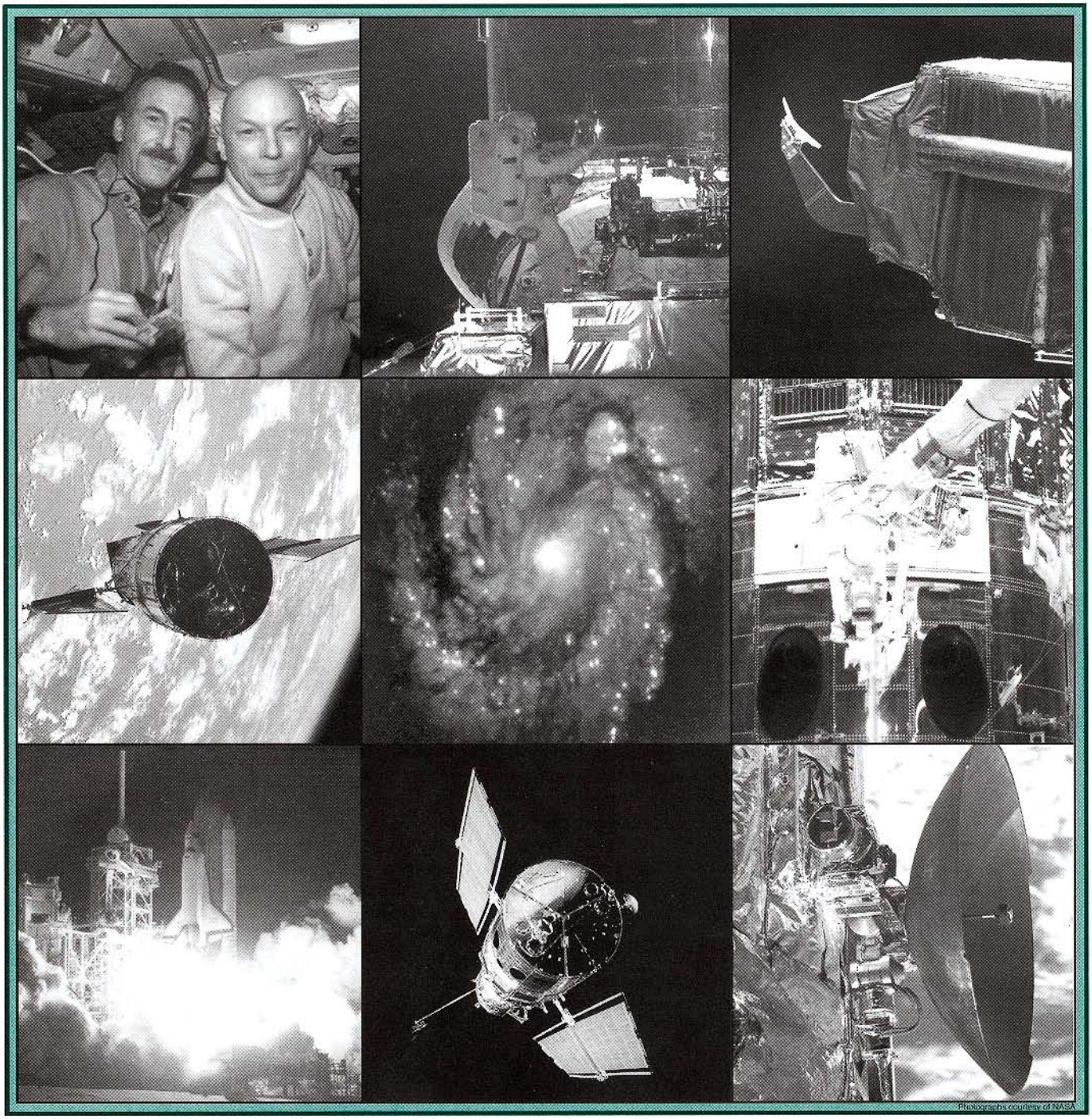
Number 21 April 1994

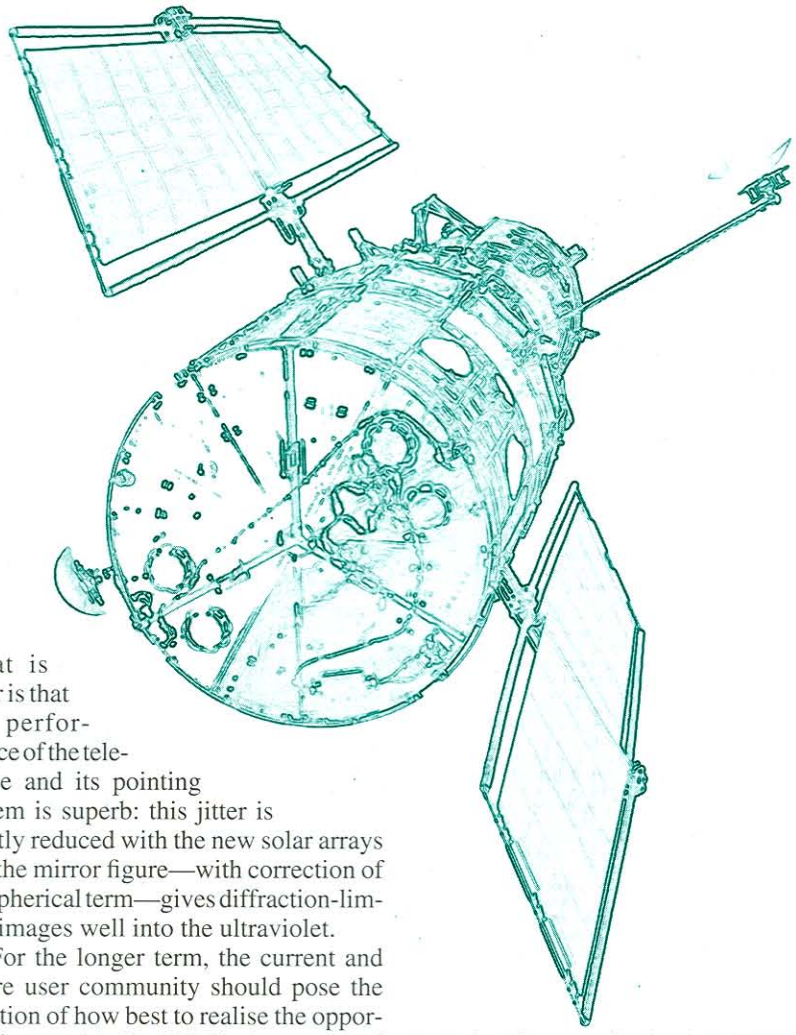
ST-ECF Newsletter

Space Telescope — European Coordinating Facility



Photographs courtesy of NASA

Editorial



Amongst the many servicing tasks performed by the STS-61 astronauts from 'Endeavour' in early December, the installation of the second Wide Field Planetary Camera (WFPC 2) and the corrective axial 'instrument' COSTAR has finally given the Hubble Space Telescope the imaging performance awaited for so many years. The enormous care taken throughout the process of building and executing a recovery strategy following the discovery of spherical aberration in 1990 was rewarded by a faultless mission. The potentially complex and time-consuming process of aligning the new optics and bringing the telescope and its instruments back on-line was compressed into just a short period over Christmas and the New Year with the first images being released to the press and other mortals on the 13th of January.

During a visit of all seven astronauts to Garching on the 16th of February, it became clear to us first hand that the meticulous preparation which they underwent—many components of which they developed themselves—and the construction of numerous contingency plans—none of which had to be used—ensured that the outcome would not be the result of luck. Rather, the success achieved was the direct result of a lot of hard work by many people.

So what is the state of the 'new HST', how can we best plan to exploit it in the future and how could it be further improved? Some of these questions we attempt to answer in this issue by giving short summaries of the status of the instruments as far as it is known at the moment. What is clear is that the performance of the telescope and its pointing system is superb: this jitter is greatly reduced with the new solar arrays and the mirror figure—with correction of the spherical term—gives diffraction-limited images well into the ultraviolet.

For the longer term, the current and future user community should pose the question of how best to realise the opportunities provided by HST in the context of other developments which are occurring on the ground and in space. The study report "The Future of Space Imaging" edited by Robert Brown of the STScI (published October 1993) addresses this issue and demonstrates that steps have to be taken now in order to secure a camera capable of fully exploiting the telescope into the next century. Miley and Fusi Pecci, in a letter to ESA (published here) point out the scientific benefits of a European involvement in the development of such an 'Advanced Camera' which would be launched with the 1999 servicing mission.

The next cycle of proposal submission and selection starts very soon and the ST–ECF, as part of its rôle, is offering a limited number of 'Euroseminars' in ESA member states between now and midsummer in order to explain HST's new capabilities and help people to prepare competitive applications for time.

Servicing mission astronauts visit Garching

Rudolf Albrecht

Barely recognizable without their space suits, the STS-61 astronauts visited ST–ECF/ESO on the 16th of February. For them it was the nth stop along their Grand Tour of Europe, for us it was a brand new experience, coordinating between the NASA and ESA public information offices, German media people, local VIPs, and accommodating a record number of schedule changes.

As everything had to be crammed into the time between 11:00 and 18:00 hours, we had arranged for a planeside VIP pickup of the group. On condition that they could take some photographs for their internal newspaper, the German border police dispensed with all formalities, and the astronauts arrived in record time at the ESO office, where we fed them coffee in order to prepare them for the press conference which immediately followed. About 20 media people (press and TV) had shown up, as had many of the diplomatic representatives of the ESO member countries and of the United States. Prepared extremely well by the ESO public relations people (Richard West and his team) the press conference went well, with the astronauts performing in a professional and quite obviously extensively prepared manner: apparently they do not only train for EVAs, they also train for other aspects of their jobs.

By fortunate coincidence Jim Crocker, the project manager for COSTAR, happened to be in Munich. Riccardo Giacconi, now the ESO DG—director of the Space Telescope Science Institute until a year ago—was the person who actually started the decision making process—*Strategy Panel*—which eventually identified COSTAR as the most realistic method to correct the HST spherical aberration. With Piero Benvenuti and Ray Wilson, two more members of the Strategy Panel were at hand.

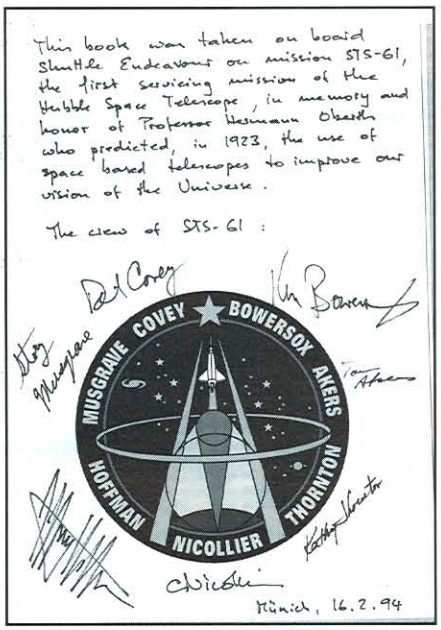
After lunch there came the big event: the astronauts' account of the Servicing Mission, complete with slides and video presentation. On this we took a bit of a gamble: we had sent out invitations to all institutes in the Garching research area, and to all astronomy and space-related institutions in the region. Consequently we had arranged to have the presentation in the large auditorium of the Technical University, which holds more than 400 people. Would we be able to fill it, or would it be embarrassingly empty, especially since this was the time of spring vacation? Bets were hedged, and we watched nervously as the lecture hall slowly filled. By the time the video started the auditorium was packed, and rumour has it that Britt, our secretary, will not have to buy champagne for some time to come.

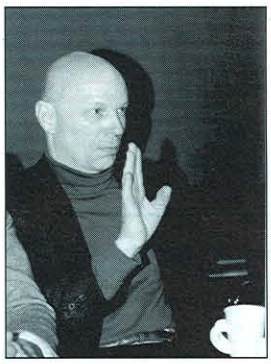
For the ST–ECF staff members, most of what the astronauts told the audience was not exactly new: of course we had been following the Servicing Mission closely. However, not only is there a difference between seeing things on a TV screen and actually being able to ask questions to the person who performed the activity, we also realized the extreme degree of thoroughness with which this particular mission had been prepared. The crew spent hundreds of hours practising: in the simulated zero gravity environment of the water tank, in the Shuttle mock-up, with computer simulations, etc. Special tools had been developed and tested under realistic conditions, possible contingency situations had been analysed and rehearsed. Thus when it turned out that the badly warped solar panel could not be retracted, the procedure of jettisoning it was available in the manual. It was due to this process of extremely thorough preparations that the STS-61 mission became so successful: launched according to schedule, all planned tasks accomplished, several additional contingency and unplanned tasks also accomplished.

Of course we also wanted the astronauts to know what we are doing, so back in our building we told them about ESO and ST–ECF activities and showed them the video of the production and delivery of the first 8-m mirror blank for the VLT. A short informal get-together over drinks and crackers concluded the visit.

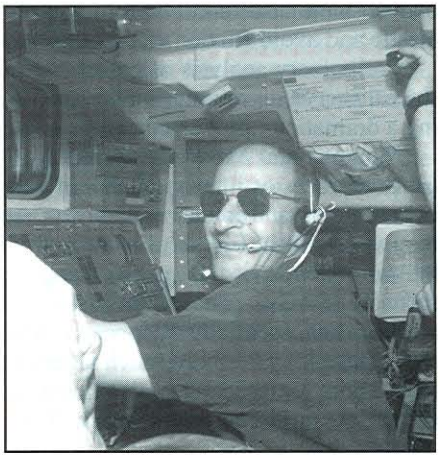
The STS-61 Hubble Space Telescope First Servicing Mission not only restored the full capabilities of HST, it also validated many of the concepts which had gone into the design of the HST program. We are now confident that the HST will be available for the planned mission lifetime of at least 15 years and that future servicing missions will be able to upgrade the telescope with advanced technology instrumentation.

Seventy years before the First HST Servicing Mission, in 1923, the German rocket pioneer Hermann Oberth wrote the book "Die Rakete zu den Planetenräumen", in which he proposes, among other applications, to establish an astronomical observatory in orbit. A facsimile reprint of the book was flown on mission STS-61 for the ST–ECF. Claude Nicollier, the European crew member—responsible for the remote manipulator arm—is seen here returning the book to us. Looking on are, from left to right, Jim Crocker, Jeff Hoffman, Story Musgrave, Kathy Thornton, Riccardo Giacconi, Piero Benvenuti, Richard Covey, Ken Bowersox, and Tom Akers.





The real Story Musgrave identifying himself. At age 58, a medical doctor with several more degrees in other fields, thousands of hours piloting jet aeroplanes, a skydiver, veteran of five Shuttle flights, and a no-nonsense haircut, Story is one of the more remarkable characters in the US astronaut corps.



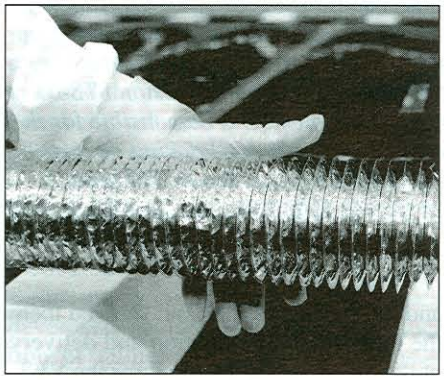
Claude Nicollier—on duty

The new HST jitter performance

Equipped with new Solar Arrays, the HST is now capable of extremely stable tracking performance.

Pierre Bely†

The new set of solar arrays installed during the servicing mission were redesigned to be much less sensitive to orbital thermal shocks than the original set. The 6 meter long deployable (bi-stem) booms are now insulated (see the photograph) and predicted to bend by no more than 6 cm at the tip, due to transversal thermal gradient, compared to 90 cm for the original set. This small residual deflection was shown in lab tests to be purely thermo-elastic, thus preventing the stick-slip effects between the two shells of the boom, which was thought to a major source of jitter with the first set of arrays.



The 'Chinese Lantern' insulators for the deployable (bi-stem) booms on the new Solar Arrays.This picture was taken at British Aerospace before delivery of the arrays to NASA.

In addition, the mechanisms intended to compensate for the differential thermal expansion between the booms and the blanket were also modified to be purely elastic and avoid friction effects.

Preliminary analysis of on-orbit data since the servicing mission is indeed showing a dramatic improvement.

Figures 1 and 2 show the current typical time traces of jitter in pitch and yaw over one orbit and compares them to what they were with the first set of arrays before the introduction of the special damping software (SAGA). The day-to-night disturbance has essentially disappeared, and the night-to-day has been much reduced, from about 1 arcsecond peak to peak to about 100 milliarcseconds (mas). Also,

† STScI

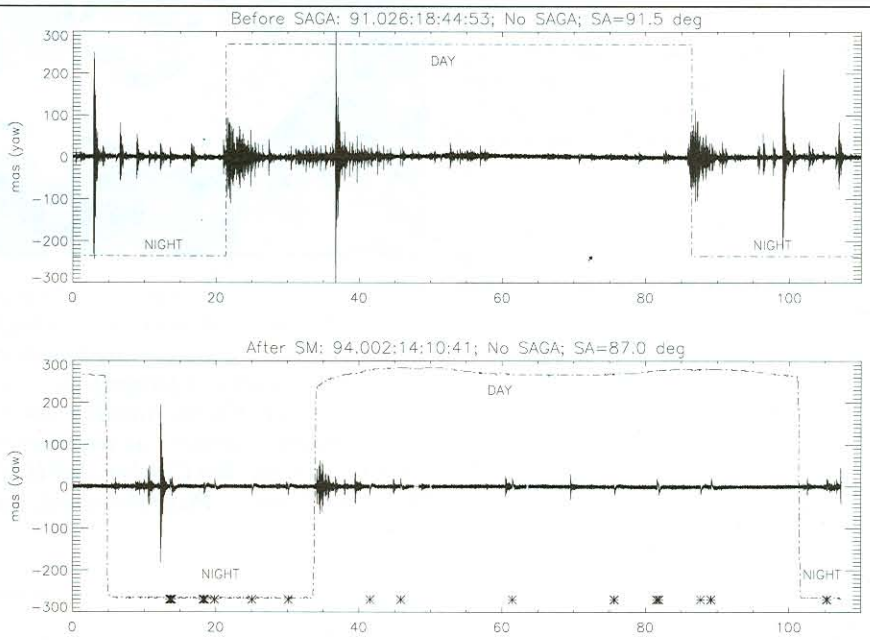


Figure 1: Typical time profile of line of sight jitter in yaw with the original solar arrays but without any damping software (ie, without SAGA), top, and with the new solar arrays, bottom. The small disturbances during day or night are due to the reaction wheel speed going through zero (as indicated by the asterisks).

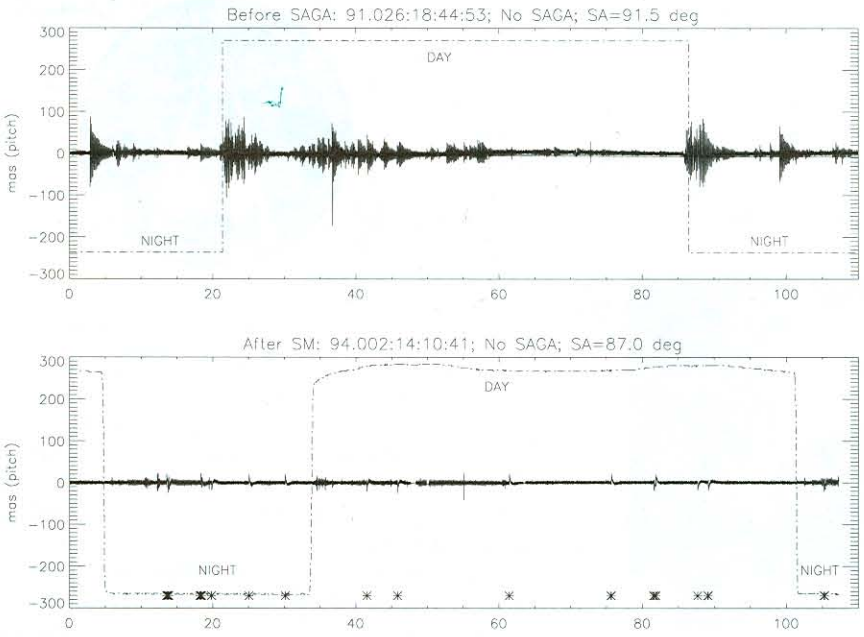


Figure 2: As Figure 1 but in pitch.

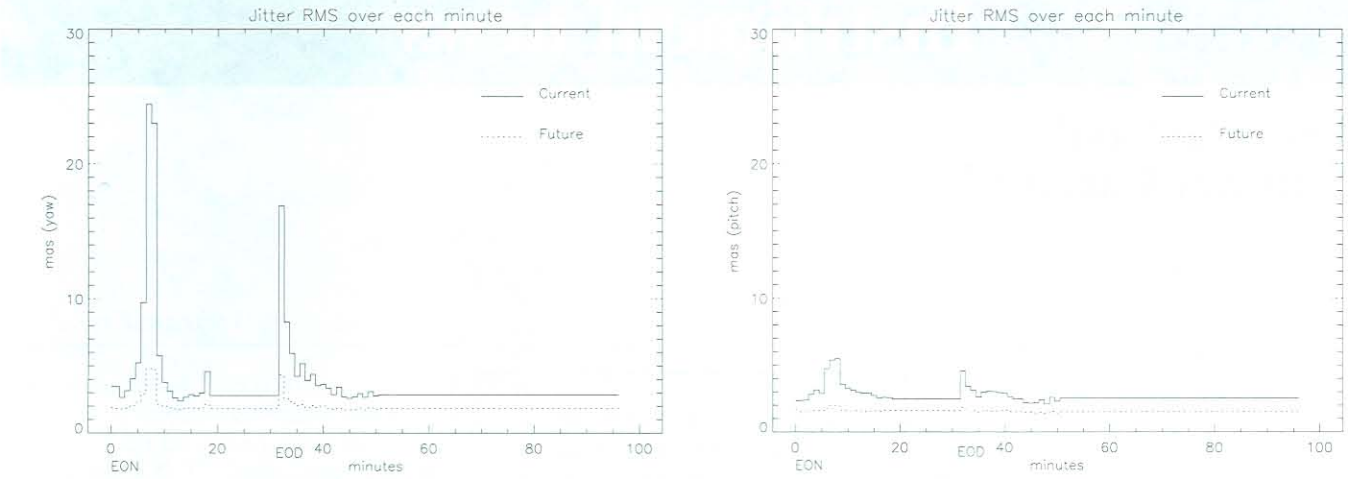
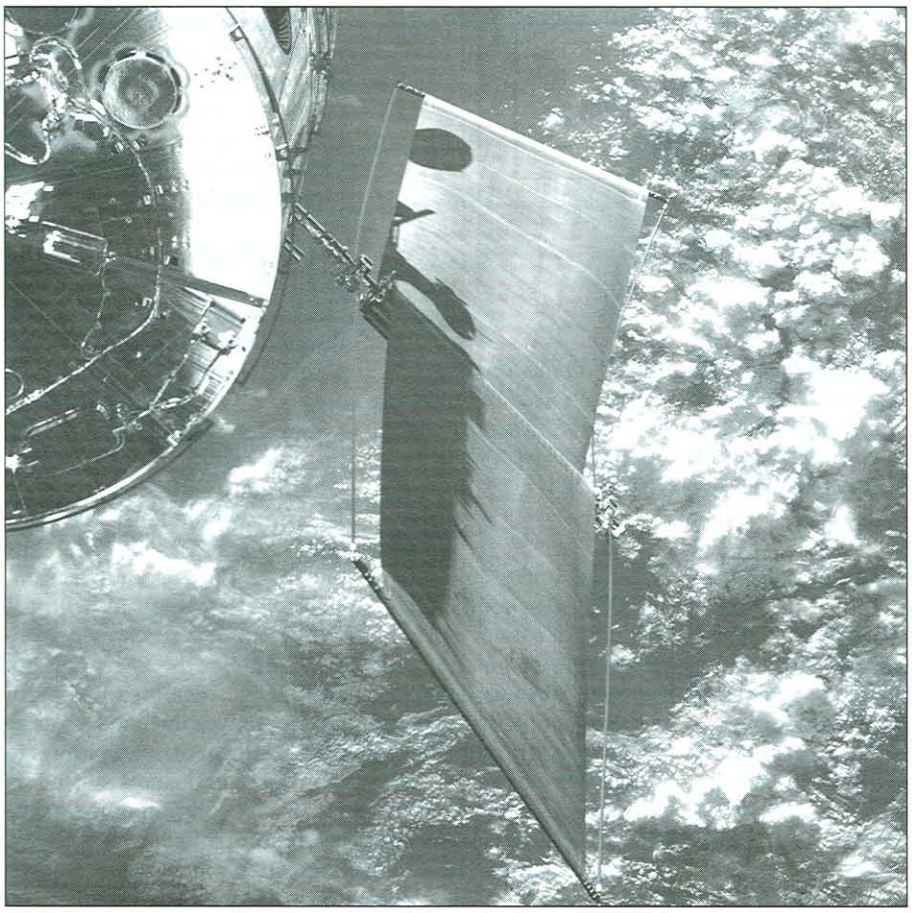


Figure 3 & 4: Current distribution of the one minute rms line of sight jitter in yaw (left) and pitch (right) over the orbit (solid line) and prediction of what it will be once the pointing control filtering software is installed (dotted).

the secondary shocks that were experienced during the day and night periods are much reduced, except for one: a salient disturbance which occurs 8 minutes after entering orbital night. This disturbance, which is virtually unchanged from before, is about 450 mas peak to peak in yaw, and 80 mas in pitch.

With no known source of possible stick-slip in the solar array, the fact that the 8-minutes into night disturbance has not disappeared is somewhat of a surprise. The frequency (0.65 Hz) and direction (in the plane of the arrays) of that excitation correspond to a main vibration mode of the arrays. Clearly then, the solar arrays are moving and induce the observed line of sight motion. Clearly also, the excitation is thermally driven. However, it is not obvious whether the solar arrays are responsible for it, or are simply reacting to a shock triggered somewhere else on the spacecraft.

Referring again to Figures 1 and 2, one also notices minor features, on the order of 20 mas appearing in both day and night. Most of these can be traced to the reaction wheels. The rotation speed of the four reaction wheels varies continuously, typically between ±500 rpm, to compensate for the aerodynamic and gravity gradient effects on the spacecraft. When the speed passes through zero, the reaction wheels have to overcome the static friction and this results in a small jog of the spacecraft. This is not a new situation, but the jog is now much larger than before the servicing mission. This is attributed to the fact that the reaction wheels were stopped for several days during the servicing mission, resulting in a redistribution of the bearing lubricant. Experts predict that this effect will disappear with time, as large slews requiring peak rotation speed are performed.



HST just before being grappled by the shuttle. This shows the bent bi-stem rod on one of the Solar Arrays

Since very short exposures are rare, it has become traditional to characterize the effect of line of sight jitter on observations by its rms over one minute. Figure 3 and 4 show this one-minute rms distribution for the entire orbit. One recognizes the entry of night and 8-minute into night disturbances described above. Since the servicing mission, the pointing control system has been in its original configuration, and the special control system filtering developed to damp out the excitation of the original solar arrays has been deactivated. It is planned to install a similar filtering system in a few months, once the changes in dynamic characteristics of the spacecraft have been fully quantified.

A prediction of the effect of the selective damping software is shown in Figure 3, and indicates that once installed, the one minute rms jitter should be less than 5 mas over the entire orbit.

In conclusion, the modification of the solar arrays to reduce their sensitivity to thermal shocks has been a real success. Although some disturbances remain, they are small enough to be fully correctable by enhancement of the pointing control system. Once installed the pointing of the telescope should be well within the original specifications.

Instrument news

Wide Field and Planetary Camera 2

Wolfram Freudling

This series of four short articles gives a summary of the state of the HST instruments: WFPC 2—which has its optical correction built in—and FOC, FOS and GHRS which work with COSTAR. Much more detailed information will become available in instrument reports etc. as verification and calibration proceeds.

The Wide Field and Planetary Camera is one of the primary instruments on HST and one which creates the bulk of the HST data. It is a photometric camera which covers the spectrum from 1,150 to 11,000Å. It also provides rudimentary polarimetric capabilities. WFPC 2 can be used as the prime instrument for target acquisition and for parallel observations. It is the instrument of choice for imaging which requires a wide field of view if the full diffraction-limited resolution of the telescope is not essential and/or can be recovered, and for imaging at wavelengths red of about 5000Å.

Basic Capabilities

Unlike the original WFPC 1, the new camera WFPC 2 has only one imaging mode with 3 CCDs (called WF2 through WF4) in the wide field mode with a scale of 0.1 arcsec per pixel, and one CCD called PC1 in the planetary mode with a scale of 0.046 arcsec per pixel. The layout of the four CCDs is shown in Figure 1. The arrows show the readout direction of the chips, which is the direction in which saturated images bloom. The size of each CCD is 800 × 800 which results in a field of view for the three wide field chips of 2.5 × 2.5 arcmin^2, and 35 × 35 arcsec for the planetary chip. Standard broad-band filters extended to the far UV and a series of narrow-band filters as well as polarizers are available.

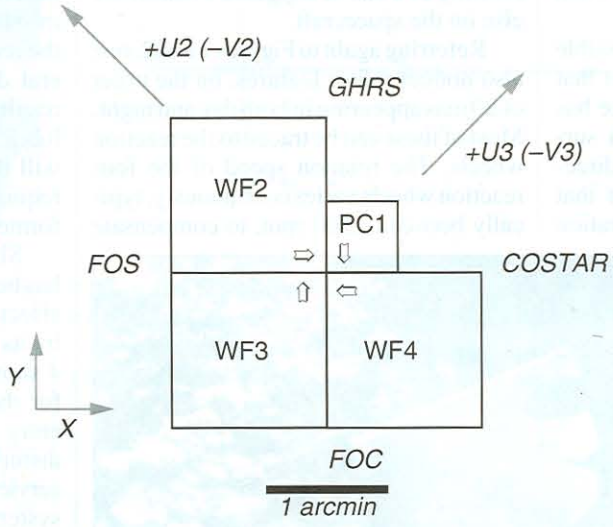


Figure 1: The WFPC 2 Field of View on the Sky. The readout direction is marked with arrows near the start of the first row in each CCD. U2,3 and V2,3 refer to the spacecraft coordinate system. (Adapted from WFPC 2 Instrument Handbook Version 1.0.)

CCD Chips

The CCDs in WFPC 2 are thick frontside-illuminated chips fabricated by Loral Aerospace. The 800 × 800 chips with a pixel size of 15μm have a low readout noise of 7 electrons/pixel. Their gain can be set to take advantage of the line full well capacity of about 70,000 electrons/pixel. The UV sensitivity is achieved through coating with a thin film of lumogen, which converts photons with λ < 4,800Å into visible photons. The total system throughput ranges from a peak of about 13% at 6500Å to about 1.5% at 1,200Å. The wavelength range of the camera is limited by the transmission cutoff of the MgF_2 field flattener at 1,100Å and the silicon band-gap in the infrared at about 11,000Å. In-orbit tests have verified the photometric stability of the CCDs and the whole camera system. The blooming properties, stability and quantum efficiency hysteresis are all significantly improved as compared to WFPC 1. The cosmic ray event rate measured in orbit is within 10% of the one measured for WFPC 1, which is about 1.7 hits/second/CCD: some of these will be multiple-pixel events. Figure 2 shows how one of the chips is affected after an exposure time of 100 seconds. Because these CCDs are frontside illuminated, the QE varies within the pixel area, ie, the detection probability of a photon depends on where it hits a pixel. Because the point spread function of the aberration-corrected camera is so sharp compared to the size of the pixel, this will affect the photometry of stars at the level of a few percent. To account for this effect, sub-pixel shifts between exposures are recommended (see below). Blooming in the directions indicated in Figure 1 occurs when more than 100,000 electrons accumulate in a single pixel. An example is shown in Figure 3. The blooming can be prevented from spilling over into neighbouring columns by operating the serial transfer register clocks during the integration. The trade-off is a higher dark current in this mode.

Point spread function

Unlike the other science instruments, WFPC 2 does not look through the corrective optics of COSTAR but has its own correction for the spherical aberration of the primary mirror built in. This results in a PSF with a significant position dependence which can be modelled with software developed at STScI. The correcting optics built into the camera leads to near diffraction-limited PSFs over the whole field of view. Therefore, with the Airy disk of a 2.4m mirror at λ = 10,000Å of 0.105 arcsec, even the planetary camera severely undersamples the PSF at all but the longest wavelengths, where the PSF is critically sampled. An example of this is shown in Figure 4. A recommended strategy to recover some of the resolution lost by the undersampling is to break up any exposure into three or more exposures shifted by non-integer multiples of the pixel size. A splitting of the exposure time is necessary in any case for the identification of cosmic ray hits, which are almost indistinguishable from stellar images due to the sharp PSF in comparison to the pixel size. Virtually no additional overhead is required for this shift, and a procedure to automatically carry it out is currently being developed. A de-

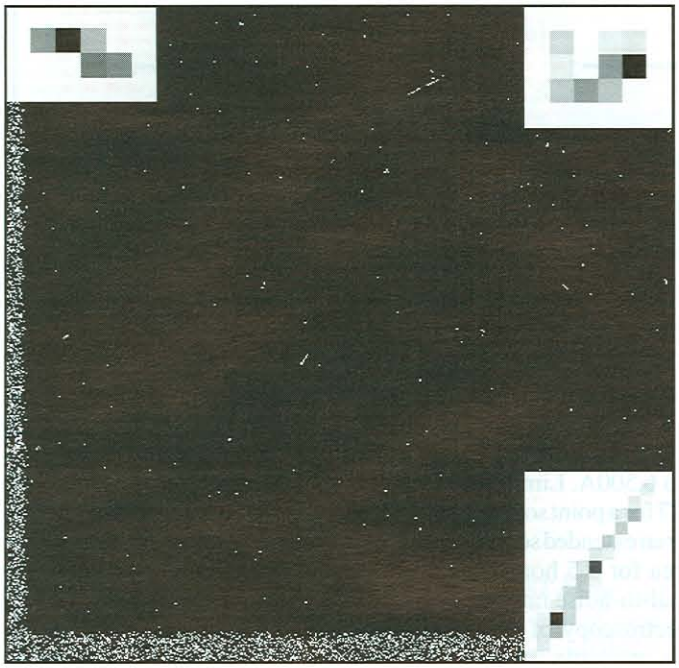


Figure 2: WF3 exposure which shows CR hits after 100 seconds. The images were created by subtracting two images of the same field and setting all pixels with values less than 4 times the measured rms to zero. The three insets show multiple-pixel CR hits and demonstrate the difficulty any automatic classification of single image will have.

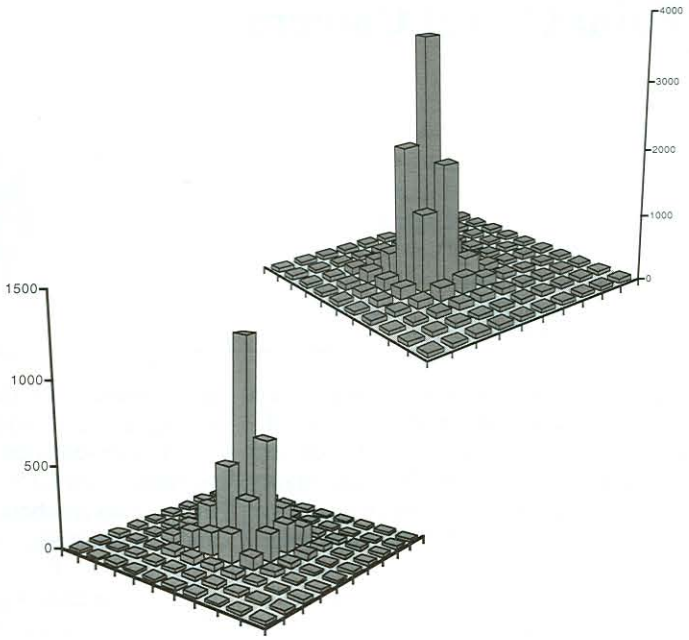


Figure 4. Undersampled stellar images, shown as pixel arrays, taken with WF3 (top) and PC (bottom) chips. The affect can be alleviated by taking multiple exposures with sub-pixel shifts.

tailed discussion of this observing strategy and software to recover full resolution in the presence of cosmic rays has been given by Freudling (1993 and 1994). This observing strategy gains additional importance due to the variation of the QE over the area of the WFPC 2 CCD pixels, discussed above.

Optical Filters

Unlike the FOC, which is sensitive to wavelengths shorter than 5,000Å (see article on FOC by A. Caulet in this issue), WFPC has useful sensitivity at wavelengths between 1,200 and 11,000Å. A set of 48 filters is available to take advantage of this wide wavelength range. This set is mounted in12 filter wheels with 4 slots each. The set includes a broadband "UBVRI" set plus an extension to the UV, a Strömgren series, a Woods filter for far-UV imaging without a red leak, a series of selected narrow-band filters, a ramp filter series covering 3,700–9,800Å and methane and polarizing quad-filters. The broad filter and Strömgren sets do not replicate ground-based standard filters. Ground-based observations of standard stars have been carried out with a replica of the filters and WFPC 2 CCDs, which can be used to transform the WFPC broadband colours to more common standard systems.

UV Capabilities

The total throughput in the UV (without filters) ranges from about 1.5% at 1,400Å to about 3% at 3,000Å. A set of UV filters with nominal wavelengths between 1,220 and 3,000Å are available. All of them have significant red leaks. Because many astronomical objects emit up to 10^7 visible-light photons for every FUV photon, the redder photons can easily overwhelm an image due to those red leaks. A Wood's filter, F160BW is provided to minimize the red leaks. The throughput of this has degraded since the WFPC 2 handbook was issued — please check with the instrument scientists for the latest figures.

The throughput of the camera using F170W is degrading by approximately 10% per month due to contamination building up on the filter. The original throughput can be restored by a decontamination procedure, which warms up the camera in a well-controlled manner. The decontamination procedure also restores some of the hot pixels on the CCDs. At the time of writing, the first decontamination of WFPC 2 has been successfully carried out, but it is not decided yet whether there will be a regular monthly decontamination or whether the decontamination will be less frequent but followed by a UV campaign during which most UV observations are performed.

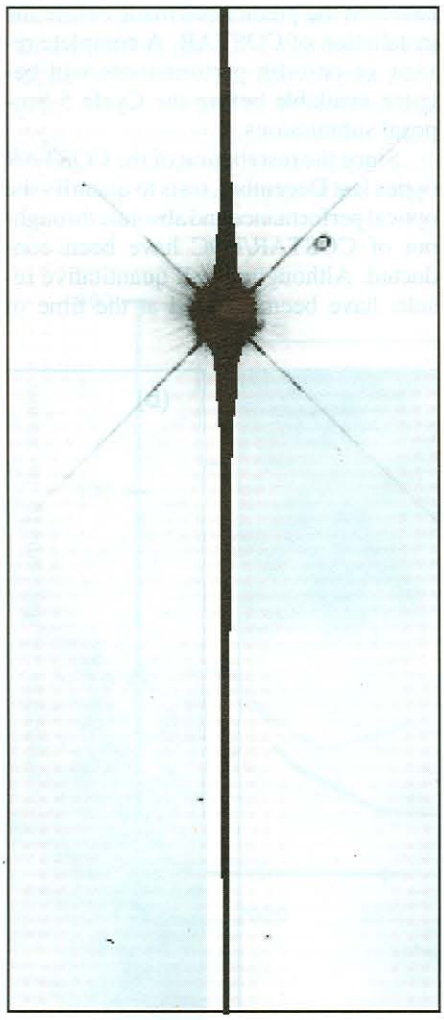


Figure 3: WFPC 2 image of a grossly overexposed star. Three to four columns are affected by blooming over the whole image.

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"Wide Field and Planetary Camera 2 Instrument Handbook", 1993. Burrows, C., ed.

Freudling, W., 1993. "Cosmic-ray removal and image co-addition", ST-ECF Newsletter 20, p. 8

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Faint Object Camera

Adeline Caulet

The capabilities of the Faint Object Camera are restored by COSTAR. FOC is now a diffraction-limited camera in the visible with superb image quality and the highest spatial resolution ever achieved in the 1,150–6,500Å wavelength range. The FOC throughput is compared with that of the WFPC 2. The correction of the spherical aberration has introduced several 'side-effects' that will need special care during the treatment of the data.

Performance of the 'new' FOC

The magnification factor of 1.6 resulting from the COSTAR optics has increased the focal ratios of the two FOC relays from *f*/96 to *f*/151 and from *f*/48 to *f*/75.5. However, the two cameras will retain the names *f*/96 and *f*/48. The corresponding new plate scales are 0.014 and 0.028 arcsec per unzoomed pixel and so the camera is capable of adequately sampling the images produced by a 2.4m diffraction limited telescope (Airy disk of radius 0".058 at 5,000Å, ie. 2–4 pixels). The maximum sizes of the fields of view are 14×14 (*f*/96) and 28×28 (*f*/48) square arcseconds. The dynamic range can be increased at the expense of the field size by using a faster TV scan rate.

A large selection of filters is available to image from 1,150 to 6,500Å. Limiting magnitudes are about 27 for a point source, and 25 mag arcsec^{-2} for an extended source over a $0."1 \times 0."1$ area for a 5 hour U-band image and a signal-to-noise ratio of 5. Low resolution spectroscopy of relatively bright objects is available for the FOC with an objective prism—both in the near- and far-UV—and a spectrograph (long-slit, cross-disperser, slitless, *f*/48 only, from 1,150 to 6,500Å). The performance characteristics are best described in the FOC Instrument Handbook POST-COSTAR V4.0 (Paresce, 1993) and are based on the predictions made before the installation of COSTAR. A complete review of on-orbit performances will become available before the Cycle 5 proposal submissions.

Since the installation of the COSTAR optics last December, tests to quantify the optical performance and absolute throughput of COSTAR/FOC have been conducted. Although not all quantitative results have been released at the time of writing, it is clear from looking at the publicly available FOC images that the spherical aberration present in the pre-COSTAR FOC images has been removed.

Figure 1 shows an example of "before and after" FOC images of Supernova SN1987A and its surroundings. Quantitatively, 85% of the total light from a star is now contained within a 0".1 radius, instead of 15–18% in pre-COSTAR images.

Figures 2a and b show the images of a star taken with a visible and a UV filter. The halo of ~3" diameter that spread the incorrectly focussed light and limited the contrast has been removed.

Robert Jedrzejewski and Antonella Nota from STScI are currently assessing the effect of COSTAR on throughput for the FOC. Their conclusion is that the change is as expected from the 'aged' witness samples. As well as they can measure it, the FOC throughput is reduced by a couple of percent from the values in the handbook. These are total throughput values and, for some of the UV filters, the PSF wings are quite strong, so the encircled energy within 0".1 is

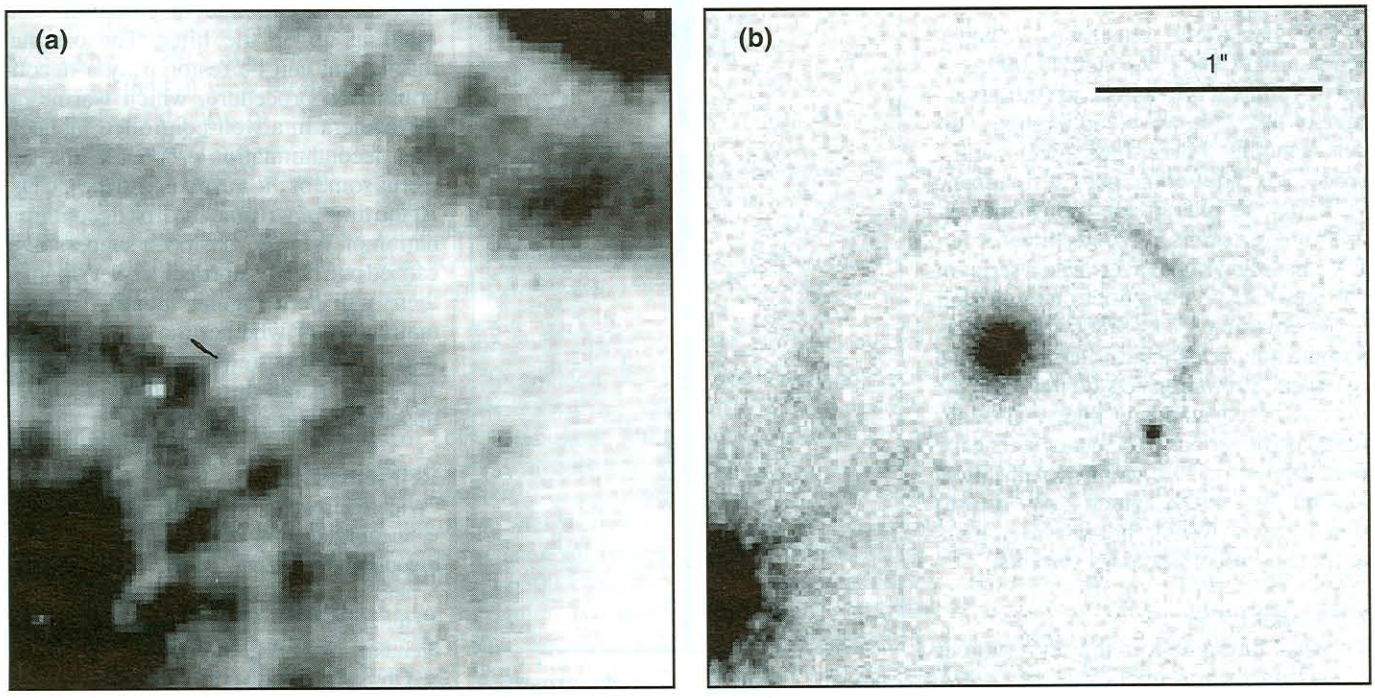


Figure 1: FOC f/96 images of SN1987A in the near ultraviolet: (a) a pre-COSTAR image taken in October 1993 and (b) a post-COSTAR image taken in January 1994.

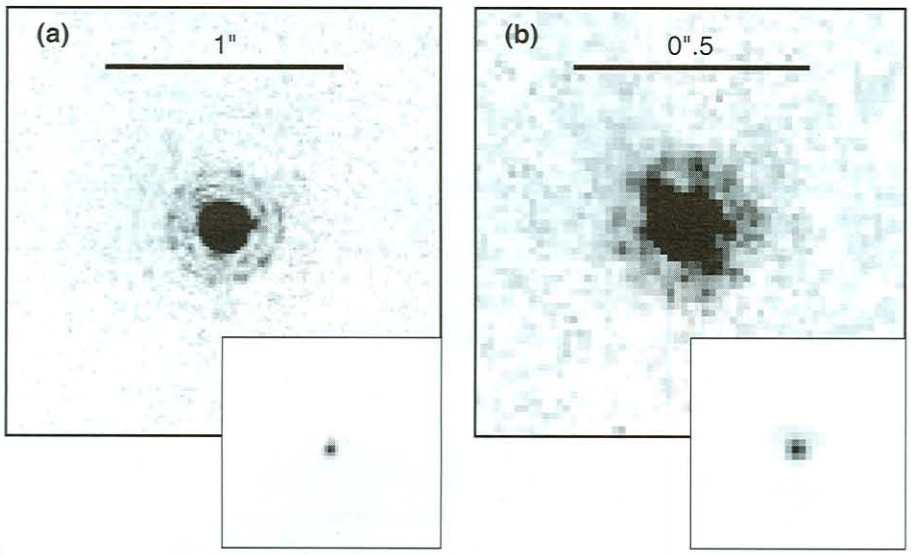


Figure 2: FOC f/96 PSFs. (a) Image X23K0108T of the star BPM16274 with filters F550M and F1ND, exposure time 896 seconds, field of view 1.8 × 1.8 arcsec. (b) Image X2340105T of the star BPM16274 with filters F342W and F6ND, exposure time 896 seconds, field of view 0.9 × 0.9 arcsec. The large frames are displayed with cuts from 0 to 20 counts while the insets—on the same spatial scale as their parents—are scaled to show the full range of 2,300 counts

correspondingly lower.

FOC is an efficient imaging camera in the ultraviolet. In Figure 3 we have plotted the number of photons per second per Å, PHOT, required to achieve a signal-to noise ratio s/n = 10 in 20 minutes of integration time on a point source. The calculations include ZOD(λ) the zodiacal light that dominates the sky background between 2,000 and 6,400Å, the dark current BP of 6.4×10^{-4} counts per second per normal pixel, and the overall quantum efficiency (OTA+COSTAR+FOC) QE(λ) (Paresce 1993, Figs. 41 and 30). An area of about 40 pixels (0".014 per pixel) has been integrated and corresponds to one WFPC 2 pixel of 0".1. The encircled energy within this pixel area is about 0.6 in the wavelength range 2,000–6,400Å (Paresce 1993, Table 8). PHOT is calculated for no filter in place. With these assumptions:

PHOT = (1 + √[1 + (96*(40.1*(BP + ZOD)))]) / (24 * 0.6 * QE)

The corresponding quantity has been calculated for WFPC 2. The point source is centered in one pixel and only the flux and noise within that pixel were considered. The comparison between FOC and WFPC 2 shows the following: while the sensitivity advantage of the FOC in the UV is small, the FOC blocks the red photons better than WFPC 2 because of the formers reduced sensitivity for λ > 4000Å given that UV filters for both instruments are affected by red leak problems. Therefore, the full WFPC 2 sensitivy can be used only for extremely blue sources. For red (or even 'white') sources, one has to block red light contamination in WFPC 2 with the Wood's filter, whose throughput is rather low. We have also calculated PHOT for FOC and WFPC 2 assuming a 500Å band-pass filter of transmission unity. Both curves are very similar to those in Figure 3 scaled down by the factor 1/500 showing that 20 min exposures are not limited by the background, even for intermediate bandwidth filters. This is the reason why this result is nearly insensitive to the bandwith of the filter.

The new PSFs, dark noise and flat fields

The COSTAR optics correct best the aberrated PSF for the central part of the FOC field. The focal plane, tangential and sagittal focal surfaces for COSTAR and those for FOC are tilted with respect to one another, resulting in field-dependent astigmatism and field-dependent focus variation that both increase linearly with distance from the fully-corrected field point. As for the field dependence of the PSF, there does seem to be a measureable effect. For most applications, however, the field dependence is not large (R. Jedrzejewski, private communication).

For a crowded field photometry of stars over the whole FOC field, measurement of the stellar images with a variable PSF (eg, using DAOPHOT II) could be a solution.

If image restoration is to be performed, this spatial variation will create problems. In practice, the Lucy algorithm has not been adapted to this problem. One of the requirements is to have as many PSFs as needed as 'look-up tables' or as analytic expressions. The space-varying PSF also means that the convolutions and correlations which form the Lucy algorithm cannot be done using FFTs and so would result in a speed penalty.

The effect of jitter (a few milliarcseconds for default fine lock, up to 15 milliarcseconds for coarse track) should be quite small. See the article by Pierre Bely on jitter in this Newsletter. Images are being examined by STScI

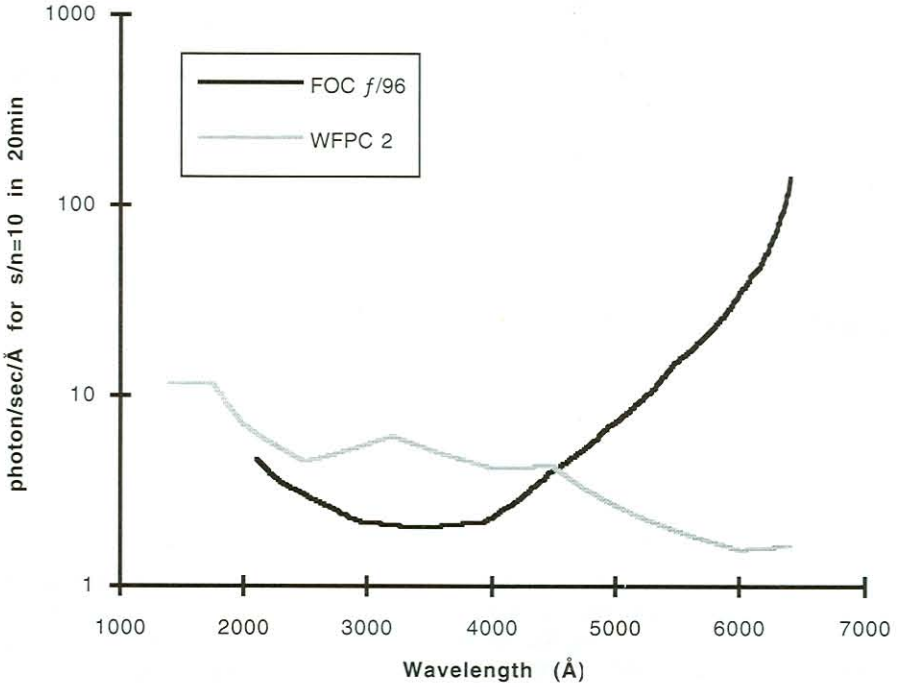


Figure 3: Comparison of FOC f/96 and WFPC 2 inverse sensitivities. The required number of photons/sec/Å (PHOT, these are photons incident on the clear HST aperture) to achieve S/N=10 in 20 min exposures is plotted as a function of wavelength (see text).

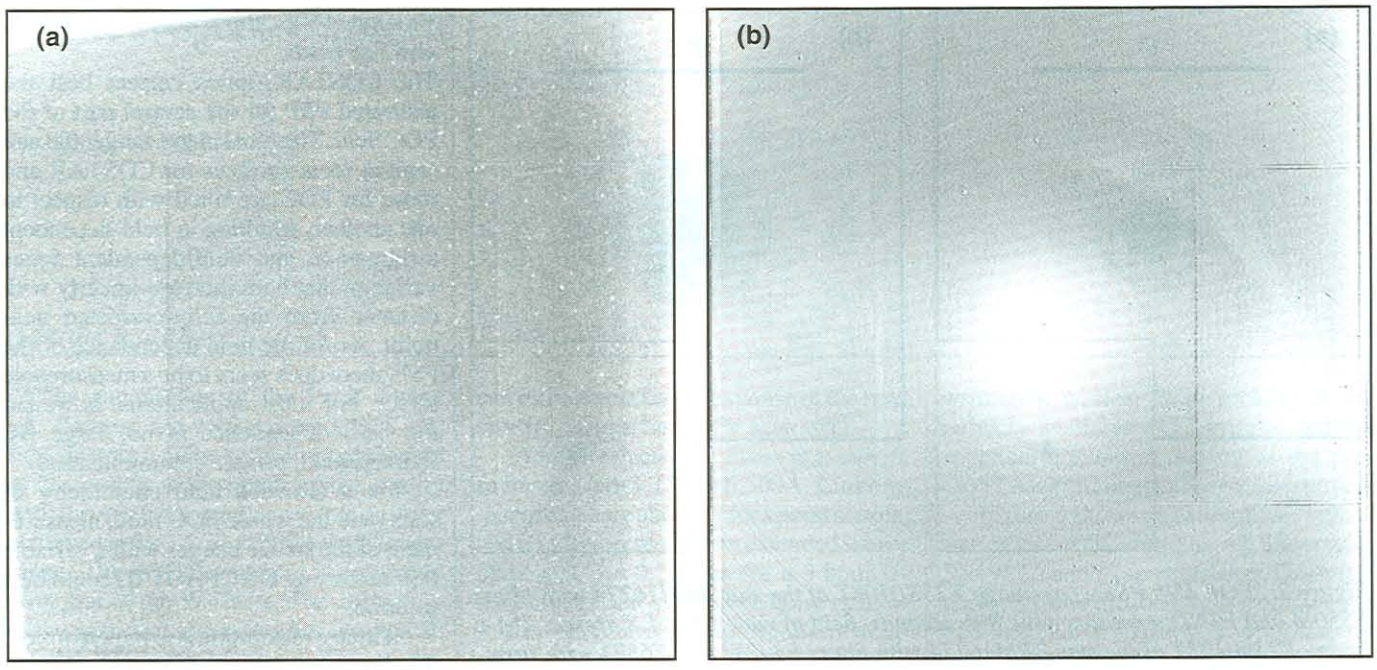


Figure 4: COSTAR+FOC flat fields, (a) f/96 extended format (512 × 1024) de-zoomed image x22z0101t, exposure time 600 seconds. (b) f/48 extended format (512 × 1024) de-zoomed image x2490201t, exposure time 1200 seconds.

instrument scientists. So far so good: "We are still looking for an example of an image which shows asymmetric jitter".

Examples of new PSFs are shown in Figures 2a and b. The PSFs are now available on STEIS in the directory */instrument_news/foc/psf_files*. An information file called *foc+costar.psf* describes each PSF file contained in the subdirectory *f96/foc+costar*. The behaviour of the PSFs with time is under study at STScI.

The dark noise is expected to be 6.4×10^{-4} counts/sec/pixel (*f*/96). Using the public dark dezoomed image x22d0103td0 (512 × 1024 pixels), we measure 5.7×10^{-4} counts/sec/pixel (*f*/96). For the new *f*/48, it is expected to be 2×10^{-3} counts/sec/pixel (*f*/96). Before the repair mission, the background noise of the FOC *f*/48 camera increased drastically during the year 1993 (Nota, 1993, FOC Instrument Science Report). The FOC *f*/48 was then successfully activated after the STS-61 Servicing Mission in December, showing normal behaviour. Then higher background was registered. The most recent turn-on of the *f*/48 did not show the large and increasing trend in the dark count rate seen previously. In order to preserve its life, however, no science observations have since been made with *f*/48. The future use of the *f*/48 channel is presently undecided.

An example of flat field images is shown in Figures 4 a and b for relays *f*/96 and *f*/48 respectively. These on-orbit images can be compared to the predicted POST-COSTAR FOC internal and external flats of the handbook. The vignetting of the *f*/48 affects the field of view. Flat fields taken with the new *f*/96 relay are as expected.

Finally, new rules for exposure time estimation had to be devised for GOs to follow for post COSTAR images. In the simplest case of point-like sources in the linear count rate regime, count rates would increase by a factor of 5, thus exposure times should be reduced by this same factor. However, the rule changes if additional neutral density filters are required to bring the count rate down into the linear regime—in these cases exposure time may even need to be increased.

Acknowledgments: I should like to thank colleagues at the STScI and the ST–ECF for providing information. In particular, I should mention Perry Greenfield, Robert Jedrzejewski, Antonella Nota, Francesco Paresce, Richard Hook and Wolfram Freudling.

Faint Object Spectrograph

Michael Rosa

After the successful correction of the HST spherical aberration, the FOS—which was not touched during the M&R mission—has been found to operate as expected. The main differences between the performance of the pre-COSTAR and the post-COSTAR FOS are an increased throughput for point sources overwhelming a slight loss at the two extra COSTAR mirrors, a gain in spectral resolution for point sources and changes in the projected sizes of the apertures. Spectropolarimetry will probably be restricted to the near ultraviolet wavelength range.

Effects of the pre-COSTAR PSF

The instrument has been very reliable and successful since it took its first spectra in mid-1990. From the observer's point of view, the effect of the aberrated PSF was principally a loss of throughput in the science apertures and a degradation of spectral resolution. This can be assessed quantitatively in Tables 1 and 2. A more subtle consequence was the loss of spatial resolution—even in the smallest science apertures—because of the broad wings of the PSF carrying information over several arcseconds. This affected target acquisition in crowded fields and the ability to

Aperture Wavelength (Å)	1".0	0".5	0".3
1500	48	24	9
2250	42	22	19
3400	40	20	8
5000	38	18	6
7500	36	16	8

Table 2. Degradation of spectral resolution with pre-COSTAR HST PSF, given as the percentage increase of the LSF's FWHM. (Source: G.F. Hartig & A.L. Kinney, March 1991, in "Update on Instrument Performance", C. Blades, STScI)

Aperture Wavelength (Å)	1".0 pre	 post	 ratio	0".5 pre	 post	 ratio	0".3 pre	 post	 ratio
1500	27	76	**2.8**	17	70	**4.1**	9	61	**6.8**
2250	35	85	**2.4**	24	79	**3.3**	14	70	**5.0**
3400	43	90	**2.1**	29	82	**2.8**	18	74	**4.1**
5000	45	90	**2.0**	30	82	**2.7**	19	72	**3.8**
7500	46	86	**1.9**	20	78	**2.6**	22	67	**3.0**

Table 1: Percentage aperture throughputs pre- and post-COSTAR for point sources. (Source: G.F. Hartig & A.L. Kinney, March 1991, in "Update on Instrument Performance", C. Blades, STScI)

obtain clean spectra of faint sources in the immediate neighbourhood of, eg, luminous stars or the nuclei of active galaxies.

Nevertheless, a large body of excellent data has been amassed with the handicapped pre-COSTAR FOS. These exploit its unique capabilities—complete coverage of the spectral interval from 1,150Å–8,300Å at R = 1,300 and R = 250 and spectropolarimetry in the UV. Neither of these could be achieved with ground-based equipment even in combination with other space-borne UV observatories.

Current FOS performance

These shortcomings have been essentially cured with the restored imaging capability of HST. Leaving aside the intrinsic performance characteristics of the instrument (see below), the FOS now performs as anticipated before launch but with three modifications:

- ❑ The introduction of an additional telescopic system results in a 10% shortening of the HST+COSTAR focal ratio. The projected aperture sizes are 90% of the design values. This adds some overhead to the procedures for target acquisition into the smallest apertures of 0.26, 0.21 and 0.09 arcsecond diameter.
- ❑ Reflective losses at two extra COSTAR mirrors reduce the nominal throughput by about 15%. Except for the largest apertures (3".7 square) this loss is more than offset at longer wavelengths by the large gain due to the improved PSF. At wavelengths shorter than about 3,000Å, the gain/loss budget is wavelength dependent and can only be reported after extensive observations of flux standards through all apertures.
- ❑ The two additional mirrors of COSTAR contribute to the instrumental polarization. At the time of writing it is not clear to what degree this will affect spectropolarimetric capabilities.

Currently the Service Mission Observatory Verification program is being carried out. This is a shortened version of the initial SV and OV programmes. For the FOS, the first results show that indeed the restored HST PSF has resulted in an improved spectral resolution as can be seen in Figures 2 and 3 which compare the pre-COSTAR and post-COSTAR FOS PSFs.

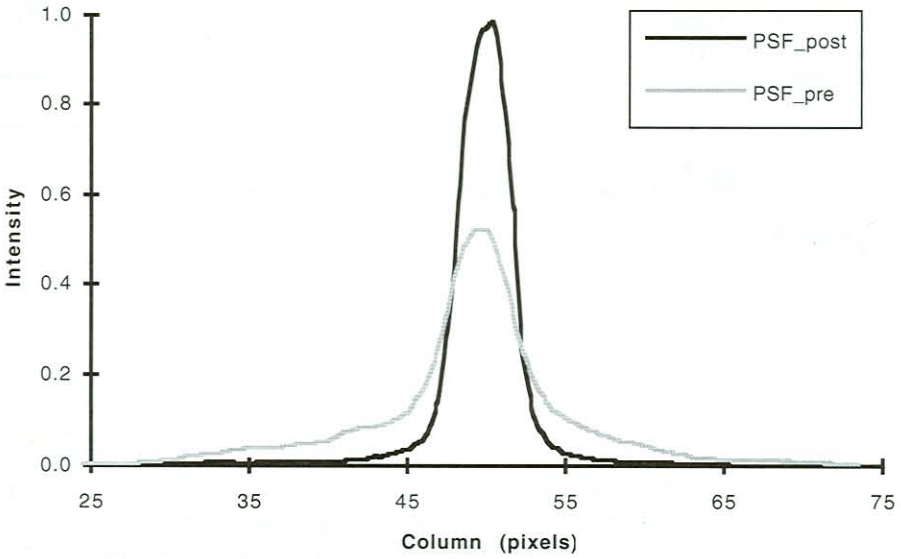


Figure 1: Cross cuts of the pre- and post-COSTAR PSF at the aperture of FOS. One pixel corresponds to 0".08. Pre-COSTAR (grey line), post-COSTAR (solid line). (Source: Kinney, A.L. et al., 1994, CAL/FOS-117, STScI)

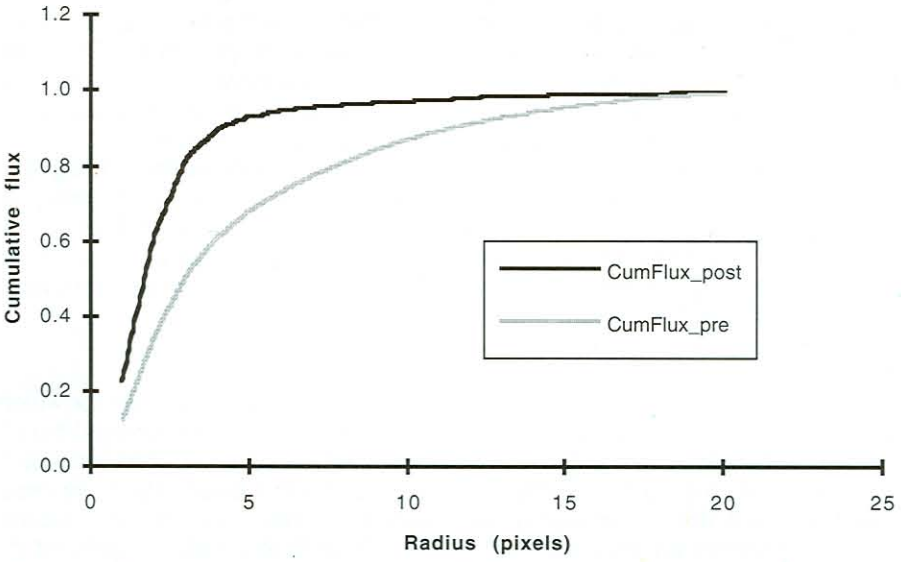


Figure 2: Cumulative flux in FOS red side PSFs as a function of distance from image centre. One pixel corresponds to 0".08. Pre-COSTAR (grey line), post-COSTAR (solid line). (Source: Kinney, A.L. et al., 1994, CAL/FOS-117, STScI)

Intrinsic performance characteristics

There are several instrumental characteristics internal to FOS which have become apparent during the 1990–93 period and will obviously not be altered by the addition of COSTAR. They are briefly summarized here for completeness.

- ❑ After launch in 1990 the magnetic shielding on the detectors was found to be inadequate. This results in a geo-

magnetically induced image motion problem (GIMP). In the red detector, this drifting has an amplitude of up to 1 diode which, if uncorrected, degrades the resolution by about a factor of 2. From 1991 onwards, the problem has been corrected off-line during pipeline processing. Since August 1993 a corrective algorithm works directly during data-taking on the electro-magnetic optics of the detectors.

- The blue side sensitivity has decreased by about 10% per year from launch until 1992, but appears to be relatively constant now. The red side sensitivity has been stable to within 5% except for a dip between 1,800Å and 2,100Å. Routine calibration observations (flux standards, flat fields) take care of these effects.
- Because of its broad wavelength coverage, the FOS is particularly susceptible to grating scatter. Observations of red targets at wavelengths shorter than about 2,000Å therefore suffer from scattered light. The ratio of counts due to true UV photons over counts produced by scattered red photons depends strongly on the wavelength of interest and the colour of the target. For a solar like spectrum it is only 10% at 1,700Å and decreases rapidly towards shorter wavelengths (see also Rosa, M.R., 1993, *ST-ECF Newsletter* No. 20, p 16). A corrective algorithm is in preparation.
- For the faintest sources, the dark counts due to Çerenkov light from energetic particles are a substantial component of the total signal observed (see Rosa, M.R., 1993, cit.). The standard pipeline algorithm which corrects for this background is being revised in order to remove deficiencies.

Goddard High Resolution Spectrograph

Jeremy Walsh

In common with the FOS, the chief effect of spherical aberration on the performance of the GHRS was a loss of throughput. The majority of targets observed with GHRS are stellar, so the throughput loss translated directly into lowered sensitivity for the detection of weak lines for example. Where the highest resolution was required, the small aperture (0.25 × 0.25 arcsec) was used and the geometrical throughput was only about 30% of the large (2.0 × 2.0 arcsec) aperture. A compromise could be reached if the large aperture was used, collecting about 70% of the total flux (at 2,000Å for example), and the spectra were deconvolved with the LSA line spread function. Quite independent of spherical aberration, the far-UV camera (Side 1) became unavailable in August 1991 as a result of an intermittent solder joint in the Low Voltage Power Supply. Subsequently, it was found that this joint was sensitive to the thermal conditions inside the instrument: the optimum condition was found and this power supply has given no problem for over two years. However since the operative Side 2 still required this power supply to transmit data to the on-board computer, it was deemed too risky to try the Side 1 high voltage to the detector.

COSTAR and GHRS

COSTAR has a two-mirror arm for the correction of the spherically aberrated beam, similar to FOS. The geometrical effect is to alter the image scale so that the large aperture projects to 1".74 square and the small 0".22 square. The throughput of the large aperture was expected to be 70% and the SSA about 50%—based on pre-servicing mission calculations. This meant that the LSA throughput should be about the same as that before COSTAR, whilst the SSA throughput should rise to about 2.3 times its pre-COSTAR value. Although the throughput of the LSA will not be much different from the pre-COSTAR value, the line spread function will have much reduced wings and so it will result in much 'cleaner' spectra with, for example, sharper lines and less infilling. The effect on SSA spectra will be dramatic with higher signal-to-noise ratios for the same observing time and, on account of the narrow PSF, more repeatable photometry.

The Reality

GHRS was the last instrument for which the COSTAR bench was deployed, but all has gone extremely well. Tests on Side 2 showed that it is essentially in the same state it was before the servicing mission and (Cycle 3) observations continued after the servicing mission and before the COSTAR mirrors were deployed. In particular, no loss of sensitivity was found as might have resulted from contamination for example. The COSTAR mirrors for GHRS were deployed successfully on 21st January and coarse and fine alignment followed. Most pertinent are the throughput measurements. Results are so far puzzling in that there is a depression in post to pre-COSTAR sensitivity of up to 15% at 2,000Å with extent from 1,500 to 2,400Å, but no significant losses in the far-UV or near-UV. Indeed, in the near and far-UV the post-COSTAR throughput exceeds the pre-COSTAR one by up to 20%. The depression from 1,500–2,400Å has also been found for FOS and so may be attributable to the COSTAR mirrors, which are optimized for the blue. The situation for the small aperture is however much as expected with the ratio of small aperture throughput post/pre-COSTAR ranging from 1.6 at 1,200Å to 2.2 at 3,000Å, although based on a limited number of observations. Clearly further measurements and analysis of the aperture throughputs are required to corroborate and understand these initial values.

Reactivation of Side 1 proceeded at a cautious pace. A number of tests of the low voltage electronics were performed, for short periods at first and then extending up to 24 hours. The tests culminated in ramping of the Side 1 high voltage to 21 kV on 12th February. All went well and dark counts were measured with a level of 0.01 counts/diode/sec being recorded: not significantly larger than the typical value of 0.007 counts/diode/sec recorded before the Side 1 fault became apparent in 1991. GHRS completed its SMOV in mid-February so Cycle 4 Side 2 observations are underway and Side 1 proposals can soon be scheduled after grating sensitivity and wavelength calibration has been checked.

Photometry with WFPC 1

This information about WFPC 1 flat fields was kindly provided by Garth Illingworth and Drew Phillips. The introduction was written by Wolfram Freudling who added the illustrations and information about the ST–ECF installation.

The pipeline flat fielding of WFPC 1 data is only a first order correction, deviations from a flat background are familiar to everybody who ever has looked at a pipeline processed WFPC1 image. An example is shown in Figure 1. This severely hampers any photometric work on the images. In the accompanying letter, Drew Phillips describes the efforts of the Medium Deep Survey (MDS) team to obtain second-order 'delta flats' for two frequently used WF filters, namely F555W and F785LP (see also Phillips *et al.*, 1994). They are applicable to data which have been flat fielded with c191513jw.r6h (F555W) and c1915143w.r6h (F785LP) respectively . Within IRAF, one can find out which flatfield was used in the pipeline by typing

*imhead *.c0h long+ | match FLATFILE*

The group made available to the community two correction images e2a1258lw.r8h and e2a1258ow.r8h which significantly improve the photometric quality of pipelined images. These images are available from the ST–ECF archive through STARCAT, but are also on disk installed in the wref database as well in the anonymous ftp account *ecf.hq.eso.org* in directory *pub/wref*. Within IRAF in the ecf domain, they can therefore be accessed as wref$e2a1258lw.r8h and wref$e2a1258ow.r8h. The pipeline processed images should be multiplied by these correction flats. The effect of multiplying the image of Figure 1 with the proper correction flat is shown in Figure 2.

The MDS group requests that the use of the flats is acknowledged in any publication based on them, the proper reference is given below.

Reference

Phillips, A. C., Forbes, D. A., Bershady, M. A., Illingworth, G. D. & Koo, D. C. 1994, A. J., accepted

Drew Phillips writes: (February 18, 1994: nb, slightly edited to reflect the introduction given above)

It has become clear over the last year that the STScI pipeline calibration for the Wide Field Camera of WFPC I for F555W and F785LP (as described in the WFPC I OV/SV report) has large scale flat field errors that have an amplitude of 10–15%. These errors are not correlated and so colors derived using these data can have even larger errors. These uncertainties are part of the reason why WFPC 1 is considered to provide poor photometric performance. However, we have found that WFPC I images can be corrected to where it is capable of providing good photometry.

As part of the Medium Deep Survey Key Project, the group at Lick Observatory has developed flat-field correction frames that reduce these errors to about 2%. These correction frames can be obtained from us or from STScI and used to correct pipeline processed data (or to derive corrections for application to existing photometric measurements). In addition, the new zeropoints for these filters have also been improved to the point where the photometric results from WFPC 1 can now approach a few percent given appropriate data and data processing techniques.

Another effort is under way within the Medium Deep Survey team by the MDS group at Johns Hopkins University to improve the overall calibration. This recalibration should be used when *complete reprocessing* of the data is desirable.

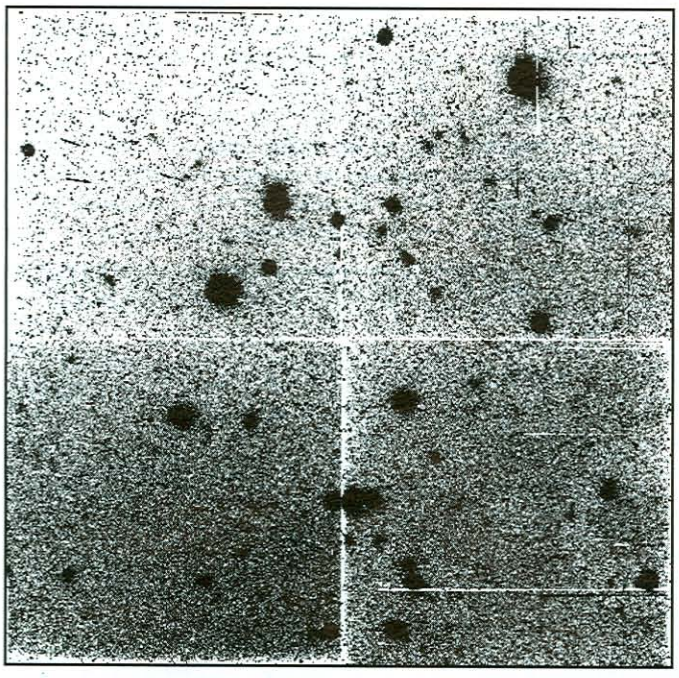


Figure 1: A mosaiced pipeline-processed Wide Field Camera image of high redshift elliptical galaxies (public archive data from a proposal by Windhorst et al., *1992). The image was taken with filter F555W and exposed for 20 minutes.*

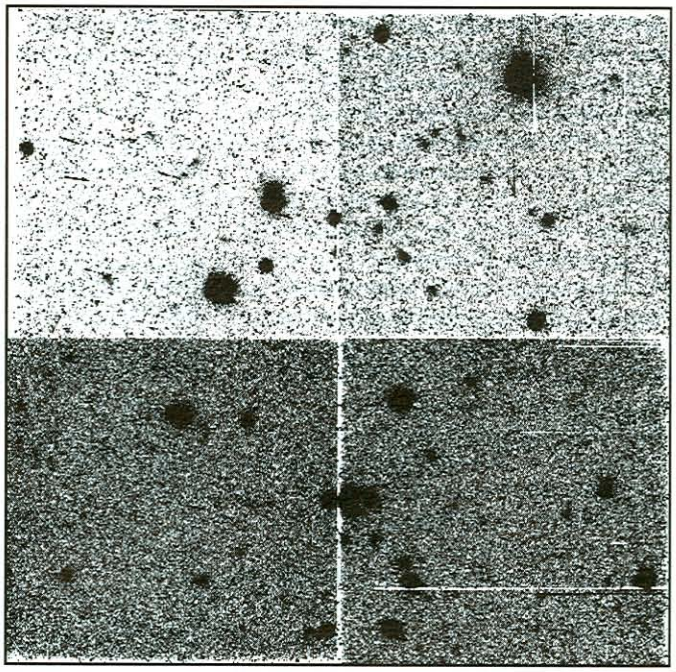


Figure 2: Same image as in Figure 1 but multiplied with the delta flats. The image is displayed on the same scale. Note the much flatter background in each of the CCDs. The photometric zero points for each of the CCDs are given by Phillips et al. *(1994).*

Reducing FOS spectropolarimetry

New software is available for the examination and analysis of the FOS spectropolarimetry data products.

Jeremy Walsh

A casual HST archive browser, or even the PI of a FOS spectropolarimetry proposal, is likely to be disconcerted by the volume of reduced data resulting from even a single observation. Admittedly there are flux and wavelength files that can be plotted, but the special polarization products (the .c3h file to be specific) contains 56 spectra. Then if the correct spectrum for the linear polarization is found and plotted, the values are scattered with seemingly no hope of deciphering polarization features. If the errors are plotted, they usually exceed the values. Clearly more tools are required to extract the scientific returns from spectropolarimetry data. This article very briefly describes the method of measuring polarization with the FOS, describes the data products that are delivered by the data reduction pipeline and introduces some routines written in STSDAS for analysing the data.

The hardware

In common with ground-based polarimeter modules mounted on spectrographs, in FOS there is a rotatable waveplate and an analyser. There are two waveplates and two Wollaston prisms mounted in pairs behind the spectrograph entrance apertures. Both the Wollastons are made from Magnesium Fluoride and the waveplates differ in their retardations to allow measurement of both linear and circular polarization over the complete UV-optical range covered by FOS. For example, Waveplate A, which is thicker than Waveplate B, has high efficiency for detecting linear polarization at Lyman-α. A full measurement of linear and circular polarization consists of spectra taken at 16 position angles of the waveplate-prism combination separated by 22°.5. For each spectrum, the birefringent Wollaston produces two spectra—with opposite senses of polarization—both of which must be recorded in two separate readouts of the FOS detector. Thus the full measurement consists of 32 spectra, although linear polarization can be measured by only four position angles of the waveplate. For a description of the instrument and its ground performance refer to Allen &Angel (1982).

The data products

The HST data reduction pipeline removes the instrumental signature of the data such as flat field and detector background, applies wavelength calibration and calculates statistical errors. For spectrophotometry data, wavelength and flux files are produced which can be plotted and subsequently analysed. For spectro-polarimetry data the same files are produced but there are as many wavelength and flux spectra as there are readouts (ie. 32 for 16 waveplate positions, referred to as 'POLSCANs'). Note also that the wavelengths of the data from two spectra at the same waveplate angle from the Wollaston (referred to as 'Pass' directions 1 and 2 and corresponding to the ordinary and extra-ordinary rays respectively) are shifted so that the flux data cannot simply be summed. *It is therefore advisable to study only the special spectropolarimetry products file - .c3h.* All this repetitive measurement is very important in the case of spectropolarimetry data, since one is attempting to detect very small differences between spectra with an instrument which has many reflecting optical components, each capable of inducing high polarization.

The further reduction steps for spectropolarimetry data consist of determining the Stokes parameters I, Q, U and V and their errors, the linear polarization, polarization position angle, and the circular polarization and their errors for each pass direction. In addition, the same spectra are produced for both pass directions combined and for both combined together with correction for interference by the waveplate and instrument orientation. This latter group of spectra are the final spectropolarimetry data products and the ones intended for further analysis; the table lists the layout of the data by the group number in the .c3h file. The same ordering is used for the Pass 1 and Pass 2 and merged pass direction data.

Analysis routines

One of the HST PI's I was supporting was Bill Somerville, who is leading a project to study the UV polarization properties of the interstellar extinction curve (see the article in the previous issue of this Newsletter). When he received his data neither he nor I had much idea what to do with it. We didn't even know how the spectropolarimetry data were stored, so slim was the documentation at that time on this 'Special Statistics file' as it was referred to. I had previously written programs for reducing ground-based Half-Wave plate spectropolarimetry data using the FIGARO data reduction system (Walsh, 1992). I rewrote some of these programs to read the Stokes parameter data from the .c3h file and manipulate polarization data. Most importantly the data need to be rebinned so that the polarization error per

Position	Parameter	Group number
1	Stokes parameter I	43
2	Stokes parameter Q	44
3	Stokes parameter U	45
4	Stokes parameter V	46
5	Stokes parameter I error	47
6	Stokes parameter Q error	48
7	Stokes parameter U error	49
8	Stokes parameter V error	50
9	Linear polarization	51
10	Circular polarization	52
11	Polarization position angle	53
12	Linear polarization error	54
13	Circular polarization error	55
14	Polarization position angle error	56

The key to Pass 1 and 2 merged and corrected .c3h data

bin is at least of the same order (preferably less) than the polarization values. Typical interstellar polarization values in the UV are 1% or less and even for bright stars the linear polarization error per channel is at least this value. These programs enabled Bill Somerville to usefully plot his FOS UV data and compare it with optical polarization measurements.

I mentioned to the STScI FOS group, and Anuradha Koratkar in particular, that I had some programs for analysing spectropolarimetry data and would they like them to incorporate the software into STSDAS. At that stage Howard Bushouse had just started as the FOS programmer and has subsequently done a great job of taking my subroutines and turning them into useful STSDAS tasks and adding many more. The section of STSDAS that is now devoted to spectropolarimetry is called spec_polar under hst_calib/fos. There were many discussions with Rich Allen from Steward Observatory along the way since he has been with the instrument since its construction and is the calibration scientist. We inadvertently reinvented many of the wheels in Rich's IDL based FOS spectropolarimetry reduction package and of course checked that the STSDAS software produced the same answer.

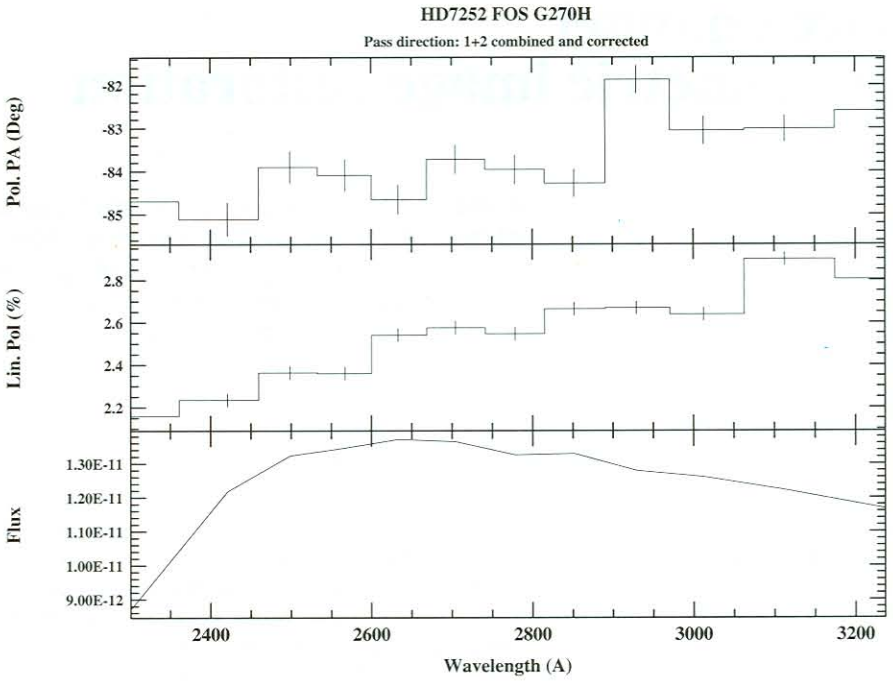
Here is a brief outline of what can be done in this package:

polbin

Binning of the polarization data: To reach a meaningful polarization error per bin the data can be binned into a given number of channels (which may be of constant width in wavelength space or in inverse wavelength space) or into channels whose extent is dictated by the magnitude of the error. The latter option can be very useful if there are features in the spectrum where the details of the polarization behaviour are of interest, such as the wings of an emission line.

polave

Averaging of many spectropolarimetry data sets: Since it is not advisable to spend more than a single HST orbit on one complete set of POLSCAN measurements, in the case of faint objects many orbits-worth of data may be required to yield useful polarization estimates. The routine *polave* performs weighted averaging of the Stokes parameters and propagates the errors. Polarization cannot be averaged, so is recomputed from the averaged Stokes parameters. In addition, another task called ***pcombine*** allows averaging of any number of flux-calibrated spectra and propagation of the statistical errors to produce the total flux spectrum for data split between several observations.



A typical plot of a reduced FOS spectropolarimetry observation, produced using 'polplot'. The flux, linear polarization and position angle for the B1V star HD7252 (E_{b-v} = 0.34) is shown from the G270H data. The linear polarization has been binned into 0.03% bins. The sharp dip in flux below 2450Å is the 2200Å extinction feature.

polplot

Plotting of the flux, linear polarization and polarization position angle and circular polarization as a stacked plot: The data can be plotted against wavelength or inverse wavelength (μm^{-1}) and error bars are indicated. There is an option to plot the two pass directions separately, or the merged pass direction data in order to investigate any systematics between the two pass directions. Alternatively a stacked plot of the Stokes I, Q, U and V parameters can be made with *polplot*.

calpolar

This routine performs the routine spectropolarimetric calibration as done by the pipeline but with a greater degree of interaction. This is very useful if some editing of the data had to occur to disregard bad waveplate positions or bad data sets caused by tracking problems for example. Other tasks are also available to compare (through plots and statistics) spectra taken at different waveplate positions—***comparesets***, correct linear polarization data for bias in Q and U associated with small quantities—***plbias***, to recalculate polarization from I, Q, U and V Stokes parameter data—***polcalc*** and to normalise the Q, U and V Stokes parameter spectra by the Stokes I—***polnorm***. Details of the spec_polar package and the use of these tasks are contained in the 'help' document, accessible on-line.

As an example of the application of this package, the figure shows a stacked plot of flux, linear polarization and polarization position angle resulting from polplot. The data are from an FOS G270H spectrum of the early type star HD7252; the PI is Bill Somerville and a paper describing the results for this star and another early-type star is in press (Somerville *et al.*, 1994). The linear polarization has been binned into bins of 0.03% polarization error. A trend in the linear polarization values across the spectrum is evident and possibly also in the position angle, with no polarization structure apparent over the 2200Å extinction feature. This plot is very easy to produce as is the whole package to use—you don't need to be a polarimetry expert to do FOS spectropolarimetry.

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Two channel photometric image restoration

In this part of a continuing series of articles on the application of iterative restoration codes to astronomical data, it is shown how the separation of unresolved stars from resolved background provides a powerful method of performing crowded field photometry. There are also applications to separating point sources from faint surrounding nebular structure in high dynamic range observations.

Richard Hook, Leon Lucy,
Alan Stockton† & Susan Ridgway†

The successful correction of the HST spherical aberration means that the rôle of HST image restoration has changed. For many observations, particularly of very faint sources, restoration will simply not be needed. However, it is likely to still be used, when there is adequate signal, to gain up to a factor of two in resolution and suppress the remaining features in the point spread function such as spider diffraction spikes. It will also naturally remain important for processing the large volume of archive data from before the repair mission.

However, the most important developments from the era of spherical aberration are probably not simply ways of suppressing the effects of the defect but the more generally applicable techniques for image processing which can be developed from them. One example is generalised image co-addition which we have described in earlier articles (Lucy 1991, Lucy & Hook 1992, Hook & Lucy 1992,1993a/b). Here we describe another technique, developed as an extension of the Richardson-Lucy method (Richardson 1972, Lucy 1974), which allows accurate photometry.

Introduction

The scientific aims of image processing are to extract information from the image, not just make it look more pleasing. This information may be the structure of objects in the frame or quantitative measurements such as the photometry of stars. The most popular and effective methods for image restoration are non-linear and hence redistribute flux in a way which often degrades the photometric content of the data. They also cause artifacts to appear in the background when large numbers of iterations are used, while the number of iterations which will give best results is often difficult to estimate. As a result, the restored image—although it may look better to the eye—is often less suitable for scientific use that the unrestored one. An illustration of these problems is given in Figure 1. Several studies (eg, Cohen 1988; Linde & Spännare 1993) have suggested that a workable compromise for point source photometry is to use restored images—which show better contrast and object discrimination—to identify objects and then to perform photometry by using standard PSF fitting packages (eg, DAOPHOT, Stetson 1987 and ROMAFOT, Buonnano et al. 1983) on the unrestored data. Other work (Busko 1993) has shown that there is often a trade-off between photometric accuracy in the measurement of point sources and the quality of the background in the resultant restored image.

Many astronomical images do not contain a uniform spread of spatial frequencies. Instead, they consist of many point sources and a smoother background intensity distribution. Standard restoration methods do not use this information and hence cannot significantly sharpen point sources without causing the background to break up into speckles. Other methods,

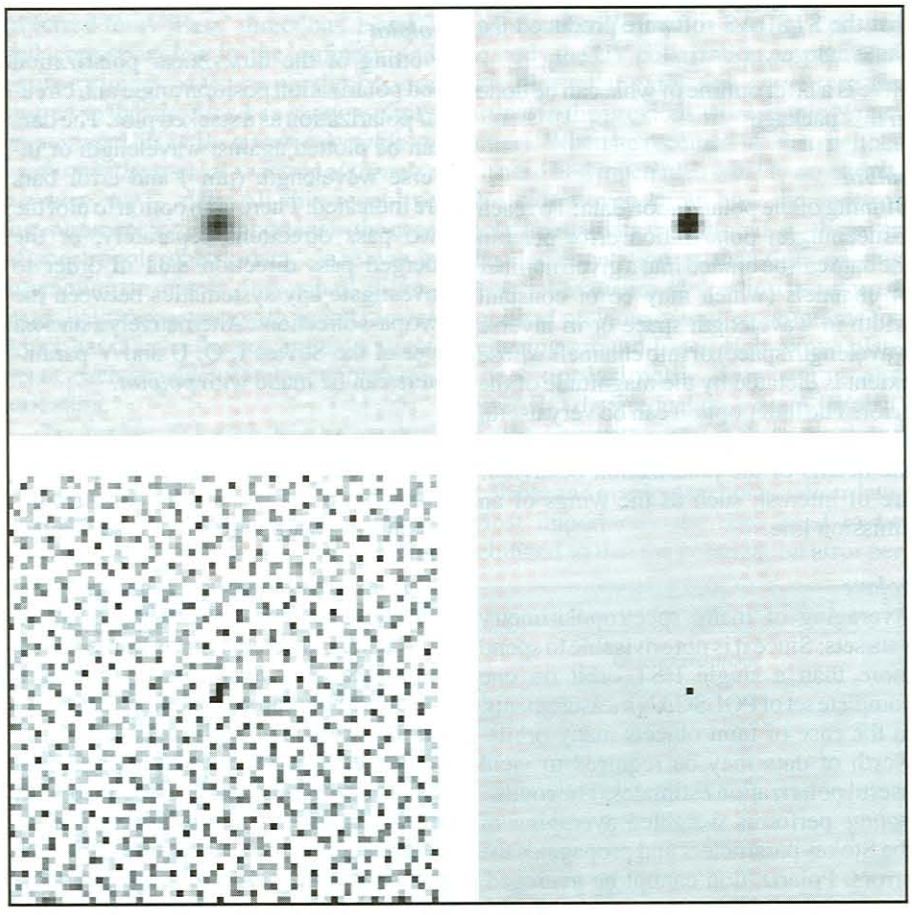

Figure 1: A typical small piece of sky. The upper-left image shows a simulated CCD image of a star on a background. The background has a mean of 100 counts/pixel and the star has a FWHM of 3 pixels and contains a total of 10,000 counts. Realistic noise is included. The upper-right image is a restoration of the upper-left one using 20 accelerated iterations of the Lucy method, the lower-left is the same continued to 1,000 iterations. The lower-right image is the result of applying the photometric, two channel method described in the text.

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such as those based on Maximum Entropy considerations, can impose smoothness but generally underestimate point source fluxes. We have adopted a different approach which separates the known point sources—which are forced to be delta-functions—from a background which is forced to be smooth. Hence we obtain the best of both worlds by using extra information about the image. As a further generalization, the method may be used to derive the PSF iteratively from the data. Descriptions of the logical steps in the development of these methods and more detailed mathematics are given elsewhere (Lucy 1994, Hook & Lucy 1994). Here we present a brief description of the method —along with two examples using different kinds of data—and details of how the software may be obtained over the network.

Method

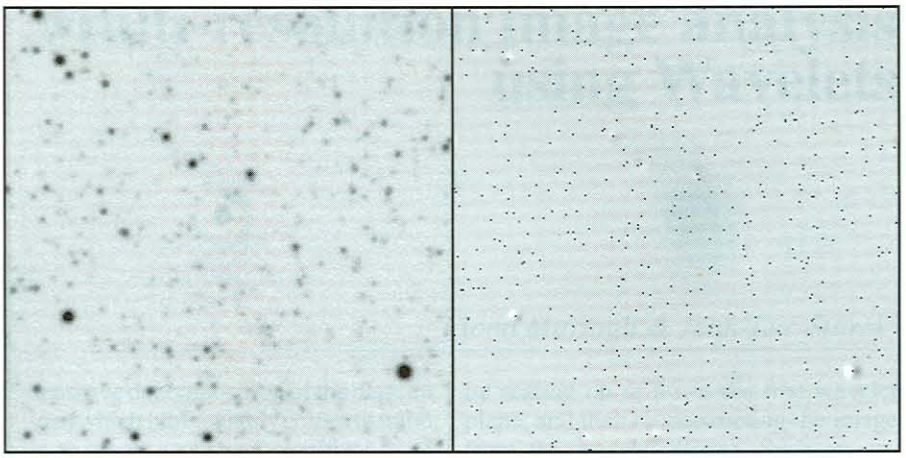
We divide the estimate for the true intensity distribution on the sky into two parts. The first consists of delta functions at the observer-supplied positions of point sources in the frame and the rest is zero. The second models the intensity of the smooth background under these point sources. A scheme for iteratively finding the maximum likelihood estimate for these may be derived in a manner analogous to that of the simple Richardson-Lucy algorithm. However there is a clear ambiguity—a star may be represented in the delta function channel or in the other or partially in each—and this does not lead to a useful result. However, if we add an additional constraint to the background channel which prevents it from having very sharp features such as stars, the ambiguity is removed and a genuine two channel photometric method results in which all the star flux goes into the delta functions and the background channel fits to the smooth features underlying them. The additional constraint is chosen to be an entropy-type regularization. The entropy may be determined relative to a constant, flat 'prior' or a to a smooth 'floating prior' which is taken to be a smoothed version of the current estimate for the background. In both cases there is a free parameter which controls the relative importance of the entropy in the expression being maximised: typical values are between 0.1 and 1. With the floating prior, the smoothing kernel applied to the current background estimate when calculating the prior controls the spatial scale of the smallest features which are permitted in the background channel—and is another free parameter.

The initial estimates for the two channels may be chosen so that half the flux goes into each and all the stars are initially equal. Alternatively, some approximate estimates for the star and background strengths may be used. Because the background is regularized, the iterations should be allowed to proceed to convergence: there is no need for the often rather arbitrary stopping rules used with simple RL restoration.

The lower-right image of Figure 1 shows the result of applying this method to a simple simulation of a single star on a flat background with realistic noise. All the flux has gone into the delta function, there is no unpleasant artifact around the star and the background is smooth. The flux in the star is determined to be only 0.006 magnitudes from the true input value, well within the error expected from poisson noise on a star having 10,000 counts.

Examples

To illustrate the possibilities of this technique two extreme examples are given in Figures 2 and 3. The first is classical crowded field with flat background where the aim is good photometry of the stars. The second is a very deep ground-based image of a QSO where the aim is to find the structure of the underlying 'fuzz' by removing the dominant effect of the QSO itself. Some other examples can be found in Hook & Lucy 1994.



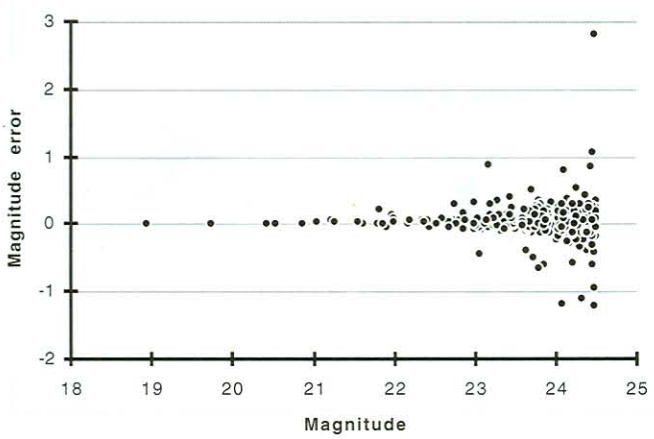


Figure 2: The left image shows a simulated deep CCD image of a moderately crowded field. The PSF is adequately sampled and accurately known. There are 500 stars with known positions. The noise is appropriate and the sky background is strong, averaging 1000 counts per pixel. The right hand image shows the result of restoration using the two channel method. The stars are now all delta functions at the designated positions and the sky is smooth. Some small artifacts are visible near the brightest stars which are caused by the centre of the star images not being exactly at the centre of a pixel where the delta function is located. The graph shows the quality of the photometry which has been achieved, the star magnitudes are arbitrary (although realistic) and the magnitude errors are accurate. The photometry is seen to be linear to faint levels and the scatter is small.

Implementation

This method has been implemented as a FORTRAN code called PLUCY which uses the F77/VOS as an interface to the IRAF package. Both stationary and floating defaults are available as well as acceleration, sub-pixellation, simultaneous PSF determination and several other options. It is not fully supported but there is a detailed help file and it is made available to anyone who wishes to try it out. All the files and instructions necessary to build a local version are available on the ECF anonymous FTP archive (ecf.hq.eso.org = 134.171.11.4) in the directory pub/swlib/restoration/iraf. The same core code is also available to run within the MIDAS system and this may be collected from the same FTP site in the directory pub/swlib/restoration/midas/lucy. It is planned to incorporate these codes into future releases of both STSDAS (in the contributed package) and MIDAS.

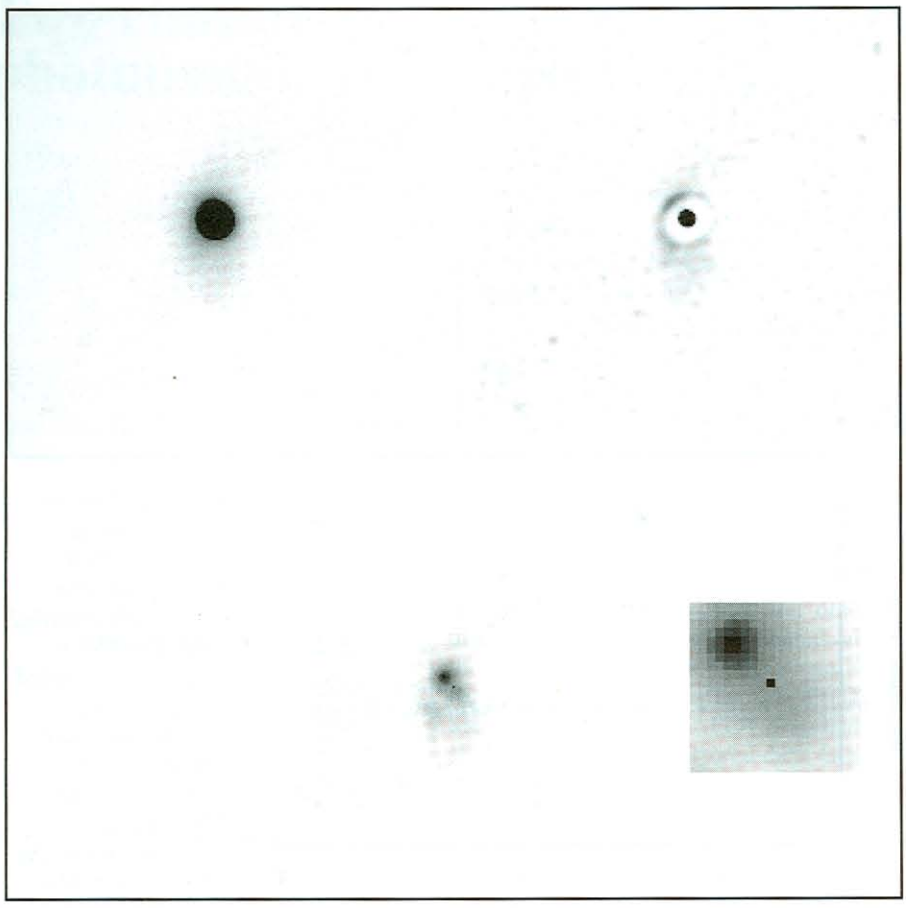


Figure 3: The upper-left frame shows a very deep image of the QSO 3C48. It was obtained and reduced by Alan Stockton and Susan Ridgway and published in Stockton & Ridgway 1991. It is the sum of 23 frames with a total exposure time of 4140s made with the 2.2m University of Hawaii telescope using a filter centered at 7655Å with a FWHM of 1270Å (this avoids bright emission lines coming from the QSO) and a TI CCD. The seeing varied from 0.6 to 1.0 arcsec with a median of 0.7 arcsec. In the original analysis, the QSO was subtracted by very careful PSF scaling and subtraction. This works well but inevitably there is a region around the QSO where the amplified noise in outer parts of the PSF becomes apparent. The upper-right frame is a conventional Richardson-Lucy restoration of the same frame and clearly shows how ineffective such a direct approach is for this kind of problem—a very strong artifact has formed around the QSO which largely destroys the faint features of interest. The lower frame shows a re-reduction of this data set using the two channel method described here. The artifact is now totally missing and all the QSO flux has gone into a single pixel (shown more clearly in the insert). The secondary nucleus (3C48A) is very clear and the structure found originally is well seen but without the artifacts of PSF subtraction.

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Servicing Mission Observatory Verification (SMOV)

Update, 11 March 1994

Almost all SMOV requirements have now been met. The only activities that remain are several observations to pin-point the locations of the FOS small apertures to enable the bulk of Cycle 4 science, and an early release observation (ERO) for the GHRS. These activities are scheduled for completion by 3 April 1994.

(Information from STScI)

STScI NEWSLETTER

The Space Telescope Science Institute publishes a Newsletter at regular intervals (3–4 times per year). The STScI Newsletter contains information of interest to proposers, including updates on the status of the HST and its instruments. Subscriptions are available at no cost to all interested scientists; requests to be added to the mailing list should be sent (by regular or electronic mail) to the User Support Branch at the following address:

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Multi-resolution image analysis using Wavelets

Fionn Murtagh & Jean-Luc Starck[†]

Wavelet background

The wavelet transform has proved itself to be a versatile tool. Here, we look at a range of applications of importance for the image analysis of 1D and 2D HST data. We also point to some of the issues opened up by this work, and to some exciting opportunities.

Examples of the use of the wavelet transform in astronomy include: assessing the statistical significance of large-scale cosmological structures (Slezak *et al.*, 1993), and galaxy luminosity measurement (Lorenz *et al.*, 1993). Bijaoui (1993) has described the wavelet transform as the corner-stone of an astronomical vision model. The wavelet transform is used for image compression in the Digital Sky Survey.

Using a wavelet transform, one may obtain a series of resolution-related views of an image. Specific mathematical relationships exist between these resolution levels. The latter give rise to wavelet planes, which in some cases—including the case of the particular wavelet transform given high priority by us for use with astronomical images—are of the same dimensions as the original image. The original image can be expressed as an additive combination of the wavelet planes.

Motivation

Use of the wavelet planes is motivated by reasons such as the following:

- ❑ They provide a sensitive decomposition of the image so that faint extended structures may become visible in these wavelet planes, whereas they are not at all evident in the original image.
- ❑ Since they are defined as differences between resolution levels, they may conveniently allow the user to ignore problematical varying background, — it is 'differenced' out.
- ❑ one can carry out a wavelet transform without major computational overhead in the context of other image processing operations, in order to get a better handle on the data—a salient example of this is in image restoration.
- ❑ given that the wavelet planes provide a sensitive decomposition of the data, an idea which immediately comes to mind is to assess statistical significance of image structures by means of significance in the wavelet space. This idea works well!

An extensive wavelet package is available in MIDAS. (Other wavelet code is available in IDL; from Press *et al.*, 1992; public domain code is available at different anonymous ftp sites, etc.). The MIDAS package supports applications such as filtering, deconvolution and image comparison; and display possibilities. Operations may be carried out on the wavelet planes: for example, high frequencies in the image can be enhanced or suppressed, by scaling up or down the first wavelet plane, and then reconstructing the image from the wavelet planes. Such an approach works well for the removal of fixed pattern noise in FOC images. For such an application, the frequency filtering may have untoward effects on real objects in the image. To avoid this, we can carry out the filtering in such a way that real objects are left inviolate. This will be discussed below.

Wavelet-based image restoration for denoising

The Richardson-Lucy (RL) iterative image restoration method is supported in the MIDAS wavelet package. So, too, is the

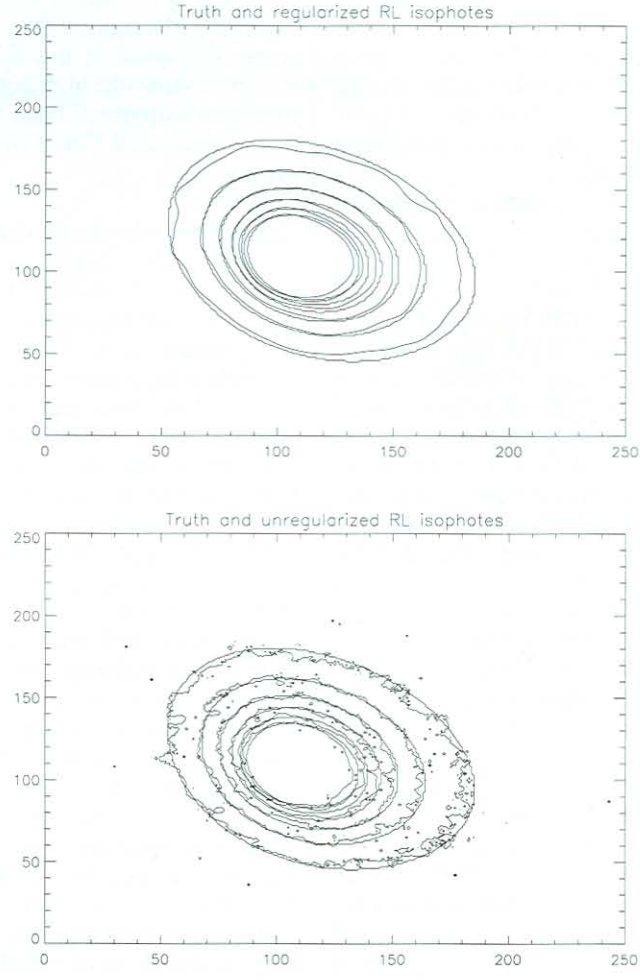

Figure 1: Isophotal contours corresponding to (a) 'truth image', and wavelet-regularized RL restoration; and (b) 'truth image' and unregularized RL restoration.

[†] Cisi-Ingénierie, Valbonne, France

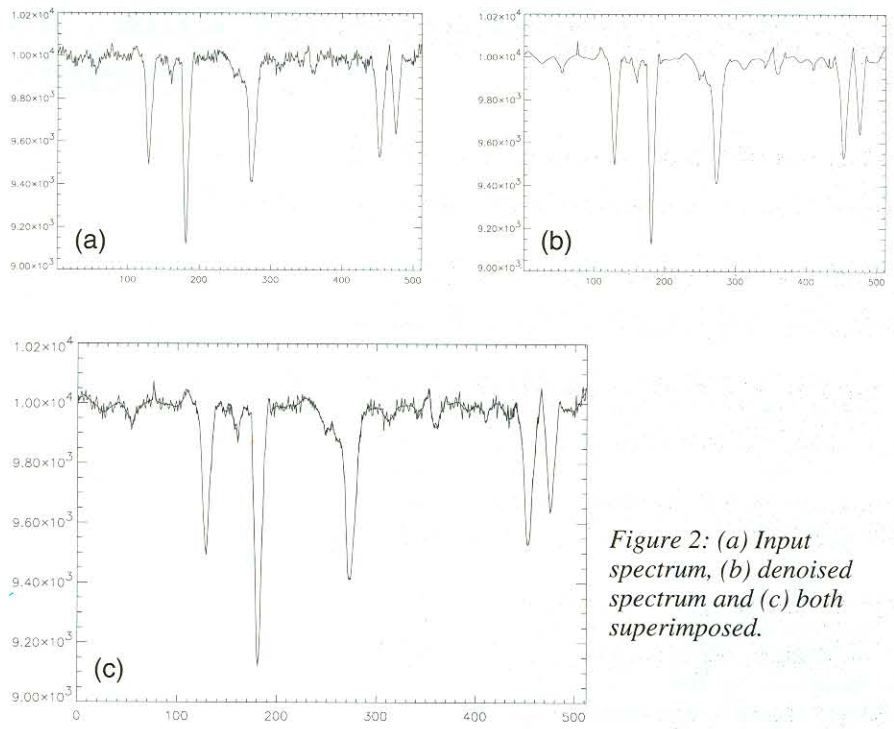

Figure 2: (a) Input spectrum, (b) denoised spectrum and (c) both superimposed.

enhancement of this method to allow for noise suppression by means of removal of insignificant wavelet plane coefficients. This provides as output a regularized (and restored) image, together with an additive residual noise image. To assess significance, either Gaussian or Poisson models are supported. We will review some programs which go beyond what is currently available in MIDAS.

The program ***regrestmsc***, available by anonymous ftp from *ecf.hq.eso.org:/pub/swlib/restoration/wavelets*, is a standalone executable which prompts for its input image, the PSF image and user requirements. The MIDAS BDF image format is currently supported (and a conversion to FITS is planned). Iterative image restoration methods supported are RL, Van Cittert and One-Step Gradient. Gaussian and Poisson models are permitted. An additional enhancement relates to the possibility of noise-removal doing damage to real objects in the image. Photometric fidelity is thus compromised. A way around this problem has been found: find the astronomical objects based on their statistical significance in wavelet space and protect them from the noise removal procedure. Such an image mask or support is built up as the iterations are carried out. Figure 1 shows a simulated galaxy (one of the elliptical galaxy images described in Hanisch, 1993) restored using this algorithm. Figure 1a shows isophotes arising from the prototypical (unblurred, noise-free) image, overplotted with isophotes from the restoration method described here. Figure 1b shows isophotes, again from the prototypical image, but this time with RL restoration results overplotted. This example made use of a small number of iterations only and is further discussed in a forthcoming paper (Murtagh *et al.*, 1994) which builds on Starck & Murtagh (1994). Another example discussed in the last-mentioned reference shows the high degree of photometric and astrometric fidelity found when using simulated WFPC 1 globular cluster images.

General wavelet-based denoising

Noise removal, independent of image restoration, is possible. In fact, the multiresolution support constraint is also very valuable here. Figure 2 shows an example of a spectrum, the denoised spectrum and the two superimposed. Note how the important spectral lines are accurately preserved. This program, ***filterline***, is available as an executable for SunOS machines at address *ecf.hq.eso.org:/pub/swlib/ipl/wavelets*. MIDAS BDF image format is supported (FITS will be available in the future).

We are currently pushing this approach further towards the general goal of object detection. In previous paragraphs, we have described how the support is constructed. This directly gives us all objects in the image, which is the overriding objective of image processing. Our reasons for doing astronomical object detection in this way is motivated by (a) the sensitivity provided by the wavelet transform, in particular for faint structures, and (b) the easy incorporation of a stochastic model, which leads to the statistical assessment of pixel significance. Implicit in this approach is that astronomical structures on varying resolution scales are being sought.

Some future directions

An obvious topic for near-future investigation relates to the decomposition of an image into a denoised image and a residual noise image. The latter, by definition, is incompressible. But the former ought to allow for considerable compression by any of the commonly used compression approaches in astronomy. Thus we view it as a preliminary denoising stage, as an aid in the subsequent stages of compression.

Another issue which is of importance for HST image analysis, especially with WFPC 2, is that of undersampling. Images with subpixel offsets must be combined. Image registration using multiresolution has been explored in Djamdji *et al.* (1993) and Bijaoui & Giudicelli (1991). Multiresolution, per se, provides added value in the algorithmic matching process: it emulates the human visual process. That the multiresolution approach used incorporates a stochastic model aids further. Wavelet planes are increasingly smoothed relative to the original image which helps object matching. Finally, the wavelet transform respects certain properties, relative to image offsets, which can be used in developing matching and registration strategies. It will be interesting to test these properties on undersampled imagery.

The wavelet transform achieves a number of worthy goals in an explicit manner: the astronomical objects themselves are demarcated; a stochastic model of the image can be taken into account; image denoising in its own right opens up many new perspectives; and regularization, and stopping criteria in iterative image restoration, are taken care of without the user having to face difficult (if not impractical) choices of system parameters.

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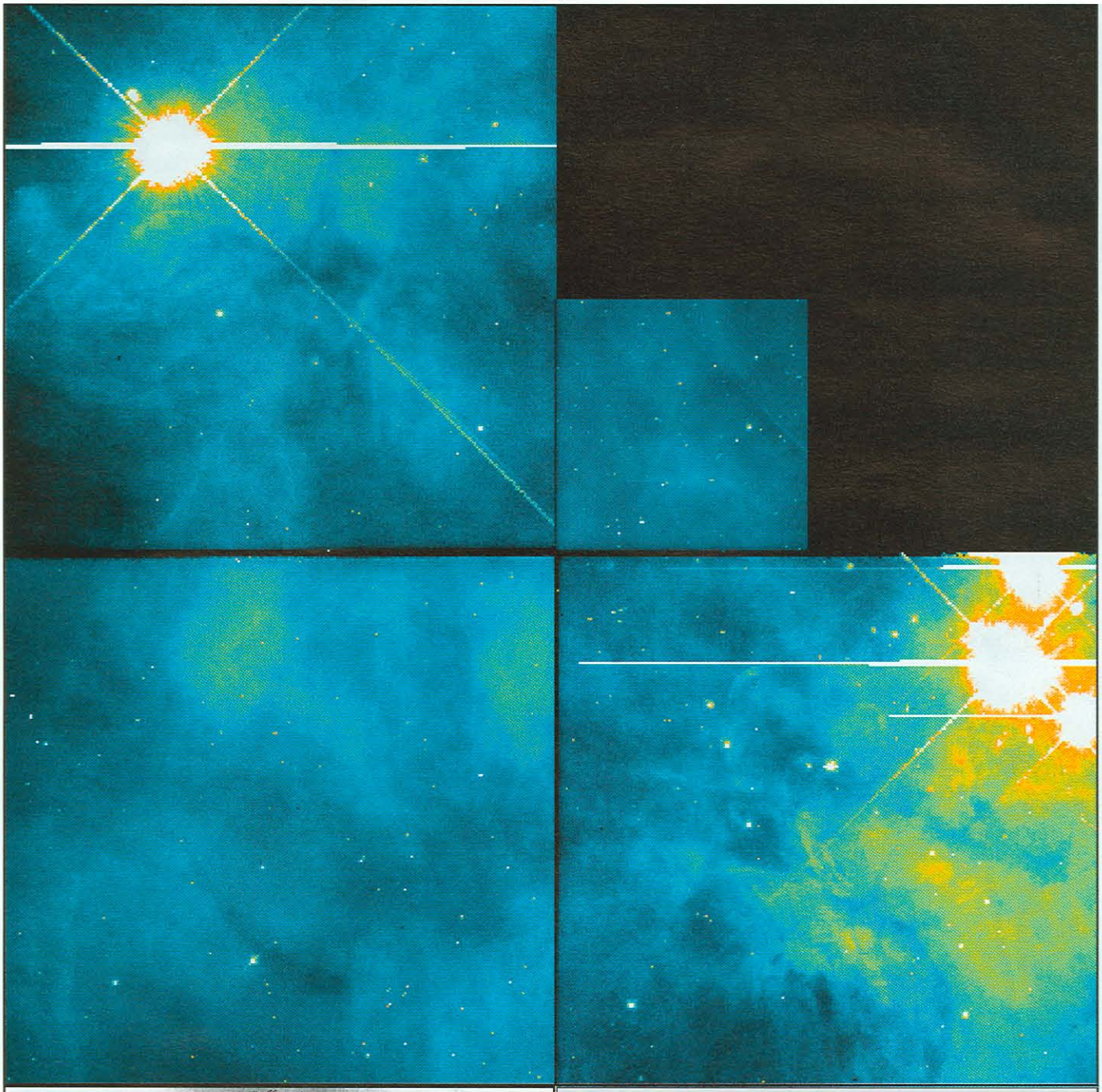
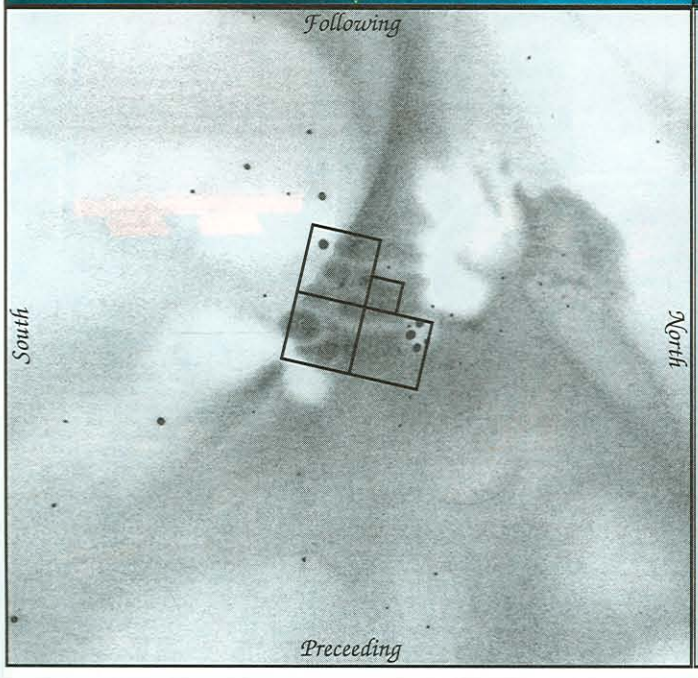
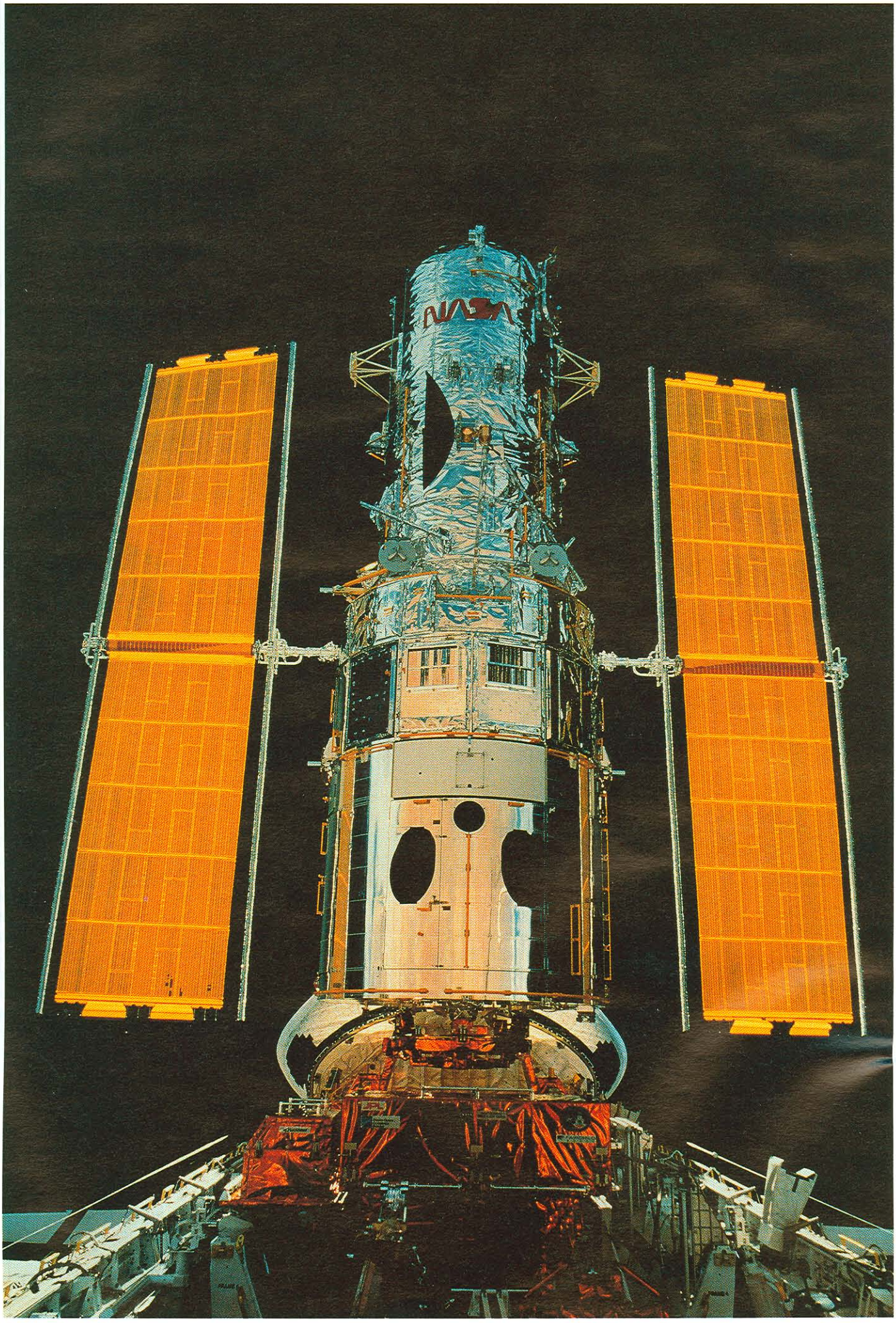




Pipeline processed WFPC 2 image of the region near the trapezium in the Orion Nebula (NGC 1976). The exposure time was 100 seconds through the F547M filter. The images from the four CCDs are displayed to correspond in orientation, position and size to Figure 1 in the article on WFPC 2 by Wolfram Freudling in this issue. Only pixels 41 through 800 in both x and y are displayed for each of the CCDs, which are the contiguous fields. This results in approximately correct relative positioning of the partial images. At the inner edge of each field, there is a vignetted area with a width of about four arcseconds. No further processing was applied to the images, ie, they are exactly in the state a GO would receive data. In particular, no cosmic-ray removal, co-addition or geometrical correction has been applied. To the left, the format is shown overlaid on a drawing of the Orion Nebula made by Sir John Herschel during the 1830's from the Cape of Good Hope.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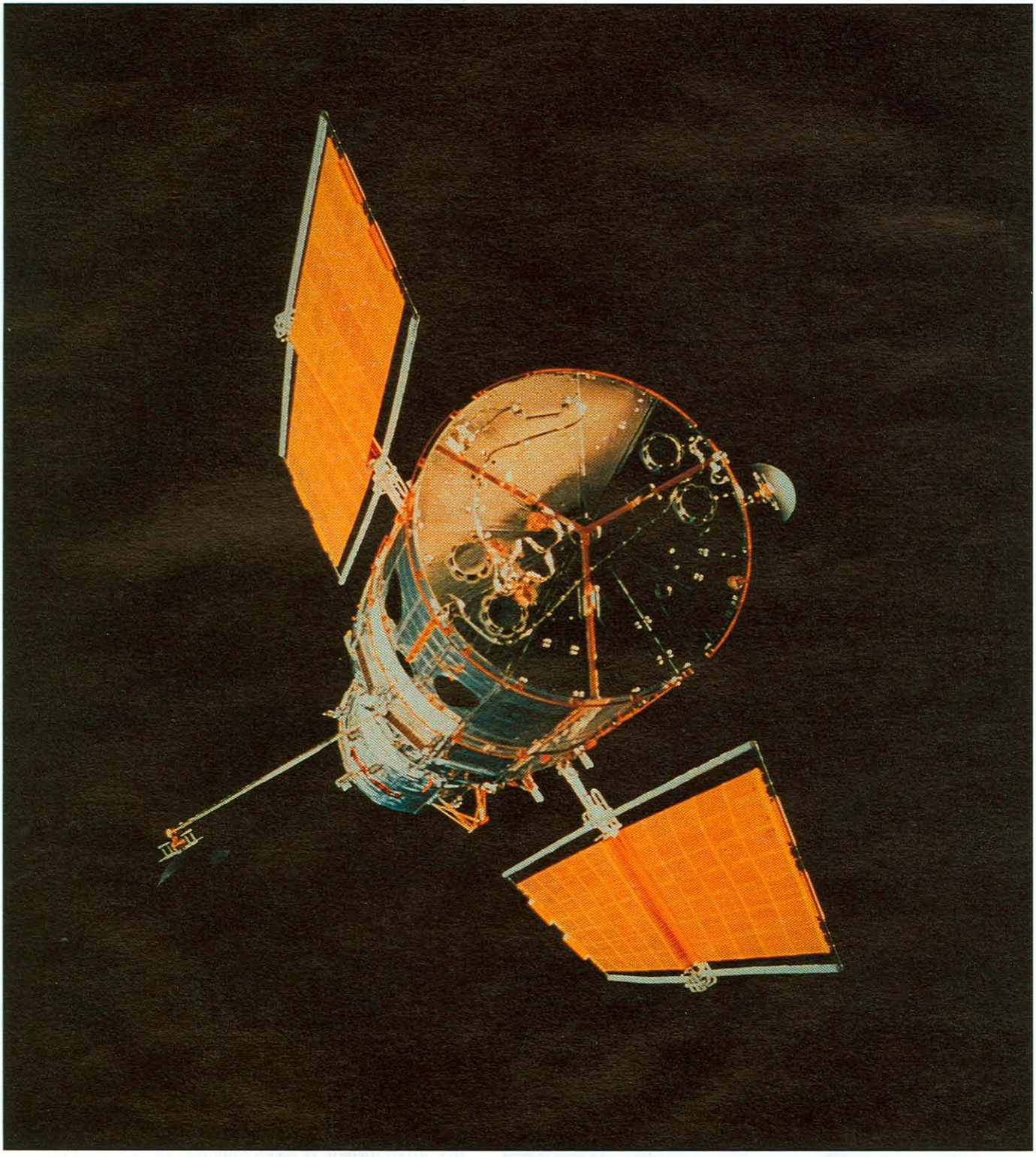
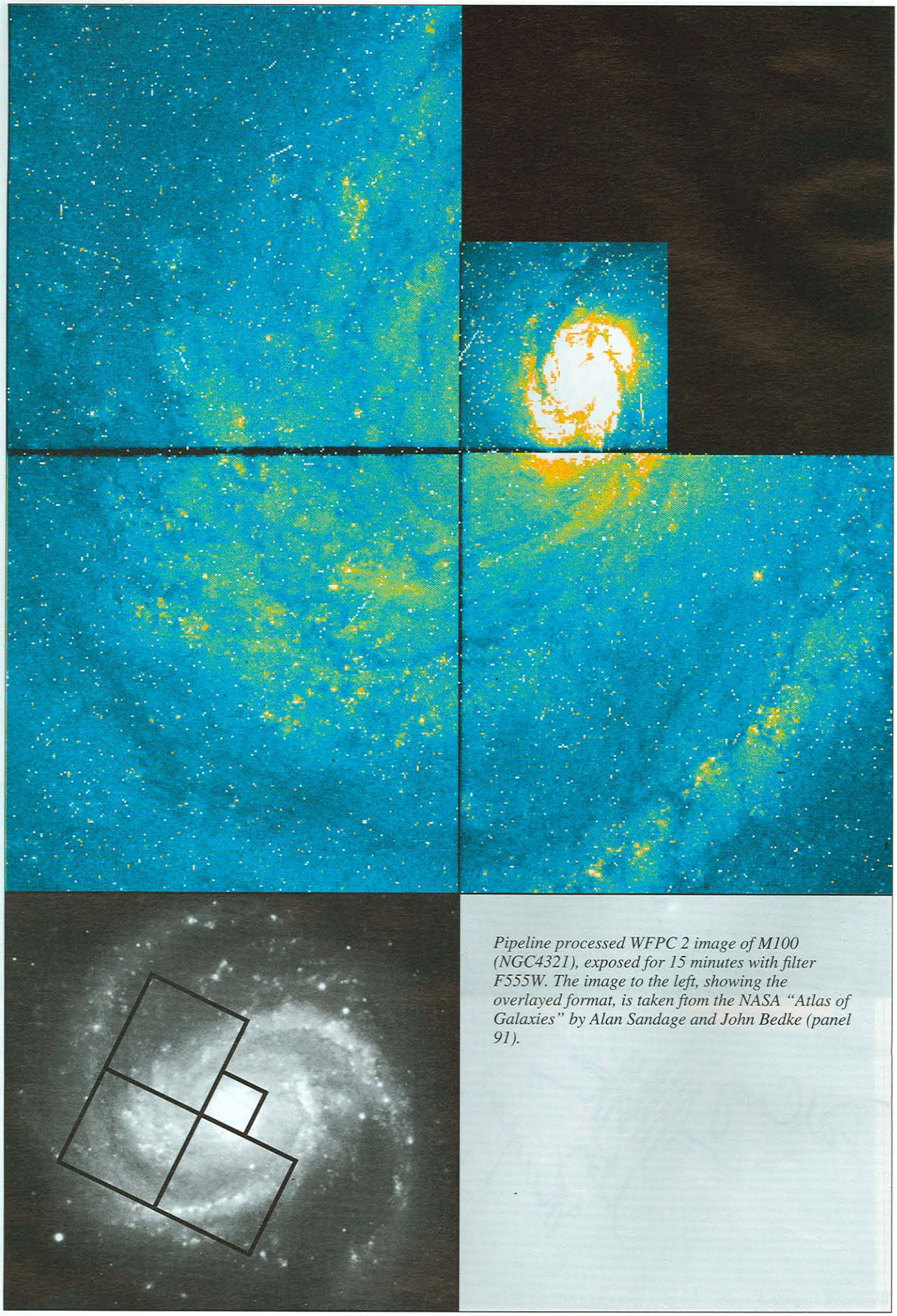


We thank Claude Nicollier for providing us with these splendid pictures of the refurbished HST.



Pipeline processed WFPC 2 image of M100 (NGC4321), exposed for 15 minutes with filter F555W. The image to the left, showing the overlayed format, is taken ftom the NASA "Atlas of Galaxies" by Alan Sandage and John Bedke (panel 91).

European collaboration in an Advanced Camera for the HST

This is the text of a letter to ESA, composed by George Miley & Flavio Fusi Pecci (ESA members of the Space Telescope Users Committee—STScI), signed by 59 European HST Principal Investigators. It argues the scientific benefit of a European collaboration in the construction of a new camera to be installed into the spacecraft at the end of the decade.

Following the complete success of the refurbishment and repair mission, we are just now beginning to appreciate in the most direct fashion the superb quality of the Hubble Space Telescope and its pointing control system. This telescope now provides a wonderful platform for imaging and spectroscopy from the ultraviolet to the infrared. It is clear that the HST is destined to have a profound influence on the development of astronomy.

As European astronomers who—along with many colleagues—enjoy competitive access to the observatory, we are concerned that appropriate steps should be taken now to ensure that the telescope is maintained in its currently fine state. We also argue that there is an unassailable scientific case that it should be supplied, in a timely fashion, with state-of-the-art instrumentation which is capable of fully exploiting its qualities.

The corrected telescope has been shown to be essentially diffraction limited down to near ultraviolet wavelengths and—with the new solar arrays in place—has a pointing and tracking performance to match. The current imaging instruments: WFPC 2 and FOC/COSTAR, while poised to reap a rich harvest of scientific discoveries, are not fully able to exploit the images presented to them by the telescope.

The wide field channels of WFPC 2 seriously undersample the PSF—even at the longest wavelengths—and this has a serious impact on both its photometric and astrometric performance. Although capable of detecting stars some 3 magnitudes fainter than WFPC 1, accurate photometry at this new fainter limit will be significantly affected by variations in the pixel response function. This deficiency will manifest itself, for example, in extragalactic Cepheid monitoring programmes—one of HST's key projects. Also, the WFPC 2 CCDs have a low DQE when compared to modern, back-illuminated devices. At the time of the 1999 orbit re-boost mission, WFPC 2 will be seven years old (five in orbit) and will have exceeded its expected lifetime.

The FOC with $f/150$ and, possibly, $f/75$ COSTAR-corrected channels can critically sample the PSF at all but the shortest wavelengths. It has, however, an extremely narrow field of view ($14'' \times 14''$ max at $f/150$) and a small effective dynamic range due to counting rate limitations.

For these reasons, initial steps have been taken to provide a new, Advanced Camera (HST–AC) to be ready for the scheduled Shuttle mission to reboost the HST orbit for the solar maximum around the end of the century. The scientific case for the camera and the technical feasibility are described in the report ("Frontiers Of Space Imaging", Ed. R. A. Brown, STScI, 1993) of a community-wide study panel which met three times late in 1992. There has also been a proposal made to ESA for half of the funding for a camera as part of the Horizon 2000, M3 call for proposals in 1993 (see *ST-ECF Newsletter* No. 20, August 1993, p3).

The camera would offer wide field (between 3 and 4 arcminutes) optical and near-ultraviolet imaging with a spatial sampling a factor of two finer than WFPC 2 and a DQE a factor some 2-3 times higher with a considerably lower CCD readout noise. The far-UV channel would critically sample the PSF and would be solar-blind for 1000–2000Å. These capabilities are a substantial improvement over current HST imaging and are very well matched to the excellence of the telescope. Exploitation of these unique capabilities on the HST is likely to have a fundamental impact throughout astronomy ranging from planetary studies—storms on Jupiter—to the most distant objects in the universe—the host galaxies of quasars.

ESA understandably postponed a decision on participating in the development of this camera until after the Repair Mission had taken place. In view of the total success of the mission and the remarkable quality of the first data from "new" HST, we believe that the case for pursuing the Advanced Camera is compelling.

The provision of such a camera is vital to ensure that maximum scientific benefit is obtained from the HST investment. The participation of the European Space Agency in the planning, design and construction of the instrument would place European astronomers in the most favourable position to continue their successful exploitation of the observatory into the next century. Should there be no European participation, it is likely that the HST would be equipped with imaging instruments of considerably lower scientific capability and there is a serious risk that European astronomers would have reduced access to the observatory after the expiration of the ESA/NASA Memorandum of Understanding in 2001. This would be less than seven years after the availability of the properly functioning telescope in contrast to the projected fifteen year lifetime.

A participation on an equal footing with NASA would cost less than 20% of an M3 mission. In our opinion, this would represent one of the most scientifically profitable investments for European astronomy. We therefore urge ESA to do everything possible to participate in the Advanced Camera at a substantial level.

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Bergeron, J.
Bertaux, J.-L.
Bertola, F.
Bignami, G.F.
Boksenberg, A.
Caraveo, P.A.
Clegg, R.E.S.
Couch, W.J.
Crane, Jr., Ph.
Deharveng, J.-M.
Demoulin-Ulrich, M.-H.
di Serego Alighieri, S.
Ferguson, H.C.
Ferlet, R.
Franx, M.
Fusi Pecci, F.
Gérard, J.C.M.C.
Graham-Smith, F.
Heber, U.
Hoare, M.G.
Howarth, I.D.
Jackson, N.
Jaffe, W.
Johnstone, R.
Kudritzki, R.-P.
Kunth, D.
Lagrange-Henri, A.-M.
Lallement, R.
Lamy, Ph.
Lennon, D.
Lequeux, J.
Longair, M.
Mendez, R.
Miley, G.
Nussbaumer, H.
Ortolani, S.
Perinotto, M.
Ray, T.
Reimers, D.
Reipurth, B.
Renzini, A.
Rosen, S.R.
Somerville, W.B.
Tanvir, N.
van der Kruit, P.C.
van Dishoeck, E.F.
Vidal-Madjar, A.
Vilhu, O.
Vogel, M.
von Hippel, T.
Walsh, J.
Walter, R.
Ward, M.J.
Webb, J.
Weigelt, G.
Werner, K.
Willis, A.J.
Wood, J.

The Archive column

STARCAT boasts transparent connectivity to other data centres and a number of new features. Within the limitations of the European networks, there is now the possibility to receive some archive data using ftp. As usual, some new astronomical catalogues have been added to the range.

Benoît Pirenne & Miguel Albrecht

STARCAT

By the time this issue goes to press, a new version of STARCAT (5.1) will be available. It features many of the facilities which have been promised over the past few months.

A SIMBAD access has been added to the 'Center' command. Instead of simply typing coordinates and a radius to specify a search cone, one can now look for catalogue entries around a known object by simply specifying its name. Once the name is entered, STARCAT opens a network connection to the CDS in Strasbourg and retrieves the coordinates of the object specified. There are two big advantages to this new facility: any synonym of an object name can be entered. The proper coordinates will be retrieved, regardless of the name used: eg, M 31 and NGC 224 would yield the same output.

The tool is extremely valuable for searching for observations of a given object in an observation log like the IUE catalogue, the HST or the ESO archives. For example, specifying NGC 224 and a 10 arcmin radius in the HST 'post-obs' screen would yield target names such as: G141, S-AND-OFFSET-STAR, PARALLEL-FIELD, NGC 224-10, S-AND-FIELD, NGC 224-NW2, NGC 224-NUC, etc. Such a facility guarantees that no records of potential interest will be skipped.

Figure 1 shows the new facility as it appears in the new 'Center' command. This facility is, of course, also available for our batch program and StarMail users. Because SIMBAD access is not free, STARCAT client sites will have to have a valid account with the CDS and introduce the proper username and password at the time of the STARCAT installation.

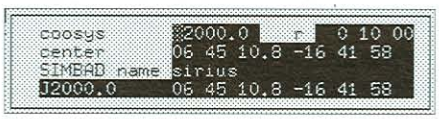

Figure 1: An example application of the 'Center' command in STARCAT

Multi-Server access was promised a long time ago. It is now a reality. It allows use of the services provided by either the ESO/ECF or the CADC archives.

By default, STARCAT will utilise the services available at the site from which STARCAT was received, ie, a French user running STARCAT at his/her institute will connect to the astronomical catalogues, the HST archive and the ESO archive at ESO/ECF. The CFHT archive screens will be transparently accessed through an 'invisible' connection to the Canadian Astronomy Data Centre (CADC) database server (in Victoria, British Columbia). However, if for some reason the connection to us is not available, it is possible to re-specify a connection to the CADC which therefore acts as a backup server.

For example, typing "starcat cat ngc" will get the 'ngc' catalog screen and data from the ESO/ECF. Typing "starcat cat ngc@astrocat!CADC" will attempt a connection to the CADC server instead.

The table illustrates the services available at both sites at the time of writing.

Service	ESOECF	CADC
astrocat	✓	✓
hst	✓	✓
eso	✓	✘
cfht	✘	✓
preview_hst	✓	✓
preview_eso	✘	✘
preview_cfht	✘	✓
preview_esolv	✓	✘
other previews	✓	✓

Services now available at ESO/ECF and the CADC.

New inter-screen navigation. In order to facilitate the navigation across the various screens available (now about 170) and in particular to remove the cumbersome HST part, a new navigation mechanism has been implemented. We think it is much simpler and more flexible than in the past. The only command syntax to remember for accessing any particular screen is the following:

cat <*screen-name*>
[@<*type-of-service*>[!<*server*>]]

where

<*screen-name*> is usually the catalogue name (eg, ngc, post-obs, pipeline, pytheas),

<*type-of-service*> is the category or database (eg, astrocat, hst, eso or cfht) and

<*server*> can be omitted most of the time, since it is defaulted to a reasonable value in the configuration file.

To facilitate navigation and short-hand access, any unique abbreviation can be used. For example: "cat post" is uniquely mapped to "post-obs@hst!ESOECF". Similarly, "cat pipe" refers to "cat pipeline@eso!ESOECF". However, "cat hr" is not sufficient to address the Bright Star Catalogue, because it conflicts with "hrcam@cfht!CADC". In this case it will be necessary to type a few more letters ("cat hr@astro" will do).

The above has described the tricks for the user already familiar with STARCAT. What about the new user? The problem with the old STARCAT was knowing the name of the available screens. This is now done in a very simple manner.

Let's take an example. I should like to know which galaxy catalogues are available in STARCAT. I need radial velocities. I know this must be in the astronomical catalogues, so I can now type: "starcat cat astro". A screen appears with a list of topics: 'galaxies', 'stellar', 'radio', 'mission_log', 'other'. I can now type 'cat galaxies' to see more. A large screen appears with plenty of options. Among them 'zcat CFA Redshift Catalogue'. I can now type "cat zcat" and start qualifying and retrieving records using the usual commands.

This pseudo-hierarchy is therefore extremely useful to find interactively what is available in STARCAT and at the same time allow for expert short-hand access to known screens.

Another set of very useful features includes the 'stacking' of screens. From within the Query menu, another screen can be called up and queries run against it. Upon exit, the previous screen will return. The 'Back' and 'Forward' commands are then used to return to previously visited screens.

New Data Request Submission tools. In order to generalise the submission of requests for off-line data products across the several archives now supported by our system, it has been necessary to develop a new tool. It is called 'ReqTool' and is started by STARCAT when the first record of interest is 'Mark'ed for retrieval. The tool runs in an independent window and provides all kinds of buttons and tools to easily prepare, edit and submit a request. It also offers the possibility of following the status of a previously submitted request. It presently supports the submission of requests for HST, ESOLV, ESO and CFHT archival data. Figure 2 shows a typical example.

Ports. STARCAT is now available for both Solaris 1.x (SunOs 4.1.x) and Solaris 2.x platforms. An HP/UX version should be ready soon. Please specify the version you prefer when registering: see the Remote STARCAT registration form in this issue.

Archive data requests

FTP data retrieval. One of the new features we have introduced in the new version of STARCAT is the possibility to retrieve archival data through wide-area network (Internet) using ftp. Certain conditions apply however. In fact, due to bandwidth limitations, the network situation in Europe at the moment precludes the retrieval of large amounts of data from our site. Therefore we have set up a mechanism whereby each archive user is allotted a quota, representing the maximum number of megabytes which can be retrieved in this way during one month. The quota is personal and calculated on the basis of the efficiency of the connection between ESO/ECF computers and the user's computer. The efficiency is estimated using daily 'pings' between ESO/ECF and external sites which provide timing information from which a data transfer rate is estimated. This data transfer rate is averaged over the previous 2 months and a number of MB is derived based on a maximum line usage of 4 hours per month per user. The current situation yields an average of about 30MB/month/user. The value is re-calculated every month.

If a request is larger than the remaining quota, ftp transfer will be refused and the request will be automatically put on the tape type chosen to be the user's preferred default at the time of registration. Alternatively, the user will have the possibility to modify the request by either selecting a different output medium or reducing the size of the request.

Data

New catalogues. The following catalogues have been added or updated.

- PPM: The Positions and Proper Motions Catalogue (Bastian & Röser, 1991, 1992) has been updated to include the final South and Bright-Stars complements.
- PMN: The Parkes-MIT-NRAO survey (Southern and Tropical) has been included. The survey covers from –87°.5 to +10° declination made using the Parkes 64m radio telescope with the NRAO multibeam receiver at a frequency of 4850 MHz during 1990. It contains 36640 sources to a flux limit that is, typically, about 35 mJy but varies as a function of declination.
- IRAS/SSC: The IRAS Serendipitous Survey Catalogue has been included. The IRAS Serendipitous Survey Catalogue (IRAS/SSC) has been constructed using the fortuitous observations at 12, 25, 60 and 100 μm of 43886 point-like sources that happened to lie in 1813 of the individual fields included in the Pointed Observation program.
- IUE92: The log of observations of the International Ultraviolet Explorer (IUE) satellite has been updated to include all observations until December 31st, 1992.
- EUVE: The EUVE Survey Bright Source List has been included. It contains 205 sources. Based on the possible optical counterpart information, the breakdown of the 205 total EUV sources by class for the all-sky survey is as follows: 49 unidentified ROSAT Wide field Camera (WFC) sources, 97 Late-type stars (F,G,K,M), 39 White Dwarfs, 7 Cataclysmic Variables, 5 A stars (four of which are WFC sources), 3 BL Lac objects, 1 Active Galactic Nucleus, 1 B star, 1 Low-Mass X-ray Binary, 1 Planetary Nebula and 1 Pulsar.
- VERON 93: The Véron & Véron catalogue (Dec. 1993 version) of quasars and active galactic nuclei. The structure is the same as for the previous versions. Simply more objects are available in each class: 7383 quasars, 171 BL Lac objects and 1855 active galaxies. The formula to compute an approximation of the absolute magnitude from within STARCAT was modified and now brings most values to within ±0.2 mag. of the printed document. In some cases, excursion up to ±0.5 magnitudes are possible. We remind you

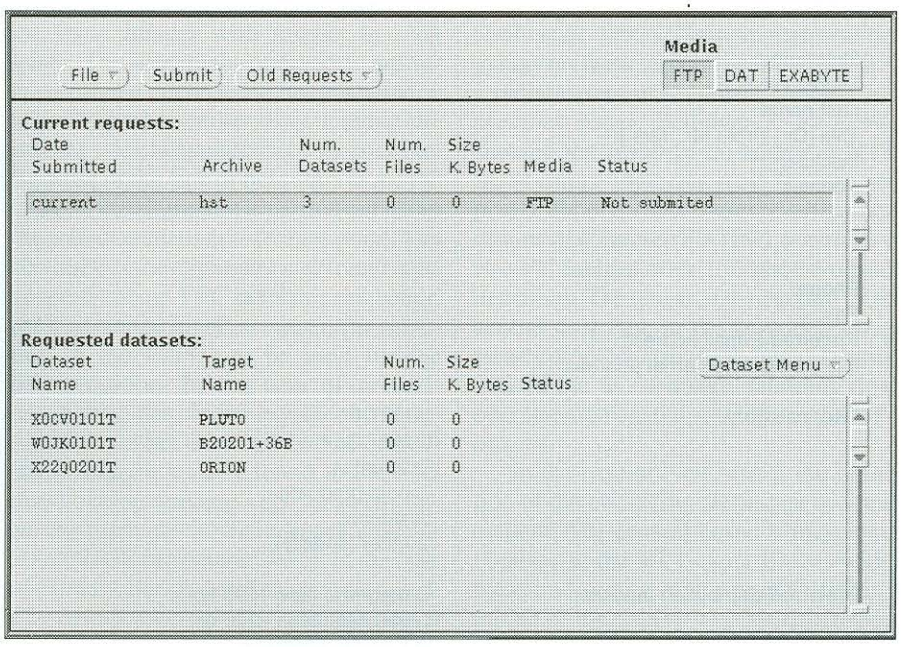

Figure 2: The new STARCAT 'ReqTool' interface which facilitates the preparation, editing and submission of an archive request.

Remote STARCAT registration form

STARCAT is now being made available to Astronomical Institutes. However, a number of technical conditions have to be met. See the 'STARCAT News' article in *ST–ECF Newsletter* No. 19, p16 for a description. Please return this form to Susan Hill at the ST–ECF or email the content to shill@eso.org

Yes, we are interested in running STARCAT at our institute. We are planning to install STARCAT on a SPARC compatible computer having access to the Internet network.

(If you would like to run STARCAT on other platforms, please indicate your interest as well. Ports to HP and DEC/OFS might be available in the near future.)

Site: _____

Address: _____

City: _____

Country: _____

Contact Person in charge of STARCAT at the site: _____

Email address of the contact person: _____

Have you ever used STARCAT before? : _____

Computer type: _____

Operating System version: _____

TCP/IP number of the computer: _____

Internet address of the computer: _____

Applicants will receive installation instructions shortly.

Archive user registration

Obtaining authorisation to dearchive HST data

If you wish to have an account set up to dearchive HST data, please complete the form below and return it to us, on paper or via electronic mail. You will be assigned a unique username and password, which will be sent to you at the e-mail address specified on the form. You will be registered for one year. One month before expiration, you will be warned, so that you can renew the registration if you wish to do so. Any changes to the information given in the form should be communicated promptly so that we can take appropriate actions.

ST–ECF Archive Registration Form

❑ new registration ❑ renewal

First name: _
Middle initial(s): _
Last name: _
Title [Dr., Prof., Mr., Mrs.]: _
Institute: _
Address: _

Phone: _
Fax: _
Preferred E-mail address: _
FTP computer internet address: _

User category:
❑ HST PI
❑ HST Co-I
❑ scientist
❑ post-graduate
❑ student
❑ other (specify): _

Preferred distribution medium:
❑ magnetic tape 1600 bpi
❑ magnetic tape 6250 bpi
❑ Exabyte cartridge
❑ DAT cartridge (not supported yet)
❑ Local Area Network (ESO users only)

FITS blocking factor (1–10): _

that the original computer-readable copy of the Véron catalogue does not contain the absolute magnitude.

Preview. The ESOLV catalogue (the Lauberts-Valentijn Surface Photometry Catalogue of the ESO-Uppsala Galaxies) now has associated preview images: 84% of the entries of this catalogue can be browsed. These are the blue images. In the future, we will probably be producing a new version, simultaneously displaying both blue and red images. The missing images are currently being processed. We are sure that this tool will be invaluable to a number of projects.

HST. In order to support the post-COSTAR HST, a new screen, 'wfpc2', has been created. It contains all the information available on exposures taken with the new camera. It is complete with instrument configuration parameters. The other instrument-related screens also contain a new field called 'k?deploy' where ? stands for the instrument abbreviation (i.e., 'x' for the FOC, 'y' for the FOS and 'z' for GHRS).

Cycle 5 schedule

The Servicing Mission Observatory Verification (SMOV) went very smoothly and allowed us to recommence science observations in February. This being the case we anticipate completing Cycle 4 high- and medium-priority proposals by the early summer of 1995. (We anticipate activating Cycle 4 supplemental proposals only if we suffer a major instrument problem or a comparable event that prejudices the existing science program.) Hence, we are already planning for Cycle 5!

We anticipate the Call for Proposals will be made in June with a deadline of mid- August for Phase I proposals. The HST TAC will meet in early November and the Phase II programs will be required by January – February 1995. We are planning new submission forms as well as new procedures for this round, as described in the April 1994 STScI Newsletter.

Scientific exploitation of the Archive — large core properties of elliptical galaxies

Combination of high signal-to-noise ground-based images with data from the HST archive gives new insights into the large-scale core properties of elliptical galaxies.

Werner Zeilinger

After the successful refurbishment mission, the WFPC 1 data archive is complete and provides a database of homogeneously calibrated images for further astronomical analysis. There are many applications pertinent to the study of properties of nearby galaxies where high spatial resolution images complement existing ground-based data. An example is the study of the core properties of elliptical galaxies. One of the main results of recent studies in this area is that a fair fraction of the objects are characterised by core features which are not resolved with typical ground-based data. The existence of such subcomponents and their properties are of particular interest since they may reveal clues about the galaxy formation process and the evolution of the parent galaxy. High-resolution images also provide important input for the modelling of galaxies.

The sample used for this study consists of all elliptical galaxies within a redshift of 3000 km/s selected on the basis of the morphological classifications in the *"Catalogue of Principal Galaxies"* (Paturel *et al.* 1989) and the *"Third Reference Catalogue of Bright Galaxies"* (de Vaucouleurs *et al.* 1991): a total of about 230 galaxies. The PC data archive contains images of 43 galaxies obtained with the F555W filter which are now in the public domain. There are normally at least two images for each object, taken in succession. The distribution of the total exposure time is shown in Figure 1. The pipeline-calibrated science data were extracted from the archive.

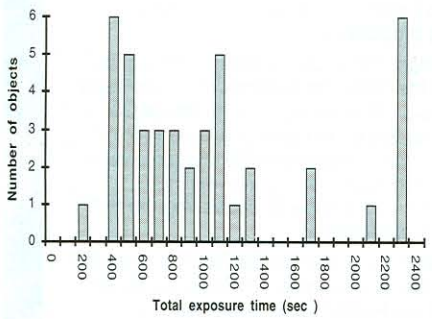

Figure 1: Distribution of the accumulated exposure time for the galaxy sample. The PC images were all obtained with the F555W filter.

For the majority of the images the galaxy is centred on the detector PC6, leaving the edges of the other 3 CCDs for the background determination. A first analysis showed that the original image pairs are already well aligned. The typical offsets between the galaxy centres are less than two (PC) pixels. Cosmic ray hits and hot spots were removed through a procedure similar to the one described by Labhardt *et al.* (1993). Additional checks of the affected pixels were performed visually in order to verify that no signal was lost.

The WFPC 1 archive images are affected by the aberrated PSF and so have a rather low effective signal-to-noise ratio. In a previous article (Zeilinger *et al.* 1993), the application of the Richardson-Lucy image restoration technique has been described using a method of co-adding ground-based and HST images. This approach conserves the spatial resolution of the PC image and consolidates the signal from the high signal-to-noise ground-based image. A detailed description of the basic method is given by Lucy (1991) and Hook & Lucy (1992). There are two key input elements for the image restoration procedure: (a) The proper alignment of the input images with respect to each other. The alignment operations are always carried out on those images with the higher signal-to-noise ratios leaving the weaker ones as unprocessed as possible. Because of the lack of field stars in the PC images, the alignment is carried out using the galaxy nucleus as reference point. The accuracy of the alignment was found to be generally about 1 PC pixel or even better. (b) The second input element is the selection of the PSF(s) to be used for the deconvolution. In the case of ground-based data, the choice is rather straightforward—either one of the (well exposed) stellar images usually found in the field may be converted into a PSF or an empirical one can be derived using packages like DAOPHOT II (Stetson 1991). In the case of PC data, the situation is more complex. The field is much smaller which makes it less likely to find a suitable stellar image. Also, the WFPC 1 PSF varies with location on the detector and changes as a function of time. Appropriate stellar images, repeating the exact instrument configuration, are therefore almost never available. One solution to this problem is the software tool TinyTim (Kirst 1992) which calculates an 'artificial' PSF for a given observation date and instrument configuration. However, one has to be aware that TinyTim is based on current best fits of aberration values for the various mirror positions and current best estimates of the obscuration positions and sizes and so may still not describe the PSF exactly.

In order to illustrate the method, one aspect of the research project on core properties of ellipticals is presented here, namely the search for dust lanes in the central regions of the galaxies. Such dust lanes indicate the presence of a gaseous disc which may be used as a probe of the galaxy potential. With ground-based data alone, these discs are very difficult to discover since their angular extension is at most a few arcsec and therefore easily smeared out by effects of seeing. Three examples were selected from the PC data archive in order to illustrate the variety of properties exhibited by this phenomenon: The E2 galaxy NGC 4261, the E6 NGC 4697 and the E4 galaxy NGC 5845. The best known of this sample is NGC4621 (Jaffe *et al.* 1993). The core region of this galaxy is characterised by a dust lane with a radial extent of less than 2 arcsec. In a previous paper, Zeilinger *et al.* (1993) showed the result of co-adding a NTT-SUSI image (detector scale 0.13 arcsec/pixel), obtained in sub-arcsec seeing conditions (0.63 arcsec FWHM), with a set of two PC images after 150 deconvolution iterations. The shape and structure of the central dust lane in the co-added image clearly profit from the high signal-to-noise data of the SUSI image, retaining however the high spatial resolution of the PC images.

In the case of NGC 4697, the limitation of the co-adding technique becomes evident. The ground-based *V* image was obtained at the NTT using EMMI with a measured seeing of 1 arcsec FWHM. A model of the galaxy was constructed using best-fitting ellipses. The residual image (Figure 2) shows clearly the presence of a stellar disc (predominantly positive residuals along the major axis of the gal-

axy) and, in the very center, a dust lane associated with the disc which is just barely visible in the original image. However, due to the limited spatial resolution of the image (0.347 arcsec/pixel), almost no information can be derived about its shape and inclination. Although noisier, the original PC images of NGC 4697 resolves its central region in much more detail. Co-adding the two data sets however did not result in an improvement as significant as in the case of NGC 4621. This is primarily because the large (× 8) difference in resolution. The best results (Figure 3) were obtained by deconvolving only the PC images—applying 10 iterations of the Richardson-Lucy algorithm—and co-adding them by convolution with a 'core' PSF of 0.05 arcsec FWHM in order to eliminate the broad wings characteristic of the HST.

As noted by Lauer (1985), NGC 5845 is another candidate for a central disc like NGC 4621. A similar technique to that used for NGC 4697 was applied to the two PC images of NGC 5845. The higher signal-to-noise ratio of the data allowed the use of 30 iterations. The resulting co-added image is shown in Figure 4 and reveals clearly the central stellar disc with the dust lane seen almost edge-on. The residual image (Figure 5) derived from the best isophote ellipse fit reveals even more clearly the stellar disc which shows also a hint of warping. In contrast to the stellar disc of NGC 4697, which extends all over the galaxy, the stellar disc of NGC 5845 is restricted to the very central regions. In order to compare the observed features more quantitatively, additional high-resolution kinematic data are needed, in particular to derive the central mass distribution.

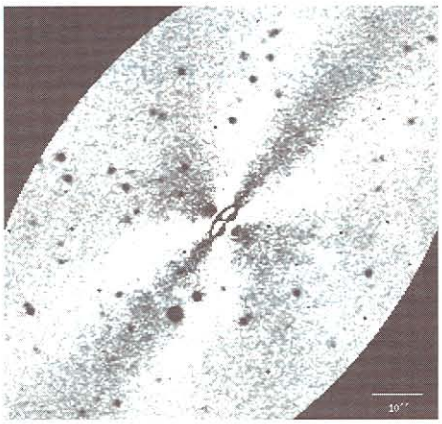

Figure 2: NGC 4697. Residual V band image obtained with EMMI after subtracting a best isophote ellipse fitting model.

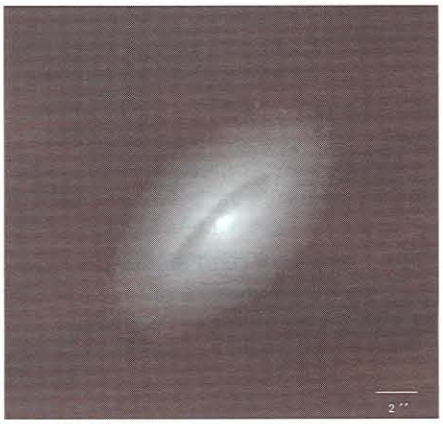

Figure 3: NGC 4697. A co-addition of 2 F555W PC images after applying 10 iterations of the Richardson-Lucy algorithm.

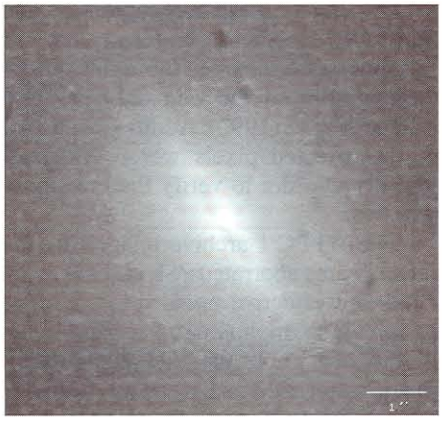

Figure 4: NGC 5845. A co-addition of 2 F555W PC images after applying 30 iterations of the Richardson-Lucy algorithm.

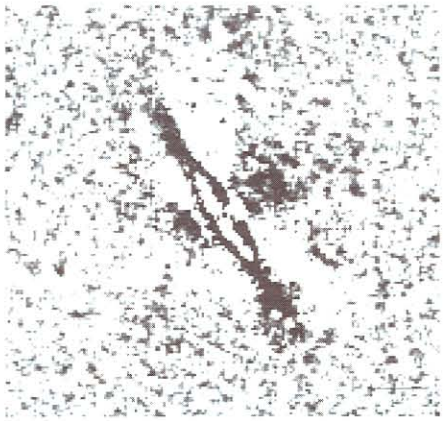

Figure 5: NGC 5845. Residual images of the co-added F555W frame after subtracting a best isophote ellipse fitting model.

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The HST Data Handbook

SPACE TELESCOPE SCIENCE INSTITUTE
Operated for NASA by AURA

The HST Data Handbook, a comprehensive guide to all major aspects of HST data reduction and analysis, is now available. This Handbook collects all of the information you need to work with HST data in one place. It describes how to understand the contents of each dataset, how to read, understand, and display HST images and spectra, how to identify and correct problems in your HST data, and how to perform common analysis and image reconstruction tasks. The Handbook assumes no prior knowledge of HST data, the IRAF or STSDAS systems, or any specific knowledge of HST instruments, other than that required to have prepared your observing proposal.

The Handbook is divided into two principal parts, plus a series of appendices. Book I, the HST Cookbook, includes the following sections (1) From Tape to Display, (2) Calibration and Recalibration, (3) Analysis, and (4) Image Deconvolution. Book II, the Instrument Data Book, contains one section for each HST Instrument. The Instrument sections are designed to prepare you to work with and understand the limitations of the data for a particular HST instrument. Basic tutorials about using IRAF and STSDAS, accessing the HST Archives, and using STEIS are provided as appendices.

The HST Data Handbook is currently being shipped to observers along with their data tapes. It has also been sent to Guest Observers whose observations occurred during the past year. The HST Data Handbook is available upon request from the User Support Branch (usb@stsci.edu) and is available electronically on STEIS.

Electronic access to HST information II — the World Wide Web

Hans-Martin Adorf

After several months of experimentation the ST-ECF announces a new service for the dissemination of HST information. Information offered in the World Wide Web can be retrieved using Mosaic, a powerful and user-friendly hypertext/hypermedia client developed at the National Center for Supercomputing Applications, Illinois.

The World Wide Web (WWW or W³ for short) is one of today's answers to the request for convenient information dissemination via the Internet. Originally conceived in 1989 at CERN, the European high-energy particle physics laboratory at Geneva, Switzerland (Berners-Lee 1992; White 1993), the idea of a wide-area information network is conquering the world. We are witnessing an exponential growth of information transfer, covering traditional text files, sound, images and even short 'animated' video clips.

Quite early experiments at the ST–ECF were carried out to explore the prospects of hypertext/hypermedia tools for HST information dissemination and retrieval (Adorf 1989). However, it required the widespread availability of graphic screens with pointing devices, the connectivity and bandwidth of today's computer networks, standard protocols such as TCP/IP and HTTP, together with a growing quantity of on-line accessible information to make the hypertext/hypermedia paradigm a real success.

In the spring of 1993, triggered by the appearance of the NCSA Mosaic client software, the ST–ECF revived its hypertext/hypermedia experiments by constructing an experimental web (Fig. 1) of HST-related information. The concept proved useful and we are now offering WISE, the World Wide Web based information service at the ECF, to the HST-community. A 'homepage' provides outside users with a convenient portal to the ST–ECF web (Fig. 2) and also offers a good starting point for ESO astronomers wishing to explore astronomical information resources on the Internet (see eg, Murtagh & Adorf 1993).

The ST–ECF effort ties in with a similar effort at the STScI, where STEIS has recently been made accessible via WWW (Jackson & O'Dea 1994).

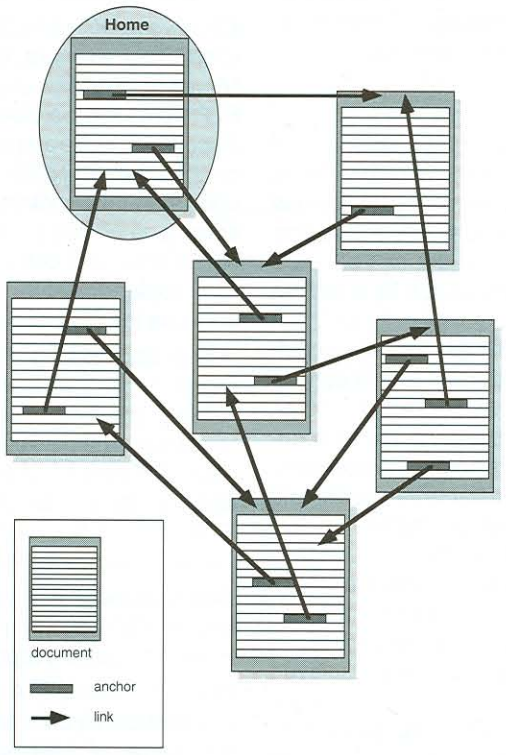

Figure 1: The WWW hypertext system. Structurally the WWW is a 'directed graph' where the documents are the nodes, and the links are the arcs to other local or remote documents. Links can be of different types: simple links to other WWW documents, or 'pseudolinks' to virtual documents generated on the fly by invoking Internet services such as FTP, Gopher, WAIS, News etc. Each WWW server hosts a network ('web') of densely linked hypertext/hypermedia documents coded in the HTML language.

Information items in WISE

The ST–ECF homepage with 'uniform resource locator'[1] (URL) *http://ecf.hq.eso.org/ST-ECF-homepage.html* (see Box 1) currently has a few sections summarising the information in WISE and how to locate it.

Priority information

Under this heading the user finds information on urgent or important matters. Currently it provides information on the first HST servicing mission and the comet Shoemaker-Levy observation campaign.

HST and science instrument information

Apart from an overview of HST, this part of the web provides information (or pointers to information) about the HST science instruments, about HST observing proposal preparation, about approved proposals, and about paper and on-line documentation at the ST–ECF or at the STScI.

Data management

This part of the web provides information on the data analysis environment at the ST–ECF including the data analysis cookbook. It offers convenient access to the HST Science Data Archive and the ST–ECF software library.

Project information

Under this heading basic information is offered covering the organizations supporting HST, ie, NASA and ESA, and also ESO, the host of the ST–ECF.

Other HST centres

From WISE links point to the other major HST centres, i.e. the Canadian Astronomy Data Center, to the UK Support Facility for HST at the Institute of Astronomy, Cambridge, and, of course, to the STScI.

Misc. HST-related services

This section collects several pointers that do not fit into the above categories, such as HST-related meetings and workshops and the two HST-related Usenet News bulletin boards, ie, sci.astro.hubble and ecf.stinfo.

Seeking information in WISE

The greater the information that is stored on-line, the more difficult it becomes to locate exactly a desired piece of information. Several mechanisms have therefore been put in place in order to facilitate the information retrieval task in WISE, the ST–ECF information web.

Wandering

This method of information gathering consists of exploring WISE by manually traversing hypertext links through clicking

[1] Although several explicit Internet addresses are given within this text, it is a major advantage of the WWW concept that it provides a convenient repository for such addresses freeing the individual user from having to keep records of these themselves.

What is the World Wide Web?

The WWW project merges the techniques of networked information and hypertext to make an easy, yet powerful global information system (see *http://info.cern.ch/hypertext/WWW/Summary.html*). It represents any information accessible over the network as part of a seamless hypertext information space.

Originally conceived for information sharing and dissemination amongst internationally dispersed teams within the high energy physics community, the WWW has spread to other areas and attracted much interest in user support, resource discovery and collaborative work areas. It is currently the most advanced information system deployed on the Internet and embraces within its data model most information in previous networked information systems.

Capabilities

Consumer's view: The WWW consists of documents and links. There are also special indices which, rather than being read, may be searched. The result of such a search becomes a 'virtual' document containing links to the WWW documents found. A simple communication protocol ('HTTP') allows a browser program to request a keyword search by a remote information server.

The WWW contains documents in many formats including plain ASCII files. Documents in hypertext format contain links to other documents (Bogaschewsky & Hoppe 1993; White 1993), or even places within documents. These documents may reside on a local or a remote host. All documents, whether real, virtual or indexes, look similar to the reader and are contained within the same addressing scheme.

To follow a link, a reader clicks with a mouse (or types in a number if there is no mouse). To search and index, a reader gives keywords (or other search criteria). These are the only operations necessary to access the entire world of data.

Embedded graphics and images are typically displayed as stamp size pictures and full-sized versions can be downloaded upon request. A history mechanism keeps track of links traversed so far and allows quick backtracking in order to take another route. Thus, with a few mouse-clicks, the user navigates to a desired piece of information which can be simply viewed, or downloaded to a local disk, or printed.

In addition to viewing hypertext/hypermedia documents, NCSA Mosaic permits the access of major Internet services such as telnet, FTP, Usenet News, Gopher (Adorf, Jackson & Murtagh 1993; Anklesaria & McCahill 1993), WAIS (Fullton 1993). Missing thus far are electronic mail (though available via the Emacs W3 client) and Archie (Emtage 1993).

Provider's view: A native hypertext document is coded in HTML (HyperText Markup Language), a subset of the SGML (Standard Generalized Markup Language), an upcoming coding standard for formatted text. Text in HTML format is conveniently edited in HTML aware text editors such as Emacs or BBEdit (on the Mac) with suitable HTML extensions.

Text can be converted to and from HTML format for a variety of standard formats including LaTeX, MS Word's RTF document interchange format, and FrameMaker.

Links are coded in the form of universal resource locators (URLs) which are typically composed of the Internet service/protocol, the server host name, the file path and the target file name. An example of such an URL is *http://ecf.hq.eso.org/ST-ECF-homepage.html* which points to the file *ST-ECF-homepage.html* in the WWW top-level directory (empty path) on host ecf.hq.eso.org using the http protocol.

WWW software

The WWW software employs the well-known client-server paradigm. Clients and servers for all major hardware platforms exist and are being further developed. Information about all aspects of the WWW is available online.

Client applications: NCSA Mosaic, presumably the most widely used client software, is available for the X-window system, Microsoft Windows and the Apple Macintosh via anonymous FTP from ftp.ncsa.uiuc.edu. Mosaic allows Internet users to discover, retrieve and display documents and data distributed on the Internet. NCSA's homepage—it is loaded by default upon start-up—contains information on which 'helper applications' (see below) are required and where to get them from. NCSA Mosaic is completely mouse-and-menu driven.

People with ASCII terminals only or Emacs enthusiasts may use the Emacs-based W3 browser instead.

Helper applications: WWW clients require a number of so-called 'helper' applications, mainly for decompressing and viewing graphics files. On the Macintosh, for instance, a typical set of helpers comprises StuffitExpander, UnZip, JPEG View, GIFViewer, UlawLongPlayer, Sparkle, GIFconverter, GhostScript and Simple Player, obtainable via anonymous FTP from sites such as sumex-aim.stanford.edu or mac.archive.umich.edu.

Server application: Fortunately, any FTP server can act as a simple WWW server. However, the server load is decreased when the special purpose HTTP server software is installed.

Filters & converters: A number of converters facilitate the task of automatically converting existing formatted documents into html format. Presently the toolset comprises software converting from MS Word/RTF, Word Perfect, FrameMaker/MIF, troff, LaTeX and BibTeX and TeXinfo formats. Also Unix man pages can be converted. There are tools for the reverse purpose, taking html formatted files into FrameMaker, LaTeX and RTF formats.

Maintenance tools: There are a few (actually too few) maintenance tools available which help to maintain a WWW information archive.

Further information

With an Internet connection one can telnet to info.cern.ch (no user name or password). This very simple interface gives access to (almost) anything on the WWW. It may be used to find up-to-date information on the WWW client program for your computer, with details of how to obtain it. This is the crudest interface to the WWW available without prior software installation.

One can also find pointers to all documentation, including manuals, tutorials and papers starting from the URL *http://info.cern.ch/hypertext/WWW/TheProject.html.*

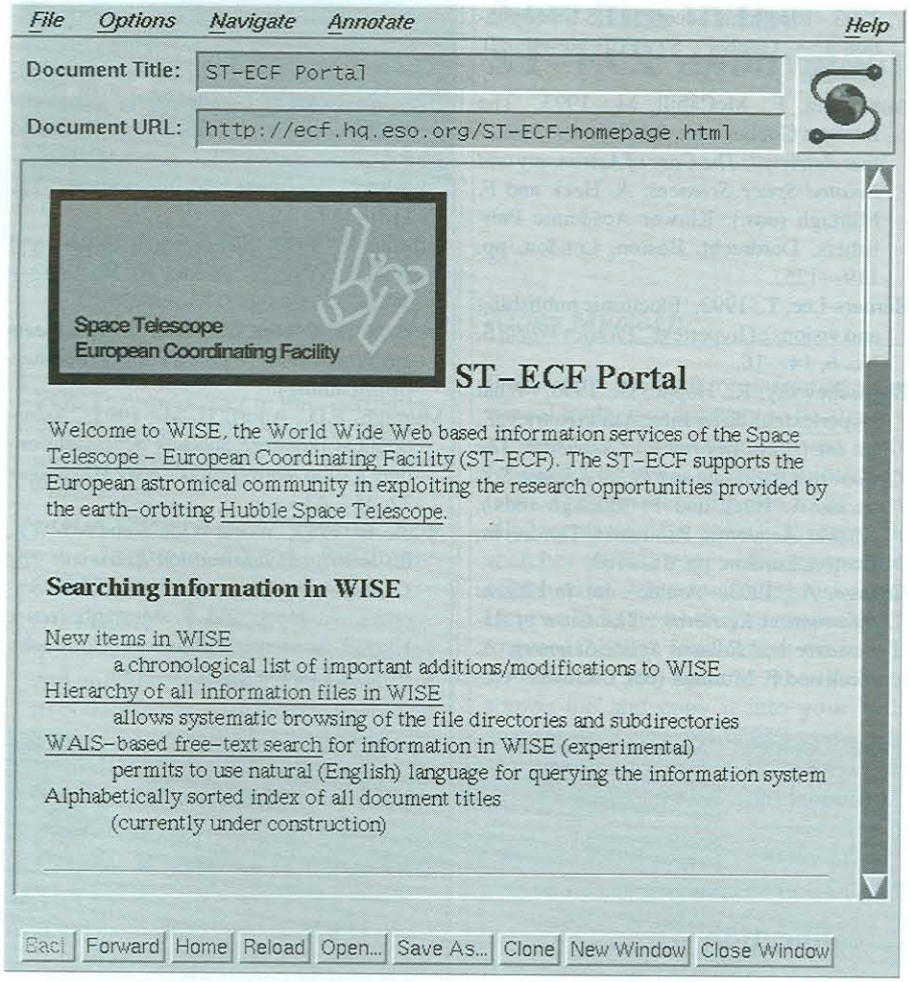

Figure 2: The ST–ECF portal. The ST–ECF homepage acts as a portal into WISE, the ST–ECF web. It offers convenient access to HST-related information and also points to other astronomical information sources available locally and on the Internet.

on highlighted, mouse-sensitive text items. NCSA Mosaic allows the user to backtrack one or more links in order to take a different route.

New items

An attempt is made to maintain a chronological list of important additions or modifications to WISE in a 'new items' file. It allows someone who is in principle familiar with the information web to quickly get an update of recently added information.

Document hierarchy

Sometimes a user may wish to systematically access all information files. To this end the hierarchy access mode puts the user at the top of the file directory tree, which he/she may subsequently visit in a systematic fashion. The drawback is that only file names are provided (rather than titles, headings or subheadings) as indicators of the documents' information content.

WAIS-based full-text retrieval

Advanced users will want to search for information using an information retrieval engine. To this end all documents in WISE are regularly indexed using WAIS. Via the WWW-to-WAIS interface this index can be easily queried using natural (English) language (Fig. 3).

Searching within documents

On Unix machines the Emacs-like command sequence <Ctrl>-X <Ctrl>-S can be used within Mosaic to locate a word or a phrase within longish document. On the Mac the usual <Cmd>-F multi-key stroke is used instead.

Information in STEIS

On-line information about HST has been accessible for a long time on STEIS via FTP, and more recently via Gopher and WAIS (Jackson 1993). Recently a convenient WWW interface was added (Jackson & O'Dea 1994). The STScI can be accessed via the URL *http://stsci.edu/top.html*, and STEIS itself via *http://stsci.edu/steis.html*.

The USB home page: The User Support Branch which acts as the primary interface between the astronomical community and the Space Telescope Science Institute (STScI) has set up its own top-level WWW document (*http://stsci.edu/usb.html*). It provides links to on-line documents which are needed by HST proposers and observers.

Documents for proposers

A potential proposer to HST can access on-line versions of the *Call for Proposals*, the *Phase I Proposal Instructions*, and the *Instrument Handbooks* (except WFPC 2). In order to avoid duplication with existing or proposed observations a proposer may use the *Archived Exposures Catalog* and the *Exposures Catalog*. In case of questions there is the *STScI contacts list* and the *STScI phone book*. Potential archival researchers may access a special *HST Archive home page*.

Documents for observers

To create an HST phase II submission one may download the *RPSS software* and access the *Phase II Proposal Instructions* as well as the *TeX templates for the budget forms* (US PIs only). The *weekly timeline* informs about upcoming observations, whereas the *HST status reports* provide information about the status of the telescope. There is also information on the current status of the *scientific instruments*. The *STSDAS data reduction software* permits (re-)calibration and data reduction. There is even a *frequently asked questions* file. Finally, the *data product guides* provide useful information about HST data and how to reduce them.

Links to the outside world

A special effort has been made to collect within WISE resources to other information servers on the Internet.

HST-related information sources

STARCAT: The HST archive at the ST–ECF can be transparently accessed from the ST–ECF web through a STARCAT telnet session. Help information for the available databases has been provided within WWW since mid-1993.

CADC: The Canadian Astronomy Data Centre maintains a WWW server accessible via the URL *http://cadc.dao.nrc.ca/CADC-homepage.html*. To the HST community the CADC provides the welcome service of maintaining an up-to-date list of HST observations that have recently (within the past 15 days) become public. The CADC web also offers access to the CADC software tools which include XHOT, an X-window tool for displaying the planned HST activities. Another handy service is the on-line access to the CADC's astronomical CD-ROMs, including the Guide Star Catalog.

UK HST Centre: The Institute of Astronomy, Cambridge, also maintains a WWW server (*http://cast0.ast.cam.ac.uk/HST/home.htmland*) which allows convenient access to its anonymous FTP archive.

Other information sources

ESO on-line information system: ESO is

currently undertaking the construction of an ESO-wide information web (accessible via the URL *http://www.hq.eso.org/eso-homepage.html*) collecting on-line information about networks & computer services, problem reports, ESO instruments (EMMI & SUSI initially), logistics, observing proposal handling, the science archive, MIDAS, ESO conferences, ESO preprints, the VLT project, etc.

Astronomical Internet resources: Astronomical information sources available on the Internet have been collected in a list (with URL http://ecf.hq.eso.org/astro-resources.html) which is structured according to the service provided (ie, bibliographic, database access, observatory information, etc.). Similar lists, ordered differently though, are maintained by Bob Jackson, STScI, Don Wells, NRAO, and by several other people around the world. An astroweb consortium has recently formed which attempts to coordinate these astronomical resource collection activities.

Future developments

While the World-Wide Web is already a powerful system through which a lot of useful information can be conveniently accessed, there are still a few shortcomings restricting the usability of the web.

Firstly, the file sizes in WISE vary substantially. This restricts the ability of a full-text search to retrieve only relevant text portions.

Secondly, a highly desirable 'thumb index' is lacking which would facilitate an organized, direct access to particular documents. Since thus far there are no generally available indexing tools for the WWW, we are offering the mentioned manual browsing of the WWW directory-tree. We will investigate the possibility of an automated construction of an alphabetically sorted index.

Thirdly, the hypertext links in the information web are not as dense and complete as we would like them to be. We intend to investigate the option of an automated crossreferencer which, given a list of titles of hypertext documents, automatically inserts the appropriate links.

Conclusion

Actually exploiting the WWW, particularly when using NCSA Mosaic, is much easier than understanding a description like this of how it all works. Therefore we recommend that you try it out and kindly let us have your comments for improvements.

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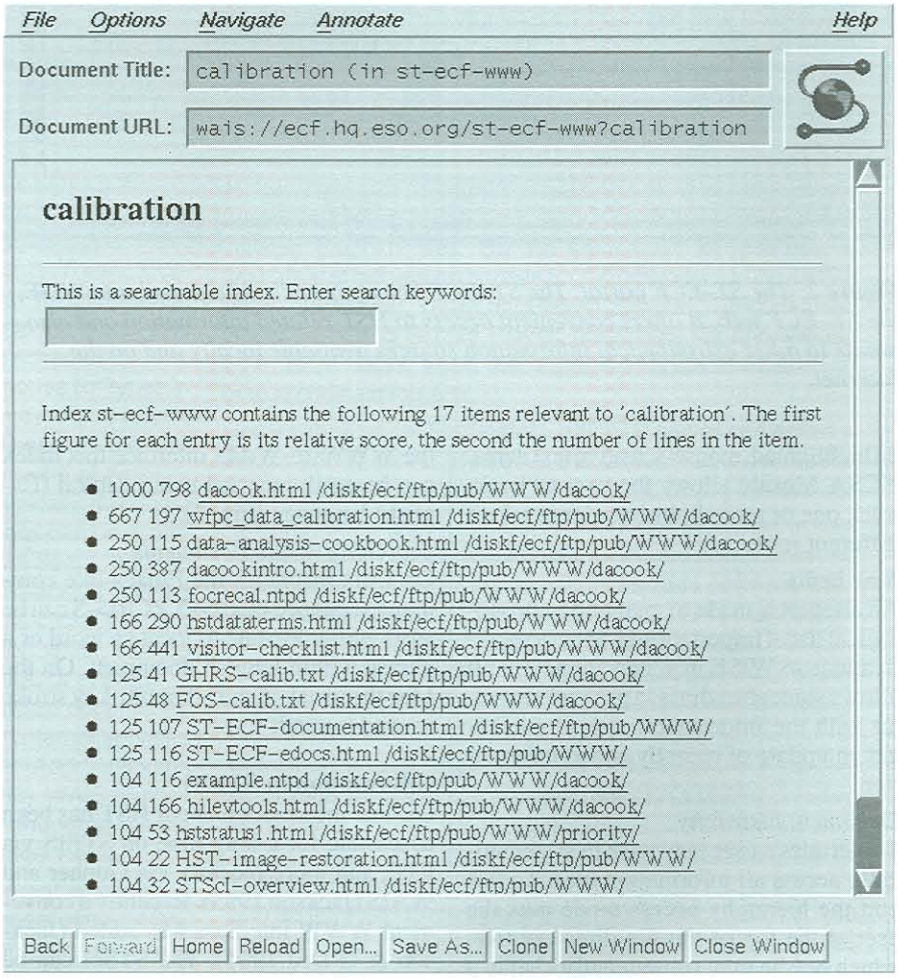

Figure 3: Free-text search in WISE. Documents in WISE can be searched using natural (English) language queries. A virtual document with pointers to relevant files is returned by the WAIS search engine acting behind the scenes.

esa
european space agency
agence spatiale européenne

Vacancy in the Directorate of Scientific Programmes

This post is open to suitably qualified men and women

POST: Astronomer in the Astrophysics Division, Space Science Department, Directorate of Scientific Programmes.

LOCATION: Space Telescope Science Institute, STScI, Baltimore (USA).

DUTIES: ESA provides personnel (astronomers, scientific systems analysts and engineers) to the STScI as part of its collaboration with NASA on Hubble Space Telescope. ESA personnel are on assignment from the Astrophysics Division of the Directorate of Scientific Programmes of ESA, to the STScI.

The functional duties of the post encompass activities associated with:

- ❑ the instruments on board HST, their characterisation, testing and calibration;
- ❑ the planning and scheduling of HST observations;
- ❑ the support of users of HST during proposal preparation and observation planning;
- ❑ the maintenance and development of the HST archive for scientific research.

The post holder is also expected to undertake an active research programme.

QUALIFICATIONS: Applicants should have a Ph.D. degree in physics or astronomy. A strong background in required in the use of modern astronomical instrumentation and of data analysis methods. Applicants are expected to have a good research publication record.

A good knowledge of English or French is required; some knowledge of the other language is desirable.

CLOSING DATE: Applications for this post should reach the Head of Personnel and Site Services Department, ESA, 8–10 rue Mario Nikis, 75738 Paris Cedex 15 (France), not later than 15 May 1994.

ESA Regulations exclude the recruitment of personnel aged over 55.

New files in the ST–ECF *anonymous* ftp account

Fionn Murtagh

Even with the best of information retrieval tools, it is not easy to be aware of the latest files which might be very useful for particular tasks. In fact, the investigation of information retrieval tools—usually involving the ability to carry out searches on full text, with user specified search terms—is a continuing task for us. Here we indicate where you can use WAIS to query the files which are discussed. To do this, you will have to take the small source file and copy it into your *wais-sources* directory. All WAIS source files have been collected in directory *wais*, from where they can easily be ftp'd.

All of the files described in the box are available in our *anonymous* ftp area (ftp to *ecf.hq.eso.org*, 134.171.1.11). In the case of large files, compressed versions are available.

Finally, we remark that much more is available in our *anonymous* ftp area. This includes GIF images of the HST refurbishment mission in December, and of the first FOC/COSTAR and WFPC 2 pictures in January. It also includes a software library, with thousands of programs.

- ❑ All proposal abstracts, Observing Cycles 1 to 4, are available. There are about 1,500 of these. These text files are available in directory: *pub/obs-proposals*. Since these files are rather large, they are also available in compressed form.

  The WAIS source file for carrying out searches is: **hst-observing--proposals.src**. The indexing takes account of dash separators between abstracts, so you can use each hit to view one abstract at a time.

- ❑ WAIS does not realize that the query 'ray' should find 'x ray' but often not the family name 'Ray'. To counteract this, we have put another version of the HST proposal abstracts in the above directory. This file has all PI and CoI names removed. We have found this more useful to use when carrying out WAIS searches.

  The WAIS source file to use in this instance is: **hst-observing-proposals-noPI.src**. As before, each abstract is indexed separately using dash separators.

  The text version of the proposal abstracts is also available in compressed form to facilitate external copying.

- ❑ A file containing publications in the literature which make use of HST data (courtesy of STScI Library) is available in *pub/doc/HST-pubs*

  A WAIS index has been created for this file. Copy the source file: **hst-publications.src**. The file which was indexed was not large, so it was indexed as a unit. If you know of other publications, which use HST data and were published in the time-frame of this bibliography, please let us know.

- ❑ The ST–ECF Newsletter (so far, only Number 20) is available in directory */ pub/newsletter*. Each page is stored as a separate postscript file. Each page is also available as a compressed file, to aid external copying. Finally, all pages/files are WAIS indexed, the source file being **stecf-newsletter.src**.

- ❑ An index of article titles and authors in the ST–ECF Newsletter is available for vols. 11-20 (May 1989 to August 1993). This index is available in *pub/newsletter/index.txt*

  This file has also been WAIS-indexed. Use the source file **stecf-newsletter-index.src**. Here, the index entries corresponding to each ST-ECF Newsletter issue is treated as a unit, for WAIS retrieval and view purposes.

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We should like this Newsletter to reach as wide an audience of interested astronomers as possible. If you are not on the mailing list but would like to receive future issues, please write to the editor stating your affiliation.

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