM were neutral, quasar spectra would be expected to show an absorption trough on the blue side of the Lyman-α line caused by Lyman-α absorption in the neutral IGM[1] (also known as the Gunn-Peterson effect). Isolated Lyman-α absorption lines from individual gas clouds (the Lyman-α forest) are a familiar feature of quasar spectra. However, there was no evidence for a continuous absorption trough until the recent identification of quasars at redshifts $z \sim 6$, leading to the inference that any diffuse neutral hydrogen in the IGM must be ionized at all redshifts $z \ll 6$. Last year, evidence for a Gunn-Peterson trough was reported in two bright $z \sim 6$ quasars originally discovered by the Sloan Digital Sky Survey, implying that observations are finally approaching the epoch of reionization[2].

Like the reionization epoch, the discovery of a field population of Lyman-α emitting galaxies is a long-awaited and exciting development in the study of the high-redshift universe. Such a population was first predicted by Partridge and Peebles in 1967, who correctly pointed out that the interaction of copious ionizing radiation from a protogalaxy's hot young stars with gas left over from the galaxy's formation will produce a strong recombination Lyman-α line. Many independent searches now find field Lyman-α populations at a range of redshifts $z = 2.4$ to 6.6[3]. All of these are fainter than the original predictions. This could be explained by small protogalaxy masses (Partridge and Peebles assumed protogalaxies of Milky Way mass) or by dust quenching of the Lyman-α line. Dust quenching is very effective because neutral hydrogen effectively scatters Lyman-α photons, which then travel by a random walk and accumulate long path lengths for dust absorption when traversing a galaxy's interstellar medium.

The Lyman-α galaxies appear to be a young population. Their median line strength (measured by equivalent width in emission) exceeds that produced by a stellar population of normal metallicity and initial mass function. The required photoionization can still be produced by starlight but only if the population is (a) young, < 10 Myr old, and (b) has either very low metallicity, $\ll 5$ % solar, or (c) has a top-heavy stellar initial

[1] *Gunn, J.E., & Peterson, B.A. 1965, ApJ, 142, 1633.*

[2] *Becker, R.H. et al. 2001, AJ, 122, 2850; Djorgovski, S.G. et al. 2001, ApJ, 560, L5.*

[3] *Hu, E. et al. 1998, ApJ, 502, L99; Stiavelli, M. et al. 2001, ApJ, 561, L37; Campos, A. et al. 1999, ApJ, 511, L1; Kudritzki, R.P. et al. 2000, ApJ, 536, 19; Rhoads. J. E. et al. 2000, ApJ, 545, L85; Fynbo, J.U. et al. 2001, A&A, 374, 443; Steidel, C. et al. 2000, ApJ, 532, 170. Ouchi, M. et al. 2002, ApJ in press; Venemans, B.P. et al. 2002, ApJ, 569, L11.*

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SUMMER [2002]

Good Times

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Watching from the comfort of mission control in Houston, it is easy to be seduced by the ease with which the astronauts emerge from their orbiting cocoon and go to work on the Hubble Space Telescope. It is only the background images of the Earth below and the blackness of space above that remind us that only a few centimeters of cloth and rubber separate them from immediate death. Floating in space with only their safety tethers binding them to the spacecraft, they go about their business without obvious anxiety. Yet to emerge from the airlock to see the heavens and Earth so juxtaposed must be a transforming experience, one that you and I will never experience down here on Earth.

I was asked recently in an interview if I would go into space like the astronauts. "In a heartbeat," I replied, yet it was an ill-considered reply. Spaceflight is a risky business, and the experience is short-lived. To witness a shuttle launch from a few miles away, where the blast lights up the sky and the noise overpowers every other sound, is to understand the danger should any one of a few million components choose that moment to fail. Yes, I would go, but there would be second thoughts along the way. The astronauts who do go risk their lives on our behalf.

There is enormous public interest in our ability to improve Hubble through servicing. Following an embarrassing start and a successful repair with the first servicing mission, the public sees Hubble as the comeback kid. And they know that we do more than fix it; we improve it. So when the first images were released from ACS, the New York Times put all four images on its front page, papers from Honolulu to London carried stories about the new capabilities, and the news networks took extra time to laud the success of the mission. Joe Rothenberg, until recently the head of manned spaceflight at NASA, told me that Hubble had more than twice the name recognition of the space station in his impromptu surveys. People know what we do, follow our success with pride, and pay attention to astronomy partly because the Hubble story is a serial saga of humankind's success in exploring the heavens.

We have come to take for granted this ability to improve our space telescope with astronaut servicing. That ability will disappear in the spring of 2004, when the final mission to upgrade Hubble is carried out. After that, Hubble will make scientific observations until a major component fails. It may make it until 2010, at which time NASA plans to bring Hubble back to Earth. The era of on-orbit servicing will come to an end and close a chapter in space exploration, just as the last Apollo mission closed the door on human exploration of the Moon. We will look back on these missions with faint nostalgia for a bygone era when the presence of humans was thought vital to getting the job done and to maintaining public support for the space program itself. We may well regret the loss of capability the astronauts have given us as well as the public interest it has maintained.

We are fortunate to have such a remarkable instrument as the Hubble Space Telescope at our disposal for a few more years. It requires many people to build the equipment, train the astronauts, launch the shuttle into orbit, and carry out the operations after the telescope is reawakened to cosmic light. We at the Institute extend our thanks to NASA, to the contractors, to the astronauts, and to our partners at Goddard Space Flight Center for making it all possible. I want to give my personal thanks to the people at the Institute who make it all go smoothly. We are in the midst of a high point in the history of astronomy, and we should all enjoy our good fortune before it recedes into the past.

These are the good times. Ω

mass function[4]. All of these properties are consistent with expectations for primitive galaxies, and we expect the Lyman-α emitters to be abundant around the epoch of reionization.

Because Lyman-α photons are resonantly scattered by atomic hydrogen in the ground state, their radiative transfer changes dramatically at the epoch of reionization. The Gunn-Peterson effect is one manifestation of this effect. However, the Gunn-Peterson trough becomes opaque at an optical depth of a few, while the optical depth for a fully neutral IGM is expected to be 3×10^5. Thus, a neutral fraction smaller than 1×10^{-4} could produce a Gunn-Peterson trough if the IGM were homogeneous. (More detailed calculations allowing for inhomogeneity of the IGM raise this threshold to about a 1% neutral fraction by mass[5].) In contrast, the most interesting and most rapid phase of reionization is the overlap phase, when the Stromgren spheres surrounding individual ionizing sources begin to merge. This stage is accompanied by a sharp jump in the ionizing radiation intensity, because a typical point in the universe can 'see' many sources of ionizing radiation once the Stromgren spheres percolate. The overlap phase corresponds to a neutral fraction of order one-half, much larger than the value for which a Gunn-Peterson trough effectively saturates.

Low-luminosity Lyman-α emitters offer another, complementary test of reionization. Because Lyman-α photons are resonantly scattered in the neutral universe before reionization, the Lyman-α line is spread dramatically in both angle and frequency. This produces a peak line intensity too weak for practical detection with present instruments[6]. Thus, the reionization redshift should be marked by a sharp decrease in the number counts of faint Lyman-α emitters. This method can only work for faint sources because bright ones ionize large Stromgren spheres, within which Lyman-α photons will not scatter. This drop in Lyman-α source counts provides a robust, direct way of determining the reionization redshift z_f and in principle can be used to look for inhomogeneity in reionization. Because the red wing of the emitted Lyman-α line is subject only to absorption by the red damping wing of the IGM, this effect becomes apparent at a much higher neutral fraction than the Gunn-Peterson effect (10% in the homogeneous case). Thus, the Lyman-α counts provide information closer to the central overlap phase of reionization. Combining both methods will yield a picture of the neutral fraction evolution as reionization proceeds.

[4] Malhotra, S. & Rhoads, J.E. 2002, ApJ, 565, L71

[5] Fan, X et al. 2002, AJ, 123, 1247.

[6] Miralda-Escude, J & Rees, M 1998, ApJ, 497, 21 ; Madau, P. & Rees, M. 2000, ApJ 542, L69; Loeb, A. & Rybicki, G. 1999, ApJ, 524, 527.

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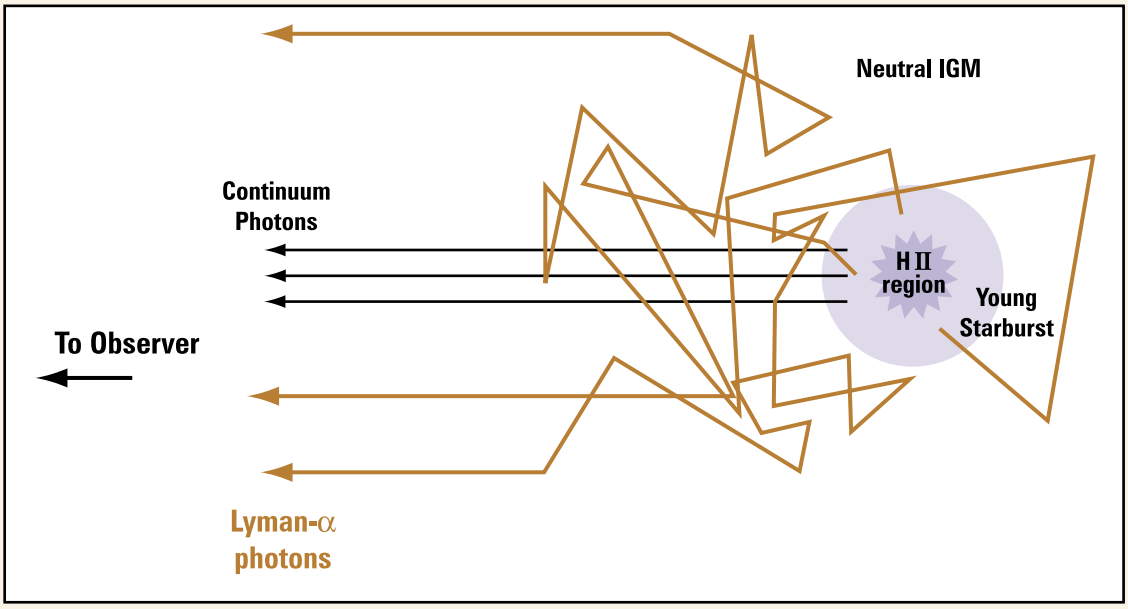
James Rhoads

Sangeeta Malhotra

Resonant Scattering Before Reionization



Radiative transfer of the Lyman-α line before reionization. Lyman-α photons scatter resonantly off atomic hydrogen in a neutral intergalactic medium. On average, each scattering results in a small redshift due to the Hubble flow. Eventually, the photon redshifts out of resonance and propagates freely. However, the effective photosphere for this to happen is ten to twenty arcsec, so large that the source will drop to an effectively undetectable surface brightness and will be missed by any currently feasible survey. Thus, the apparent abundance of Lyman-α sources will drop sharply across the reionization epoch. This test only works for sources of relatively low luminosity, because the Lyman-α emitter will produce its own ionized bubble in the IGM. If that bubble is large enough, Lyman-α photons redshift out of resonance before reaching the neutral IGM.

Luman-α
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The first application of this method demonstrated that $z_r > 5.7$ using $z = 5.7$ narrowband data from the Large Area Lyman Alpha (LALA) survey[7]. This is fully consistent with the Gunn-Peterson measurement at $z = 6$ and is just barely consistent with the Gunn-Peterson measurement at $z = 5.7$.

The Lyman-α search method recently yielded a new redshift record, the galaxy HCM-6A at redshift $z = 6.56$[8]. The observation of this source suggests that $z_r > 6.6$. However, some caveats remain. A single object may reside in the ionized bubble of a more luminous neighbor, so that its Lyman-α photons propagate unimpeded to the edge of the ionized region and by then have redshifted sufficiently to avoid resonant scattering. This mechanism can render a few Lyman-α sources visible back to the redshift of the first ionizing source but (by a simple volume argument) should apply to a minority of objects before the overlap phase of reionization. Also, the effect of the red damping wing is not a sharp cutoff. Near the reionization epoch, the optical depth will be a few, and the brightest line sources will remain above detection thresholds even after substantial attenuation[9]. However, the source counts will still show a sharp drop at z_r because sources that remain observable with optical depth greater than one are rare.

The detection of the first $z = 6.6$ galaxy thus provides a hint that the overlap phase of reionization occurred earlier and encourages us that Lyman-α source counts can constrain reionization. A robust application of the method will rely on reasonable samples, along many lines of sight and spanning a redshift range around $z = 6$. Ground-based observations lose much spectral coverage between wavelengths 0.7 to 1.0 micron, due to night-sky lines. Slitless spectroscopy with the G800L grism on the newly installed Advanced Camera for Surveys (ACS) on Hubble can provide continuous redshift coverage of Lyman-α emission lines in the range of redshift $z = 4$ to 7, currently the most interesting regime for studying reionization. Two parallel programs can potentially yield such a sample. The larger of these is the ACS Pure Parallel Lyman-α Emission Survey (APPLES), which is designed to exploit the area and sensitivity of the ACS Wide Field Camera to achieve a flux limit and volume coverage comparable to LALA (the largest volume modern Lyman-α survey) with a smooth redshift selection function that is impossible in ground-based data. Assuming nominal sensitivity and 50 independent fields, we expect to discover a few hundred Lyman-α emitters overall and several tens at redshifts $z > 6$ if the universe is mostly ionized by then. If it is still mostly neutral, we should observe a sharp decline in the number of Lyman-α galaxies across the reionization epoch. Ω

[7] Rhoads, J.E. & Malhotra, S. 2001, ApJ, 563, L5.
[8] Hu, E. et al. 2002, ApJ, 568, L75.
[9] Haiman, Z. 2002, ApJ, submitted.

Hubble Status after Servicing

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Servicing Mission 3B (SM3B) to the Hubble Space Telescope began on the morning of March 1, 2002, with the launch of the space shuttle Columbia. The launch took place at dawn, moments after Hubble had passed overhead at Kennedy Spaceflight Center. Columbia rendezvoused with Hubble two days later. The grappling and berthing of Hubble in Columbia's payload bay went very smoothly. Columbia's crew began a series of five strenuous Extra-Vehicular Activities (EVAs) the next day. During these EVAs, the crew replaced the two Solar Array 2 (SA2) wings, the Power Control Unit (PCU), and a Reaction Wheel Assembly (RWA). They also removed the Faint Object Camera (FOC), replaced it with the Advanced Camera for Surveys (ACS), and installed a cryocooler to revive the dormant Near-Infrared Camera and Multi-Object Spectrometer (NICMOS). Hubble was then safely re-deployed. Our thanks and congratulations go to the Columbia crew and the support crews at Johnson Space Center and Goddard Space Flight Center (GSFC) for their outstanding conduct of this mission.

As soon as Hubble was re-deployed, the operations staffs at GSFC and the Institute began the process of re-activating the observatory, getting the telescope back up and running, and commissioning the new instruments. In accompanying articles, Mark Clampin and Keith Noll describe the commissioning of the ACS and NICMOS, and here I will describe the status of the rest of the observatory.

Three of the EVAs were devoted to major upgrades of the power system, which was showing signs of age. The SA2 wings, installed in 1993 during SM1, had degraded output as a result of radiation damage. Astronauts replaced them with a new set of arrays. The new arrays use gallium arsenide (GaAs) cells on a rigid panel, rather than Si cells on flexible blankets like those used for the first two generations of arrays. Because the GaAs cells are more efficient than Si, the total area of the new

arrays is considerably less than the old arrays, which reduces the drag and the rate of decay of the Hubble orbit. The PCU is a complicated switching box, controlling the flow of power from the arrays into the batteries and from the arrays and batteries to all the electrical loads in the telescope. The original PCU had suffered the failure of a number of relays and had a bad connection, which affected the distribution of the load among the batteries. The PCU was not designed for on-orbit replacement and has a total of thirty-six cables entering it via connectors. Thus, it was a particularly difficult task for the EVA crew. In order to change it safely, all power on the telescope had to be shut down, which was the first time this was done since launch in 1990. The new PCU is working perfectly, with all functionality restored. The net effect of the solar array and PCU replacements has been a 27% increase in available electrical power. Most of that increased power has been devoted to the science instruments, especially the cooler for NICMOS. The new PCU has also permitted the engineers to resume the occasional process of reconditioning the batteries. The batteries will be replaced in SM4 in 2004.

Astronauts replaced one of the four Reaction Wheel Assemblies (RWA1) to upgrade the Pointing Control System (PCS). Hubble uses four RWAs—and needs at least three—to implement both fine pointing and large slews. To change the pointing direction, the PCS transfers angular momentum between the wheels and the telescope body. RWA1 had an intermittent electronics failure last fall that nearly placed the telescope into safe-mode. As the RWA1 problem was likely to be a failing solder joint, NASA decided to replace it before the problem became permanent. The new RWA is working well. Pointing jitter of the telescope is well within the .007 milliarcsecond specification. In fact, the installation of the rigid SA3 wings has improved the jitter performance of the telescope. The original, flexible SA1 design induced large pointing disturbances as the telescope passed between day and night. The SA2 design decreased these disturbances greatly but did not eliminate them. The SA3 wings are disturbance-free.

The Space Telescope Imaging Spectrograph (STIS) and the Wide Field Planetary Camera 2 (WFPC2) made it through the servicing mission activities with no change in performance. During each servicing mission, and in the period immediately afterwards, steps are taken to avoid the possibility of contaminating the optics in the instruments. This process worked well again, for both instruments, with no detectable sign of contamination. There was a small, unexplained increase in the STIS read noise after SM3A, in 1999. No such effect has been seen after SM3B.

Both STIS and WFPC2 resumed normal science operations about two weeks after Hubble was deployed. The ACS commissioning program has gone extremely well, and GTO and GO science observations have started, intermixed with commissioning activities. The cooler took about a month to bring the NICMOS down to the correct operating temperature, but the NICMOS and its cooler are now working well. We expect to enable NICMOS GO science programs in June. With four active instruments, and especially with the size of the ACS detectors, the daily data volume has (as expected) more than doubled. The scheduling systems, the Tracking and Data Relay Satellite System (TDRSS), and flight operations team have all kept up with the increased volume.

While a fair amount of work is still needed to fully characterize the ACS and NICMOS, it is clear that both instruments will meet or exceed expectations. We all look forward to the Cycle 11 science program, which should bring lots of wonderful new results. Ω

A Series of Fortunate Events: NICMOS and the NCS

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If the story of the resurrection of the Near Infrared and Multi-Object Spectrometer (NICMOS) were to be sold as a movie script, it would surely be categorized as a tale of suspense, complete with false starts, close brushes with failure, dramatic moments of decision, and, true to Hollywood form, a happy ending (so far).

The prequel is the well-known story of the mechanical deformation causing a thermal short in NICMOS, which was discovered soon after launch in February 1997. The defect shortened the NICMOS lifetime from four-to-five years to less than two. Almost as soon as the problem was discovered, NASA embarked on a bold plan to revive NICMOS by connecting a novel mechanical cooler to vestigial plumbing on NICMOS, which had initially been designed for ground testing. Fighting with limited budgets and a relentless

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NICMOS
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delivery schedule, a team led by Goddard Space Flight Center's Ed Cheng was able to bring the NICMOS Cooling System (NCS) to the launch pad on time for the servicing mission in February 2002. On orbit, the astronauts installed the NCS and the new solar panels—which supply the NCS's voracious demand for power—with amazing success, culminating this part of the drama.

The first moment of truth came five days after the Shuttle had released the serviced and repaired Hubble. At 23:13 (UT) on 16 March, ground controllers commanded the miniature turbine that drives the NICMOS cryocooler to start spinning. It started! The flow of telemetry showed the compressor turning at the anticipated rate of 7300 rps, and temperature sensors indicated the neon gas in the plumbing was beginning to cool. Nevertheless, about eight hours into the cool-down came a glitch. The turbo-alternator, another spinning part in the compressor loop, had hiccuped. Its speed dropped by almost 10% for several minutes, a behavior not seen in ground testing. Five minutes later came another hiccup, larger than before, and enough to trip the automatic safe-mode software, which commanded the NCS to shut down. Something—we still don't know what—had caused the turbo-alternator to stop dead. Many feared the worst.

After a day of analysis and worry, the NCS team decided to try again. This time when the start command was given, nothing happened. The compressor and turbo-alternator did not spin. It was a gloomy moment, when even the most faithful might have been forgiven for thinking that NICMOS was now dead. Fortunately, despair did not stop the NCS team from trying one more time. And, like a stubborn lawn mower on the third pull, the NCS started up again, this time without sputtering, and it has run smoothly ever since.

Nevertheless—as in any good suspense film—we are not through with plot twists yet. As the cooler chugged away, all eyes turned to the temperature sensors. Thermal models predicted that the cooler would take about ten days to reach the desired operational temperature for NICMOS, somewhere below 80 K. As can be seen in Figure 1, we soon realized that these predictions were too optimistic. The cooling rate was much lower than expected even though the cooler itself was delivering the promised performance. Even worse, extrapolations of the exponential cool-down trend consistently pointed to a final temperature of 110-120 K, too warm for effective scientific operation of NICMOS. By the ninth day of the cool-down, the cooling rate had reached zero. The system was actually warming up when the spacecraft was oriented at thermally unfavorable attitudes!

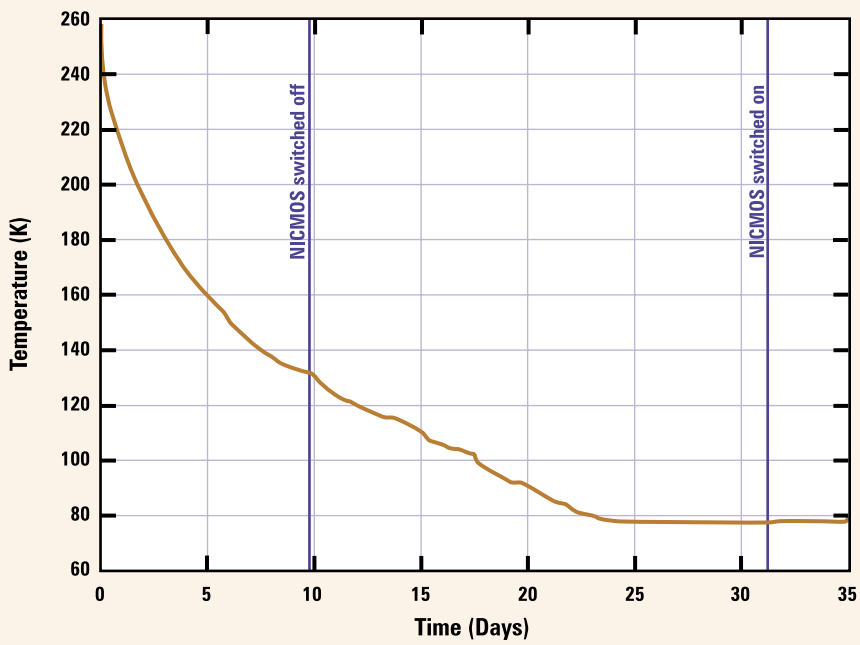

Figure 1. *The temperature versus time for the neon gas leaving NICMOS in the NCS cooling loop. Thermal models predicted cooling to below 80 K in ten days, when in fact the temperature was still 50 K warmer than required. NICMOS itself was shut off (first gray vertical line) to reduce the heat load and spur further cooling. By the twenty-third day, the system had reached the target temperature and has been under control ever since. One month after the cooling began, NICMOS was switched on and began its second life.*

In desperation, controllers gave the command to shut off NICMOS itself, to reduce the heat load by about 6%. The cooling rate immediately increased and, more importantly, changed to a nearly linear rate. For reasons that are still poorly understood, the small change in heat load pushed the cooling system over some threshold, into a more efficient cooling regime. By the twenty-third day, the neon gas in the tubes leading into and out of NICMOS had reached an average temperature of 70K—just where we wanted it to be. Cooling was essentially complete, though we had to wait several more days for all the components in the system to reach equilibrium. On the thirty-first day, controllers turned NICMOS on again, and the cooling system had sufficient reserve to maintain a steady temperature.

We have begun our long-planned recommissioning of NICMOS, the next part of the story. NICMOS has been amazingly stable in the three years since we last saw data. The focus and alignment in the three cameras has moved only slightly, the flat fields have their same familiar patterns, and there is no significant increase in the particulate contamination on the detectors.

With the NCS operating, the NICMOS detectors are at a temperature of 77 K, about 15 K warmer than in Cycle 7. At this temperature, the dark current is higher and roughly equal to the sky background. Significantly, there is no sign of the dreaded 'dark-current bump' seen during warm-up in January 1999. For most NICMOS science, the increase in dark current is more than offset by a 40% increase in detector quantum efficiency at these warmer temperatures. Amazingly, the revived NICMOS is significantly improved over its former self!

For the sake of brevity, this account has left out several subplots, including the unexpectedly long wait for surging in the cooler to cease, a wild roller-coaster ride in temperature when the thermal control software was briefly changed, and painstaking tests to preserve the fragile drive shafts on NICMOS's filter wheels. We don't know what dramatic events may await us in the future. Speaking for all those associated with NCS and NICMOS, we wish for a scientifically exciting and productive—but otherwise quiet and eventless—denouement to this story. Ω

ACS is Up and Running Great!

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During the recent, fourth servicing mission, astronauts installed the Advanced Camera for Surveys (ACS) in the Hubble Space Telescope. ACS features three imaging channels, each optimized for a specific goal. The Wide Field Channel (WFC) is a 200 x 200 arcsec field of view camera optimized for deep, survey imaging. The High Resolution Channel (HRC) is a near-UV optimized channel that fully samples the Hubble point spread function in the visible. The Solar Blind Channel (SBC) is a far-ultraviolet imager.

Immediately after the redeployment of Hubble, ACS successfully passed its functional test, and its orbital verification program began. In mid-June, WFC and HRC have been fully checked out, and the SBC is in the middle of its work-up. The charge-coupled device (CCD) detectors are achieving their nominal operating temperatures of -78 C and -80 C for the WFC and HRC, respectively. The CCD detector's dark noise and read noise are close to the figures previously reported in the ACS Instrument Handbook. The measured sensitivities are mostly within ~10% of the pre-launch estimates. The WFC and HRC image qualities meet specifications. We are performing additional precision mapping of the focal-plane occulting masks, putting the HRC coronagraphic capability behind schedule.

ACS started running General Observer/Guaranteed Time Observer (GO/GTO) science programs a few weeks after execution of the Early Release Observations (EROs). As exemplified by Figure 1, the EROs demonstrated the power of the WFC for deep-survey imaging programs. Other ACS capabilities are demonstrating their potential. The low-resolution spectroscopic capability provided by the grism is an example. In a GTO program, a few orbits of imaging with the i-band filter (F775W) and the grism (G800lp) yielded two SN1a supernovae, one with redshift 0.45 and a second of redshift 1.06. The latter was identified from its grism spectrum.

***Figure 1**. The ERO image of the 'Tadpole' galaxy (UGC 10214) showing a wealth of background galaxies.*

Currently, we are processing ACS observations using ground-based calibrations, except for bias and dark frames. Towards the end of orbital verification, we will update reference file databases and install revised sensitivities in the Astronomer's Proposal Tool (APT). Around the beginning of Cycle 11, we will add flight measurements of geometric distortion and flight flat fields to pipeline processing and on-the-fly recalibration.

ACS has met or exceeded expectations. It promises to be an exciting time as early observations by ACS programs yield new science results. Ω

NGST Project Status

Roelof de Jong, *dejong@stsci.edu,* **Nino Panagia, & Peter Stockman**

In December 2001, NASA conducted a two-panel Mission Definition Review (MDR) for the Next Generation Space Telescope (NGST), which is the formal review prior to the transition from feasibility studies to the detailed design phase (Phase B). Since then, the NGST Program at the Goddard Space Flight Center (GSFC) has reviewed and addressed the issues raised by the internal GSFC review team and the NASA Headquarters Independent Review Team (IRT). In response, NGST management has taken actions that will significantly affect the development of the observatory while ensuring its scientific potential.

The IRT recommended strengthening the role of the NGST prime contractor. Over the last few years, the engineering functions of the NGST Program at GFSC had grown, while the prime contractor's role had shrunk to providing the telescope system and performing the final integration and testing of the observatory. Now, NASA has re-emphasized the lead role of the prime contractor in total-observatory system engineering and has confirmed that the prime contractor will provide the spacecraft module (computer, power, telemetry, and avionics). Heretofore, the spacecraft was to be a contribution of the European Space Agency (ESA). These changes will reduce the management and technical complexity of the mission.

The IRT also recommended strengthening NASA's oversight of the NGST ground systems, including communications, flight operations, and science operations system. In response, NASA has decided that the same GSFC group that manages Hubble operations will manage the development and operations of the NGST Science and Operations Center by the Institute. Pooling operations expertise will facilitate the transition of capabilities developed for Hubble to those needed for NGST.

NASA has extended the selection of the NGST prime contractor for several months to permit the two bidders (Lockheed Martin and TRW/Ball Aerospace) to submit their 'best and final offers.' Also, NASA gave them a new launch date, June 2010, and funding to carry their work through selection. The new launch date reflects budget constraints in the next two fiscal years and better matches ESA's development effort. NASA has not changed NGST basic requirements like aperture and weight. Prior to the selection of the prime contractor, expected in August, the Institute will work with both bidders to establish their needs for the flight operations system, in preparation for the Systems Requirements Review in March 2003.

The final report of the IRT and approval to proceed to Phase B awaits Langley Research Center's independent cost estimate for the NGST development. By early fall, we expect to hear NASA's selection of the prime contractor.

NASA has announced the selection of the Near Infrared Camera (NIRCam) team and the NGST Science Working Group (SWG). We congratulate Marcia Rieke, the Principal Investigator of the NIRCam; George Rieke, the team lead for the Mid Infrared Camera (MIRI); the interdisciplinary scientists; and MIRI and NIRCam team members.

The first meeting of the SWG is scheduled for September 24-25, 2002 at the Institute. In addition to the newly appointed NGST flight SWG members and ex-officio representatives of NASA Headquarters, GSFC, and the Institute, participants will include representatives of the instrument teams and international partners (ESA and the Canadian Space Agency) as well as representatives of the selected prime contractor. We expect the agenda topics to include the SWG charter and organization, NGST project organization and status, Integrated Science Instrument Module status, status of individual science instruments, roles and plans of the Institute, and an update of the NGST science requirements. Ω

Simulation credit: *Christine Klicka (STScI)*

News from the Multi-Mission Archive at STScI (MAST)

Paolo Padovani on behalf of the MAST team, *padovani@stsci.edu*

Hubble Data Archive Status

The Hubble data archive now contains about 8.4 terabytes of data in about 266,000 science data sets. The archive ingestion rate reached 8.6 gigabytes per day in April after the servicing mission, and increased further in May, to about 11 gigabytes per day. This is an all-time record, almost three times as high as the average ingest rate for the past year. Lately, researchers have retrieved data from the archive at a rate almost 6 times higher, about 23 gigabytes per day.

Navigating through MAST

MAST currently provides many different types of services and searches, some of which are recent. This article provides a primer on MAST searches. It also introduces two new features: (1) the expansion of the pointing tools to include the Space Telescope Imaging Spectrograph (STIS) and the Faint Object Camera (FOC) and (2) a new search tool for papers based on observations from Hubble and the International Ultraviolet Explorer (IUE).

An on-line version of this primer is available at **http://archive.stsci.edu/mast_search_primer.html**.

Quick Target Search

The simplest, quickest way to search for data on a particular object or position is to use 'Quick Target Search.' This tool is available from our main page at **http://archive.stsci.edu**. To use it, the user either enters a target name, which is resolved by SIMBAD (the astronomical database of the Centre des Données astronomiques de Strasbourg) or by the NASA/IPAC Extragalactic Database (NED), or enters J2000 coordinates, where right ascension and declination are separated by a comma. The Quick Target Search returns a list of all relevant MAST datasets, including links to preview and dataset pages. By selecting 'Band/Data Type(s),' the user can restrict the search to specific wavelength bands. The output page summarizes the available datasets ordered by mission.

The Scrapbook

Using the spectral/imaging Scrapbook (**http://archive.stsci.edu/scrapbook.html**), the user can delve deeper, to peruse selected (preview) spectra and images from most MAST missions. Using parameters like exposure times and observing date, we have chosen these observations as 'representative' of a named target or position on the sky. For spectra, we have selected the maximum exposure time and lowest dispersion for a given grating/wavelength configuration, which provides the broadest wavelength coverage. For images, we have chosen on the basis of exposure time, eliminating multiple pointings. In the Scrapbook, the results page provides links to preview and dataset pages, where the user can both learn what data are available and gain a multi-wavelength view of the source. Using an option available for the spectral Scrapbook, the user can co-plot representative preview spectra. After selecting them, the user clicks 'plot marked spectra,' which displays them all on a single plot of calibrated flux versus wavelength. The result is a single, broad-band spectrum, possibly combining the results of multiple instruments and missions. (The Scrapbook is not available for Solar System targets.)

The Mission Interfaces

Dedicated search interfaces permit advanced searches for all MAST missions. The user can access these interfaces from the individual mission pages or from **http://archive.stsci.edu/data.html**. By this route, the user can search for a particular object or a given position, specifying a variety of observational parameters, including exposure time, observing date, filters, and gratings. The result is a list of datasets matching the criteria, including various parameters, like target name, coordinates, instrument, and the number of published papers associated with the proposal ID (Hubble) or dataset name (other MAST missions.) We are currently developing new features for the search interfaces.

Searching on a List of Targets or by Class

We provide two options for archive users to determine which sources on a list or in a class of astronomical objects have MAST data. At **http://archive.stsci.edu/search/upload.html**, the user can upload a file containing a list of sky positions to cross-correlate with MAST holdings. The

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result is a table with links to the MAST search pages for individual missions. Or, at **http://archive.stsci.edu/search/**, the user can employ our catalog cross-correlation interfaces to correlate the MAST archive with the Hipparcos and Sky2000 star catalogs, an active galactic nuclei catalog, or the Abell catalog of clusters of galaxies. We plan to expand these class-search options.

The Hubble 'Pointings' Search

To learn how many times an instrument has imaged a given region of the sky—with how many filters and when—the user can search Wide Field Planetary Camera 2 (WFPC2), STIS, and FOC exposures through the 'pointings' interface at **http://archive.stsci.edu/cgi-bin/point**. This tool is useful for variability studies and serendipitous searches. It can provide answers to questions like, "How many and which WFPC2 pointings have more than two I-band exposures and two B-band exposures?" Or, "How many and which STIS pointings at low galactic latitude have observations separated in time by at least 100 days?" With the pointings interface, the user can search by position and by ranges in Galactic latitude, ecliptic latitude, right ascension, and declination. Future versions will include other Hubble imaging instruments, notably the Near Infrared and Multi-Object Spectrometer (NICMOS) and the Advanced Camera for Surveys (ACS). They will also allow multi-instrument searches, such as, "Which WFPC2 pointings have more than two U-band exposures and NICMOS data?"

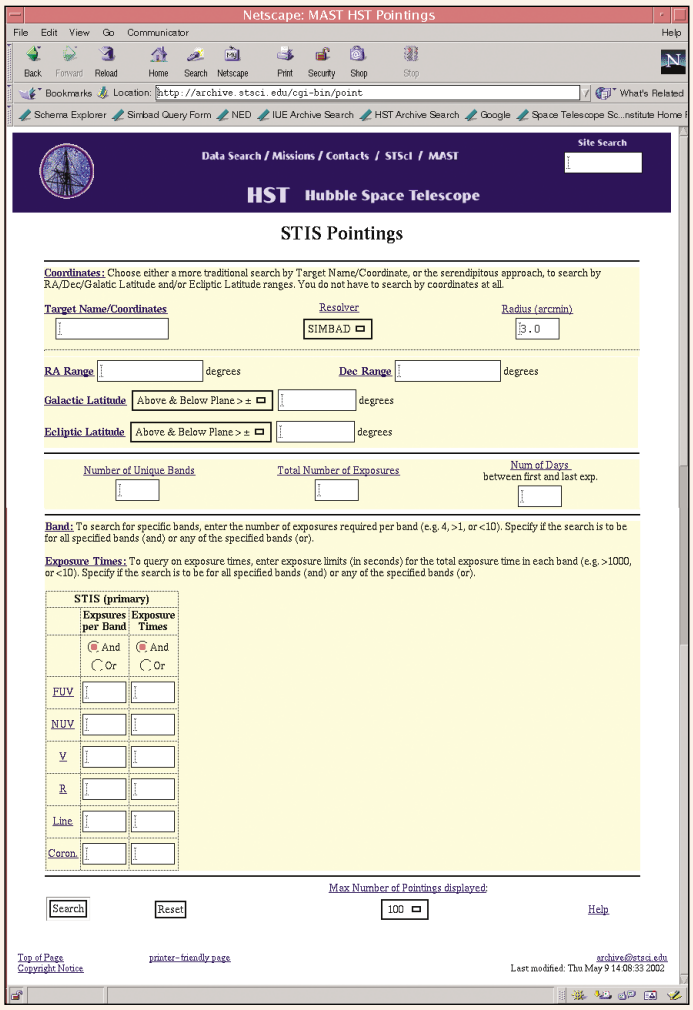

Figure 1. *The new STIS pointings interface, which allows users to query the archive to check how many times the instrument has imaged a given region of the sky, with how many filters, and when. The interface allows searches by position, ranges in Galactic latitude, ecliptic latitude, right ascension, and declination. Numbers of exposures and exposure times can also be constrained.*

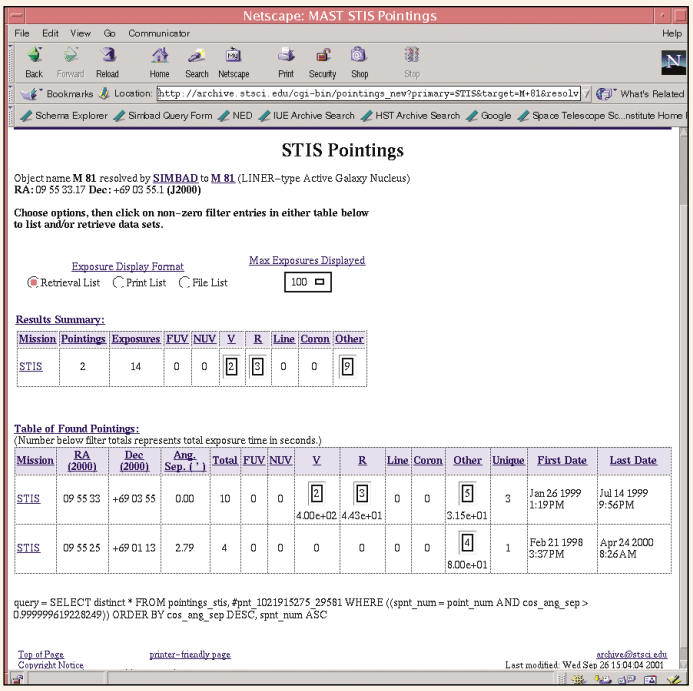

Figure 2. *The output of a search around the position of M 81. Two STIS pointings are found, the first one with ten exposures, the second one with four. Clicking on the numbers inside the boxes provides a list of datasets, which can then be retrieved from the archive.*

The Hubble Parallel Search

Responding to the recommendations of the Cycle 7 Time Allocation Committee, we began the Archival Pure Parallel Program in June 1997, at the start of the Cycle 7 observations. This program continues. It seeks to maximize the scientific return from Hubble by taking parallel data with STIS, NICMOS, WFPC2—and now ACS whenever these instruments are not prime. The resulting data have no proprietary period and are promptly made available to the community. The Archival Pure Parallel Program strives to build large, consistent, and coherent datasets for the Hubble archive. Users can find more information at **http://www.stsci.edu/instruments/parallels/** and access all pure parallel data at **http://www.stsci.edu/instruments/parallels/pure_parallels.html**.

The Abstract Search

Users interested in checking what science observations have been approved for Hubble can use the Abstracts Search at **http://archive.stsci.edu/cgi-bin/hst_abstracts**. The user specifies search words or phrases in a syntax similar to the AltaVista simple search. The search returns all matching proposal abstracts, information about the proposal, and—if the proposal has been executed—links to the archived data. A similar tool will soon be on-line for IUE and Extreme Ultraviolet Explorer (EUVE) proposal abstracts.

The MAST Data/Paper Links and Search Tool

MAST provides links between archived data and papers based on those data. These links work two ways. First, archive users can find the refereed papers based on MAST observations that were found in a mission-interface search. Clicking on the number in the 'Ref' column (which is the number of published papers associated with the found observations), the user can display the list of found papers, including title, first author, and journal reference. The latter follows the Astrophysics Data System (ADS) bibliography code and is also a link to the ADS Abstract Service, which provides electronic access to the paper. Second, readers of on-line journals at the ADS can access the data when a paper is based on MAST holdings. At the end of 2001, MAST included links to almost 8,000 papers, of which more than 3,100 were based on Hubble data and almost 3,000 on IUE data.

A list of MAST-based papers can also be searched at ADS, which now provides dedicated forms for Hubble and IUE papers. These forms are accessible at **http://adsabs.harvard.edu/Groups/search/HST** and **http://adsabs.harvard.edu/Groups/search/IUE**. The user can search on all the usual ADS fields, which include authors, object names, and abstract. Alternatively, the user can scroll down the ADS main page (**http://adsabs.harvard.edu/abstract_service.html**), select "At least one of the following groups (OR)," and then select HST and/or IUE from the group list.

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High-Level Science Products in MAST

We encourage our users to contribute high-level science products to MAST, including fully processed (reduced, co-added, cosmic-ray cleaned, etc.) images and spectra as well as ancillary products, like catalogs and object brightness profiles. Existing examples include the co-added images and associated object catalogs of the Hubble Deep Field and images from the Hubble Medium Deep Survey. We expect the Hubble Treasury, Archival Legacy, and large programs from Cycle 11 to become main sources of high-level science products in the next few years. Nevertheless, we also welcome smaller contributions from previous Hubble programs and other MAST missions, such as IUE, Far Ultraviolet Explorer (FUSE), and the ASTRO instruments. We will add most such contributions to the searchable MAST database, for retrieval with the original data files. We have posted guidelines for high-level science products—including recommended file formats, naming conventions, and delivery protocols—at **http://archive.stsci.edu/hlsp_guidelines.html**. Inquiries about contributing data to MAST should be directed to Michael Corbin, the archive scientist responsible for contributed data, at **corbin@stsci.edu**.

New MAST Tools for FUSE and Hubble Proposal Preparation

To help users prepare proposals and data-mine, we are enhancing the search tools for spectroscopic datasets in the MAST archive.

This summer, we will add a 'distinct' button option to the search forms of several MAST missions. Users selecting this option will obtain as output a list of single entries (datasets). For example, a user preparing a FUSE or Hubble proposal will be able to formulate a list of observed targets in a given region of the sky or for classes of objects.

For FUSE, we have moved the APERTURE keyword to the main search form at **http://archive.stsci.edu/cgi-bin/fuse/science**. This provides the capability of efficient searches of data for similarly observed science and calibration objects.

A new co-plotting tool has been placed on line to enable the overplotting of preview spectra from several datasets in a single operation. It can be used for any combination of targets from different missions—Hubble, IUE, FUSE, ORFEUS (Orbiting Retrievable Far and Extreme Ultraviolet Spectrometers), WUPPE (Wisconsin Ultraviolet Photo-Polarimeter Experiment)—to create a plot for an arbitrary selection of datasets. This tool is available at **http://archive.stsci.edu/mast_coplot.html**.

StarView News

We have released StarView 7.1. Users can automatically update their version. We have notified site managers to update versions of StarView accessed from a cluster.

StarView 7.1 has an updated look to make older features more obvious and easier to find and use. Query speed is significantly improved. Buttons on the results screen enable some of the most commonly used cross-qualification follow-up queries. Quick screen results include: show the proposal abstracts of the selected datasets; show more observational details of the selected datasets (opens the appropriate instrument screen(s)); and display search results based on dataset names.Since the release of StarView 7, users have been able to search and request data from any MAST holdings, including IUE and FUSE. Now, StarView 7.1 enables spectral previews to be displayed with SpecView, which was described in the spring 2002 Newsletter. With this feature, the user can plot, overplot, change axes limits, and perform limited analysis. When displaying image previews or Digitized Sky Survey images, users can choose between using JIPA, a simple image viewer, and the APT's Visual Target Tuner (which must be bundled with the StarView distribution).

Please visit our StarView homepage at **http://starview.stsci.edu** for the new download and further information.

The Future of MAST

Last summer, the Institute commissioned two internal studies for work on the future archive. Megan Donahue and Niall Gaffney co-chaired the Future of Archive Services at Space Telescope (FASST) study, which focused on archive interface issues and MAST services. Gerry Kriss chaired the Study of the Hubble Archive & Reprocessing Enhancements (SHARE), which focused on enhancing the scientific value of the data produced by the on-the-fly reprocessing pipeline. Both studies produced white papers, available at **http://archive.stsci.edu/fasst/** and **http://www.stsci.edu/science/share**.

The FASST study made recommendations on instrument retirement, user-contributed science data, and interface improvements, like seamless searches of MAST and external archives. SHARE looked at data process and reprocessing, recommending improvements in several key areas, like absolute astrometry, image combination, external catalog usage, and object catalog production. With lower priority, SHARE recommended STIS spectra combination and custom post-calibration analysis scripts.

The two committees made some common recommendations. Chris Blades is now leading a committee to scope, prioritize, and implement the FASST and SHARE recommendations that require resources from multiple divisions in the Institute. The MAST team will implement some of the recommendations, such as (1) the drafting of a policy for accepting user-enhanced science data (high level science products) into the Hubble archive and (2) completing the negotiations for storing the final versions of the Goddard High Resolution Spectrograph (GHRS) data, produced by the Canadian Astrophysical Data Center (CADC) and the FOS data, produced by the Space Telescope European Coordinating Facility (ST-ECF). (The GHRS and FOS collections will soon be available from all three sites.)

As described in a separate article in this Newsletter, the Institute is collaborating with the CADC and ST-ECF to provide WFPC2 data in the form of stacked and cosmic-ray-rejected images with improved absolute astrometry by correlation with the USNO2 and the GSC-II star catalogs. This project will also collect image statistics, like object density and detection limits, which users could query in archive searches. We expect that this project will extend in the future to include optimized ACS science products. Ω

May Symposium: Astrophysics of Life

Mario Livio, *mlivio@stsci.edu*

The topic of the 2002 May Symposium at the Institute was "Astrophysics of Life." The title reflected the desire to concentrate on the astrophysics side of astrobiology, while continuing with the theme established in recent years of bringing together different research communities. The Symposium was attended by about 150 participants, with interests ranging from geology, biology, and chemistry to physics and astronomy. The fact that this symposium took place at the Institute was no accident. The Hubble Space Telescope, originally heralded as a cosmology tool, has, perhaps unexpectedly, also become an astrobiology machine. Hubble has not only shown that dusty disks—the raw materials for planet formation—are ubiquitous around young stars but also detected the first atmosphere around an extrasolar giant planet.

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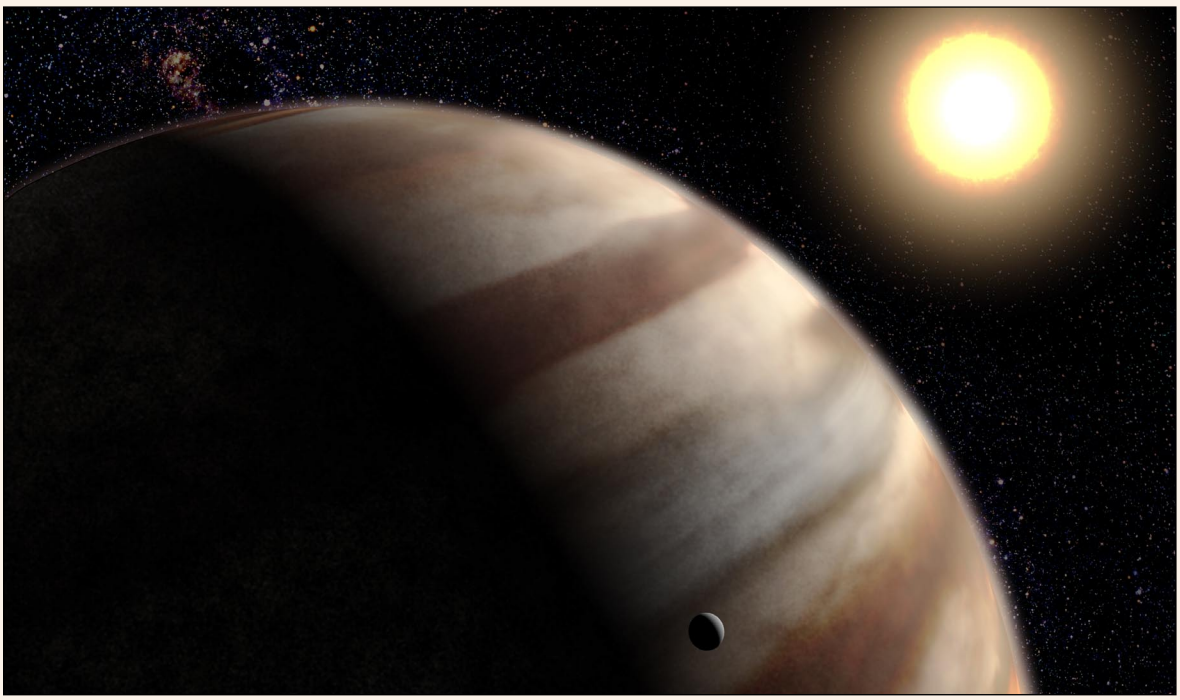

Simulation credit: *Greg Bacon (STScI)*

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Astrobiology has come a long way from its humble beginnings. While no planet around a sun-like star was known until 1995, no fewer than 85 such planets are known today, as was described in the Symposium by Geoff Marcy. Many of the details are still missing, but the general belief is that these planets form in the accretion disks surrounding young stellar objects and then migrate inward due to transfer of angular momentum between the planets and the disks. Dave Koerner, Pascale Ehrenfreund, and Jack Lissauer discussed the processes involved—from planetary formation to planet-disk torquing. John Bally emphasized the constraints imposed on the timescale of giant planet formation by the short lifetime of the disks, which are being evaporated by the intense radiation field.

Nevertheless, having giant planets is not a sufficient condition for harboring life. In order to answer the key question—"Under what conditions can life emerge and evolve?"—we must learn lessons from the Earth and our own solar system. Ken Nealson, George Cody, and Chris McKay discussed prebiotic chemistry and the emergence, origin, and essential characteristics of life on Earth, including in extreme conditions. Chris Chyba, Karen Meech, and Priscilla Frisch followed with discussions of the physical conditions in various parts of the solar system and potential sites for life or its 'building blocks,' particularly Mars, Europa, and comets. Scott Sanford, Gary Melnick, Jim Kasting, and Guillermo Gonzalez presented general reviews of organic synthesis in space, the availability of water, and the question of habitable zones (both around stars and in the Galaxy).

Once life starts, it may on the one hand influence its environment and on the other be exposed to various ecological constraints and cosmic dangers, like radiation fields and supernova explosions, as presented by Kevin Zahnle, Narciso Benitez, and John Scalo.

An important part of the Symposium was devoted to the potential characteristics of extrasolar terrestrial planets and to their photometric and spectroscopic signatures, including biomarkers. Victoria Meadows described an ambitious program of characterization, and Sara Seager, Ed Turner, and Wes Traub presented specific signatures. Ron Gilliland and Kailash Sahu described the use of transits (of host stars by planetary companions) and microlensing to detect planets and determine their masses. Transits have already proven successful in detecting the first atmosphere around an extrasolar planet, and microlensing is currently the only available technique for detecting planets down to an Earth mass and determining their statistics.

One special session was devoted to future missions, including Next Generation Space Telescope (NGST) and Terrestrial Planet Finder (TPF), and to an exposition of NASA's and ESA's astrobiology programs. Charles Beichman presented two concepts—the optical-ultraviolet coronagraph and the infrared nulling interferometer—as potential TPF architectures. Steve Beckwith demonstrated that NGST could be instrumental in the study of extrasolar planets. In particular, for previously detected transits, NGST has the potential for distinguishing spectroscopically between astrobiologically interesting aspects of extrasolar planets (in the most favorable cases). Dave Des Marais presented NASA's astrobiology program and its goals, while Alvaro Gimenez described ESA's program.

The last session of the Symposium was devoted to four topics that attempted to examine astrobiology from a 'big picture' perspective. Two of the talks were devoted to the detection of life and two to the 'meaning' of life. Jonathan Lunine summarized the current thinking about the detection of life in general, while Jill Tarter described both the past and future efforts of SETI to detect signals that might indicate the existence of extraterrestrial intelligent life.

Juan Perez-Mercader gave a clear overview of 'emergence' phenomena—how patterns and structures (including life itself) can arise from a relatively simple set of rules. Finally, Mario Livio examined the connections between cosmology and life. He reviewed the evolution of the universe from the perspective of the formation of elements (such as carbon) necessary for life and described more speculative ideas concerning the values of the constants of nature in the context of an ensemble of universes. Ω

Interview: Merle Reinhart

Merle, you have played a leadership role in implementing the Servicing Mission Orbital Verification (SMOV) program after the recent servicing mission. What is SMOV all about, and what do you actually do to make it happen?

The basic concept of SMOV is to commission the new instruments and recommission the observatory, so that Hubble can get back to doing science with the new generation of instruments as soon as possible.

The real work of SMOV begins about a year ahead of time, when we define the Activity Descriptions (ADs). We assemble these into the SMOV Plan, which we use as a basis for developing the Phase 2 proposals to execute the operations and observations that accomplish the goals of SMOV. The Servicing Mission Office in the New Instrument Support Division coordinates the SMOV work.

Developing the Phase 2 for SMOV is a bit different than the normal GO process. In the case of SMOV, launch could be delayed, the Servicing Mission could go different than expected, or there could be hiccups in executing the SMOV Plan itself. As a result, the SMOV visits must be schedulable nearly any time. Thus, instead of the default

'SCHED 30' special requirement—meaning that the visit should be schedulable in ~30% of the available orbits—SMOV requires 'SCHED 100'. We also discourage overly constraining special requirements such as 'LOW SKY', 'ORIENT', and 'CVZ'. If the availability of a particular target is not large enough, we ask the PI for alternate targets and visits, as there will be little if any time for rework when the time comes to execute a particular proposal. We discuss such aspects in Proposal Implementation Team (PIT) meetings with the PI, members of the instrument team, representatives of commanding, scheduling representatives, and OPUS, and, at times, instrument or subsystem engineers. All around one table, we discuss any issues or problems with a proposal, such as, Will the proposal meet the goals of the AD? Will it be flexibly schedulable? Can we get the data to the ground, processed, and to the PI in the timeframe requested? Will we need special commanding or other special handling to do something that the ground system doesn't support?

For the February 2002 servicing mission, SM3B, George Chapman and I began in early January to build 'representative calendars'—scheduling visits in the order of the SMOV Plan, feeding any deviations back into the Plan. Once launch occurred, the real work began, as we merged all the SMOV proposals and database changes into the operations environment, to prepare for the release of Hubble after servicing. The post-release period was a very intense two-to-three weeks, when we quickly generated Science Mission Specifications (SMSs)—scripts for spacecraft command loads—and struggled to get back on the Science Planning and Scheduling team's nominal calendar-building schedule. We had only twenty-four hours after release to deliver the first thirty-hour SMS and only a day after that to deliver the second, six-day SMS.

As you can see, there are many, various aspects of SMOV to figure out and successfully get ready for the mission. Nevertheless, from a scheduling point-of-view, probably the trickiest part of SMOV is folding all the disparate requirements and desires of the separate commissioning activities into an integrated set of calendars. For instance, early in SMOV, the PIs must see their data quickly—in as little as eighteen hours—which is very challenging.

After a couple of 'hiccups' with the NICMOS Cooling System and the ACS Solar-Blind Channel (SBC) activation, SMOV has been proceeding well. The various process and software improvements put in place between SM3A and SM3B have worked very well and made these impacts much smaller than they otherwise might have been. NASA has released the ACS and NICMOS Early Release Observations (EROs), and in my opinion, they are quite impressive. All that remains is to complete the commissioning of the coronagraphs on ACS and NICMOS.

Sometimes it feels like we'll never be done! Nevertheless, we know SMOV is winding down when we get asked for input to the SMOV 'lessons learned.'

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Reinhart Interview
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How did you become interested in astronomy and high technology as a career? How did it develop? If you had taken a completely different career path, what would it have been?

Well, I guess my astronomy interest all started by when I was 7 or 8. Dad bought me a book on stars and the constellations. I was hooked.

The Apollo program and astronauts are a big part of why I'm working with Hubble. I was 7 when the first manned Apollo mission orbited. From that point on, I wanted to be an astronaut. Well, so far, Hubble is the closest I've gotten.

My career path has been fairly straight. After undergraduate school (in astronomy), I really wasn't sure what I wanted to do, so I just did what everyone else was doing and went on to graduate school. Well, I soon realized that I didn't want to do research for a living and was getting really burned out on school, so I decided that it was time to take a job for a couple of years. That led me to the Institute in August 1985.

Believe it or not, when I entered undergraduate school, it was a tough decision between majoring in astronomy or going into concert piano. I realized I likely wouldn't get rich doing either, so I decided on astronomy.

Recently one of my old professors asked if what I had been taught had proved useful. I was happy to respond that the lectures on orbital mechanics and binary-orbit determination had wound up being quite helpful in the job I do for Hubble.

You are an expert on the functioning of the telescope and the ground system. What are the most difficult problems and most satisfying solutions you have dealt with? What is the most interesting facet of the observatory that most people don't know? After SMOV, does your work return to a routine, or is there a trick or surprise every day?

I'd have to say one of the more difficult problems was helping determine if it would be possible to use Gyro 6 for science after it had problems right after Servicing Mission 3a. By the way, we believe the answer is yes, but some flight software work is needed to allow that to happen.

The most satisfying are usually the more difficult solutions. Nevertheless, just being able to answer someone's questions quickly and correctly, providing a piece of information that will help someone's science program, is also quite satisfying.

Personally, I think Hubble's least-known aspect is just how well the spacecraft takes care of itself when it has a problem. It just complains. When it decides to take action, it enters a safe-mode.

I always like to think that things will return to a routine after SMOV, but Hubble always seems to hide a surprise or challenge just around the next corner.

You are an avid rock climber and mountaineer, yet I believe you were raised in the flattest part of the country. What has climbing meant for you—an exploration of the unknown, a retreat from the office, or both? What hiking challenges and summit moments are most memorable? Where are you planning your next expedition?

It's a bit of both. I always liked to go camping, fishing, and canoeing as I was growing up, so getting outside has always been very relaxing for me. The climbing gets me outside, but gives me views and experiences that not too many people have had. For instance, when I climbed Devil's Tower in 1991, only about 3400 people had been to the summit since the first ascent in 1893, which was via a wooden ladder; the first real 'climb' occurred in 1937. Only a very small fraction of those who have seen the tower have seen the top, which makes the summit that much more special.

Each climb is special in its own way. In the Wind River Range in Wyoming, I remember watching a nesting pair of golden eagles defend their territory against another eagle, while at the same time I noticed a young chipmunk, which had never seen humans, trying to decide what I was. I remember watching Perseid meteors from our camp 18,000 feet high on Illiamani in Bolivia. I remember taking in the fall colors from the top of Seneca Rocks in West Virginia. And watching great blue herons flying up the Potomac while climbing at riverside in Great Falls National Park just outside of DC. In some way or other, they are all memorable.

The picture of me was taken just below the summit of Huayna Potosi in the Cordillera Real in Bolivia, at about 20,000 feet.

I haven't decided where I'm going next. It partly depends on when SMOV finally ends. Some possibilities are the Canadian Rockies, Patagonia, or even back to Bolivia. Who knows, something else may pique my interest as a destination. Ω

The Space Telescope – European Coordinating Facility

Bob Fosbury, *rfosbury@eso.org,*
& **Rudi Albrecht**

Introduction

Whatever else was occupying the minds of ESA bureaucrats during the early 1980s as they wrestled with the task of establishing the collaboration with NASA for what was to become the Hubble Space Telescope, it was certainly not the issue of the brevity and elegance of institutional titles. While the Space Telescope Science Institute has been—not perhaps without a little presumption—abbreviated to "The Institute" or even "the 'tute", those of us saddled with the grotesquely European ST-ECF were left with an acronym broken by a hyphen.

So, what is the ECF? Why was it established, and what is it supposed to do?

It all started with the Memorandum of Understanding (MoU), signed by NASA and ESA in October 1977, governing their collaboration on the Hubble Space Telescope project. This stipulated that ESA provide one of the science instruments, the Faint Object Camera (FOC) the solar arrays plus their associated electronics, and fifteen ESA staff members on assignment to the Institute. In exchange, ESA astronomers would get a minimum of 15% of the observing time on Hubble and a complete copy of the science data archive.

The concept of a European Coordinating Facility for the Space Telescope developed subsequently and was stimulated in part by the FOC instrument science team, whose task it was to advise ESA on the science requirements for the instrument and on its design. It became clear that, for astronomers with the relatively primitive software tools available in the1980s, the process of observing with and reducing the data from the FOC and the other Hubble instruments would be a formidable task. Planning and specifying the observations would require access to an extensive library of technical information and, furthermore, few European astronomical institutes were equipped to do the extensive digital image processing that was going to be necessary. It was also realised at an early stage that, for a digital archive to be established and utilized properly, a lot of new ground would need to be broken.

In response to these concerns, ESA issued the Call for Proposals for the Space Telescope – European Coordinating Facility in mid-1980. The idea was that the successful bidder would host the organization and provide half the financial support in the form of a fraction of the staff as well as an institutional infrastructure within which the ECF could operate. Five organizations responded, and the European Southern Observatory (ESO) was selected as the host institute. The formal agreement to establish the ST-ECF as a separate unit at the ESO HQ in Garching, near Munich, Germany was signed in February 1983 by the respective Directors General of ESA (E. Quistgaard) and ESO (L. Woltjer). Strong points of the ESO proposal were the large, although not 100%, overlap of the ESA and ESO scientific communities and the fact that ESO was already operating a major multi-national observatory in Chile using an operating concept similar in many respects to that foreseen for Hubble. With the benefit of (a long) hindsight, it is rewarding to see that the synergy between operational models has been exceedingly beneficial to both the ground and space communities of observational astronomers. The fact that ESO operates its Very Large Telescope (VLT) on Paranal in northern Chile using a 'service observing' scheme is due, in no small measure, to the connection with the Hubble observatory via the ECF. This mode has proved to be very successful and has earned a surprising degree of popularity amongst its users.

During the early part of its history, the ECF was an entirely European affair. Its role was purely the support of European astronomers, and its existence was neither acknowledged nor accounted for in the ESA/NASA MoU. This situation has changed somewhat now, but we shall come to that later.

Early History

Following the conclusion of the ESA/ ESO MoU, the ST-ECF started operating in early 1984. The staffing level was set at fourteen: seven ESA and seven ESO employees. However, with ESO proving the infrastructure and operational support the effective level was somewhat larger. The head of the ST-ECF was to be the European Hubble Project Scientist. Available resources included one VAX-11/780 and several image processing workstations. The host data-analysis software system was ESO's MIDAS, then state-of-the-art.

With launch scheduled for 1986, the build-up of the ECF had to be very quick. Staff had to be recruited and things made ready for operations. An important element was the science data archive, which was to be based on emerging optical disk technology. It was apparent early on that the archive would be shared between Hubble and the science instruments at the ESO telescopes. This has been achieved and, while Hubble was certainly the driver during the early days, the science archive is now numerically dominated by the VLT and the growing complement of wide-field imagers at ESO.

Mechanisms for user support were implemented, such as the STDESK service (an email hot line). A number of seminars were arranged at major centres of European astronomical research in order to make the community aware of the opportunities offered by access to Hubble and to lay out the plans for observing proposal preparation and eventual data analysis. This tradition of 'Euroseminars' was repeated whenever major changes in the observatory took place and has continued into the NGST planning era. A newsletter was started and has continued with an average of around two issues per year. We like to think that this helped pioneer the use of emerging desktop-publishing technology in astronomy. With the exception of the final printing run, the entire process of design, layout and production was carried out in-house, by ECF staff. For many years now, some 3,000 copies per issue have been distributed throughout the world. A series of data analysis workshops was started and, in the mid-1990s, merged with the regular Astronomical Data Analysis Software and Systems (ADASS) events. Steps were taken to ensure that software developed at the Institute could be used at the ECF and, if required, elsewhere in Europe.

> ... for a digital archive to be established and utilized properly, a lot of new ground would need to be broken.

Operational Era

The Challenger accident in January 1986 introduced a long delay. When the telescope was finally launched in 1990, however, the archive was ready and much work on instrument calibration had already been done. The spherical aberration bombshell prompted a lot of hard thinking and, until the situation was effectively recovered in hardware as a result of the first servicing

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mission in 1993, software was the only option. At that time, Leon Lucy was a member of the ESO scientific staff, and he quickly appreciated that, provided that a good knowledge of the aberrated point spread function (PSF) was available, an iterative, non-linear deconvolution method could do a pretty good job of recovering the Hubble resolution, if not its limiting sensitivity. Leon subsequently joined the ECF staff as an ESA staff member and stayed with us until he returned to the UK in 1998. While, in retrospect, those three years of aberrated Hubble operation have been largely eclipsed by the superb optical performance subsequently achieved, the mathematical infrastructure triggered by those early needs has matured and grown into many areas of astronomical data analysis, including spectroscopy as well as imaging.

One of the more-or-less, depending on your viewpoint, endearing aspects of imaging with Hubble—at least after the FOC and until the recent launch of the Advanced Camera for Surveys (ACS)—has been the undersampling of the PSF by the pixels of the detector array. While this was done for good design reasons, including the scarcity of pixels in early CCDs and the need to minimize the effects of detector noise, it led inevitably to some creative operational and data reduction strategies. Thus did the terms 'dither' and 'drizzle' enter the Hubble vocabulary. Whilst the ECF should not take all the blame for these lexical aberrations, it should be said that there was considerable attention given in Garching to these undersampling problems long before they became an integral part of Hubble operations. Hans-Martin Adorf, another ECF member now departed to the commercial world of operational scheduling (also a Hubble by-product), was regularly seen wandering the ESO hallways clutching pieces of paper covered in squares and muttering about something called 'Fisher information'. (We refer the *really* interested reader to chapter 7 of "The Future of Space Imaging", 1993, Institute study report, ed. R. A. Brown). The application of these techniques came to full public attention as a result of the monster data reduction efforts needed for the Hubble Deep Fields. It has led to a continuing collaboration between the ECF and the Institute on the development of new image combination tools, the need for which has recently been emphasized by the significant geometric distortion present in the ACS wide-field channel.

The calibration of the instruments on a space observatory is a time-consuming and consequently an expensive process. The advantages of basing the calibration strategy on a firm foundation of knowledge of the physics and design parameters of an instrument, although not generally part of astronomical tradition, are now manifestly apparent—not exclusively amongst those who listen to Michael Rosa! The construction of 'instrument physical models' has been of great benefit to Hubble and VLT spectroscopy and will surely be the basis of calibration of the ESA-supplied NIR spectrograph for NGST. The retroactive application of these methodologies to the FOS has led to a greatly improved calibration accuracy, which is now available to users through the archive. The availability of the scheme to recalibrate Hubble data 'on-the-fly'—a concept developed jointly by the ECF and the Canadian Astronomical Data Centre (CADC)—has enabled the benefits of such calibration improvements to be realized in a manner convenient to the user and has also simplified and reduced the size requirements of the archive. Further streamlining and cost saving has been enabled by assiduous tracking and exploitation of new storage technology such as CD and DVD ROMs.

Another example for this 'added value' approach is the introduction of so-called 'WFPC associations,' whereby multiple observations with the same instrumental configuration of the same target or field can be identified in the archive and grouped for subsequent automatic co-addition. This concept is now being extended to other Hubble instruments.

In many ways these efforts typify the way in which the ECF operates. Given the level-of-effort funding, it was clear that not every aspect of the Hubble project could be covered equally by a small European team. Instead it was decided only to offer rather basic services, i.e., user support and data-analysis assistance, across the board. Beyond that, the strategy has been to focus on selected topics, the choice of which has been agreed with the Institute and, where appropriate, the instrument teams. Where possible, these topics follow common themes that allow the building up of significant expertise within the group. A current example is the provision of slitless spectroscopy software and expertise for the ACS. This started with an agreement to work on the grism capability on NICMOS, for which the ECF provided a quick-look tool and a calibration capability. This accumulation of spectroscopic know-how is already being applied to the studies and the design assessment of the NGST spectrograph.

Being relatively small in number carries both advantages and disadvantages for the group. It means that resource limitations require a continual re-assessment of priorities and impose a severe limit on the number of projects that can be pursued at any one time. On the other hand, it enables excellent internal collaboration. With all ECF staff around the table once a week, we have been able to maintain a high level of communication between the different activities being carried out at any time.

Figure 1. *The ECF is small enough to meet around a table. Here, in the 'James Bond Room' (the ESO Council chamber) in January 2002, the staff presents its work to the User Committee chaired by Max Pettini. At regular Monday meetings, it is possible to present highlights of all current projects and to cover appropriate topics in more depth as and when necessary.*

Members of the ECF have, over the years, played their part in many Hubble administrative and oversight affairs. ECF has helped in the selection of, and travel support for, European members of the TAC and its associated panels, membership of science review and study teams, and, most recently, participation in the various NGST teams and committees. There are always calls from within Europe for public and professional talks and seminars about Hubble and NGST, and rarely does a month go by without one or two of such events.

The ECF maintained its traditional role of data analysis, user support, and maintenance of the science data archive until about 1994, when, as a result of the Internet revolution, it became apparent that an evolution was warranted. While it was still

necessary for ESA to have an independent European source of expertise on Hubble, a data-analysis capability, and ensured access to the science data, the ECF should do more than just mirror for Europeans what the Institute was doing so effectively for the entire user community.

Recognising these changes in emphasis, ESA called a mid-term review of the ECF, which was carried out in 1996 by a team comprising Len Culhane, Rolf-Peter Kudritzki, and George Miley. This process endorsed a more direct role for the ECF in the Hubble project, with selected activities becoming part of the renewed ESA/NASA MoU, which ran originally for only eleven years following launch. Some specific tasks resulting from these recommendations were the pre-processing of the plate-scan data (from Turin Observatory) for the second Guide Star Catalog (GSCII), the establishment of a post-operational archive calibration team to work on refined calibration of de-commissioned instruments, and the creation of a small Public Relations team to work with ESA on the European exposure of results from Hubble and other ESA spacecraft. Several new posts were opened to support these activities and the current size of the ECF is just over twenty.

Most recently, the ECF has received endorsement from ESA to spend a fraction of its resources on NGST preparations. The highest priorities here are supporting the efforts on the European instrument, the near-infrared multi-object spectrograph (NIRSpec) and the mid-infrared instrument (MIRI), to which several ESA member states are contributing. The ECF works closely with the European NGST project at ESTEC in The Netherlands and with ESA's industrial contractors.

The ESO Connection

ESO has provided much more than an operational infrastructure for the ECF. It has created a rich and active scientific environment for the staff and enabled the exchange of ideas on a wide range of technical issues. Any ECF member, past or present, would be delighted to recognize the vital role that the host organization has played in the life of the group. Thanks to the positive attitudes of a series of ESO Directors General, both ESO and ESA ECF staff have enjoyed all the privileges our host can offer. While maintaining its individuality, the ECF is very firmly integrated into ESO and participates fully and without prejudice in many of the host's activities. This involvement, of course, carries its own responsibilities, and we think it is fair to say the ECF has pulled its weight in tasks associated with the ESO Faculty as well as a number of management and technical activities. Indeed, for a while the head of the ECF, Piero Benvenuti, was also leader of the ESO data management division. Partly because of its close day-to-day connection, through the Institute, with developments in the US, the ECF was always concerned with computer-support issues and, most recently, with the collection and distribution of astronomical software within the 'Scisoft' initiative.

> Perhaps the greatest advantage offered by this stimulating environment is the ability it gives to participate in major scientific programmes...

Perhaps the greatest advantage offered by this stimulating environment is the ability it gives to participate in major scientific programmes, some of which involve both the ground-based telescopes operated by ESO and Hubble. The Great Observatories Origins Deep Survey (GOODS) is a recent—and admittedly large—example of such a cooperation. Since the ECF has been present in Garching for essentially the entire construction phase of the VLT, it is very rewarding for us to see this project reach completion and earn such worldwide respect as one of the major observatories of our age. The imminent addition of the UK to the membership of ESO brings the ESA and ESO communities considerably closer to congruence.

One of our greatest and most pleasant (well, certainly most stimulating!) surprises was to find in 1993 that we no longer had to fly the Atlantic in order to bump into Riccardo Giacconi in the corridor! During Riccardo's term as ESO DG, the ECF enjoyed a particularly—and sometimes it must be said embarrassingly—high profile within ESO. The refrain, "Why don't you do this like the ECF?" from Riccardo at an ESO review did cause the occasional cringe and the launching of the odd metaphorical dagger. There is no doubt, however, that the level of active scientific and technical engagement between ESO and ESA is higher now that it was before this period.

The Future

Recent changes in the organization of the Space Science Department have resulted in the ESA space telescope activities in Baltimore and Garching being merged into a new Space Telescopes Division. This clears the way for the growth of NGST activities within ESA to take their place alongside the established Hubble contributions. Ω

Acknowledgments: *We have mentioned few names in this article. The ones chosen seemed appropriate at the time but there was no intended favouritism. Volume 2 (the unabridged version) will, perhaps, contain them all! We could not finish this article, however, without mentioning Britt Sjöberg who has been here since the beginning, undoubtedly holds the place together and carries most of the history—at least the more interesting parts—in her head!*

Contents:

Calendar

GO Cycle 11 observations	*start July 1*
SM3B OV/SV	*ends August 31*
First NGST SWG meeting at STScI	*Sept. 24-25*
ADASS Conference at STScI	*Oct. 13-16*
HST Calibration Workshop	*Oct. 17-18*
Cycle 12 CP released	*Oct. 14*
Cycle 12 Phase I deadline	*Jan. 24, 2003*

Contact STScI:

The Institute's website is: *http://www.stsci.edu*

Assistance is available at *help@stsci.edu* or 800-544-8125.
International callers can use 1-410-338-1082.

For current Hubble users, program information is available at:
http://presto.stsci.edu/public/propinfo.html.

The current members of the Space Telescope Users Committee (STUC) are:

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James Dunlop, Royal Obs. Edinburgh
Debbie Elmegreen, Vassar College
Holland Ford, JHU
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