Number 24 March 1997

ST–ECF Newsletter

Space Telescope — European Coordinating Facility

STS-82 before launch
with STIS and NICMOS
on 11th February 1997

STS-82 and beyond

Piero Benvenuti & Robert Fosbury

Early in the morning of Tuesday the 11th of February, the Space Shuttle 'Discovery' set off on the second Hubble Space Telescope servicing mission. Following the very careful preparation and extensive training of the STS-82 crew and an undelayed launch, the installation of the new instruments and other telescope components proceeded with a precision which we have come to expect but is nonetheless impressive. Four days of scheduled EVA saw the replacement of GHRS and FOS by STIS and NICMOS respectively; the exchange of an ailing FGS (Fine Guidance Sensor) with a new one; the installation of a new-technology solid-state 'tape' recorder of much higher capacity, the insertion of a number of other pieces of hardware and a modest orbit reboost. A fifth EVA day was scheduled to patch-up some areas of the telescope where the thermal insulation showed signs of age. As this is being written, the new instruments are in the first stages of their Science Mission Orbital Verification (SMOV).

While this was happening at an altitude of about 360 miles, successful Cycle 7 proposers were beginning the task of transforming their scientific programmes into completed phase II proposals. For STIS and NICMOS, this will necessarily be an iterative process as more is learned about the in-orbit performance of the instruments.

After nearly seven years of HST operations it is, perhaps, timely to sketch out what we know about the future of the observatory and what plans are being made for a successor. It is clear that HST is not only a primary source of astronomical data in its own right but that, in combination with new, large groundbased telescopes and other space missions, we have a complementary set of observational tools of formidable power.

Photo: Bob Fosbury

After the solid rocket boosters have separated, Discovery—on main engines alone—is seen as a trail projected behind the floodlights from the smoke-enshrouded launchpad.

Two more HST servicing missions are firmly scheduled by NASA. In 1999, the Advanced Camera for Surveys (ACS) will be installed in place of ESA's FOC, another FGS will be replaced and the telescope—with new solar arrays—will be reboosted to a higher orbit in order to withstand the next solar cycle maximum. For the mission in 2002, NASA issued an announcement of opportunity for a new instrument late in 1996 with a proposal deadline set for mid-April of this year. What will happen in 2005—the nominal end of the HST mission—is still very much under discussion and will depend on the progress of other plans. The recommendation of the 'HST and Beyond' committee (see Box) is to operate HST beyond 2005, perhaps in a reduced-cost mode, with emphasis on ultraviolet spectroscopy and imaging and on wide-field optical imaging. In 2001, the current Memorandum of Understanding (MoU) between ESA and NASA concerning HST expires. An interagency working group is currently exploring options for renewing this MoU. Unfortunately, because of budget restrictions in the Science Programme, ESA is not in a position to offer a new European instrument for the year 2002, an option which would have been more than acceptable as a contribution to the extension. However, if the STJ detector (see ST–ECF Newsletter No. 23, p6, 1995) is a component of a selected proposal for the NASA 2002 Instrument, ESTEC will support the developement of the STJ flight unit, including the cryogenic section.

Photo: Bob Fosbury

Discovery clearing the tower. The view from 3.5 miles before the sound arrives.

Photo: Bob Fosbury

Go Discovery! The afternoon before lift-off on pad 39A at the Kennedy Space Center in Florida.

It is important for us to appreciate how closely Europe is involved with the HST at the moment, what splendid value we are getting from the project and how crucial it is to ensure that the relationship continues beyond 2001. Indeed, Europe has always obtained more HST observing time than the formally agreed 15% lower limit: in Cycle 7 the fraction is 22% of the orbits (see article by Leon Lucy in this issue). The continued access to HST by European astronomers will become vital in the near future when the potential for joint programmes with the new groundbased facilities such as VLT and Gemini, is realised.

A major initiative is currently underway in the USA to develop the second of the 'HST and Beyond' recommendations, namely the planning of a space observatory, with an aperture of 4m or larger, optimised for imaging and spectroscopy in the 1–5μm wavelength range. This has become known as the Next Generation Space Telescope (NGST) and 1996 saw three major studies of a concept for a passively-cooled telescope, up to 8m in aperture, in an orbit much further from Earth than HST. There is a considerable quantity of information about the NGST on the Web (see Box) so we will not attempt a technical description here. The assessment of the scientific case used to derive a 'Design Reference Mission' is described in the article by Stiavelli et al. in this issue.

There is, as yet, no official European

involvement in NGST although quite a number of European astronomers have been and are involved in various aspects of the study. ESA has been formally invited by NASA to participate in the 'Origins' program, of which NGST is an integral part. ESA has responded positively with the proviso that the NGST collaboration should find its place within the ESA Science Programme, *Horizon 2000+*. This is not a particularly easy task at the moment since the entire programme in under revision following the loss of the *Cluster* experiment. Nonetheless, the Space Science Advisory Committee, considering the very high scientific return for European astronomers that an ESA participation in NGST would represent, recommended the appointment of an external NGST advisory team which will have the task of examining possible European contributions. In particular, the team will analyse the advantages and technological risk reductions which could be achieved by using *Ariane V* as a launcher. It is expected that the team will issue its recommendations to ESA in about a year from now when NASA's intentions and schedule on NGST become better defined. Meanwhile, the interest in NGST in Europe has been growing and we have been requested to illustrate its science goals and technical challenges with several seminars in different Institutes. A European Workshop on NGST for later this year is under consideration.

Information sources for HST and NGST

Information about STS-82, including lots of pictures and movies, is available from:
http://ecf.hq.eso.org/sts82/
this includes the report of the SM2 Independent Science Review team.

The new HST instruments STIS and NICMOS are described at:
http://www.stsci.edu/ftp/instrument_news/NICMOS/topnicmos.html
http://www.stsci.edu/ftp/instrument_news/STIS/topstis.html

The NASA AO for a 2002 instrument can be obtained from:
http://ecf.hq.eso.org/AO.html

The report of the 'HST and Beyond' committee, chaired by Alan Dressler, is available as a PDF file at:
http://ecf.hq.eso.org/priority/Dressler_report.html

The NGST story is told at:
http://saturn1.hst.nasa.gov/ngst/ and *http://ecf.hq.eso.org/ngst/ngst.html*

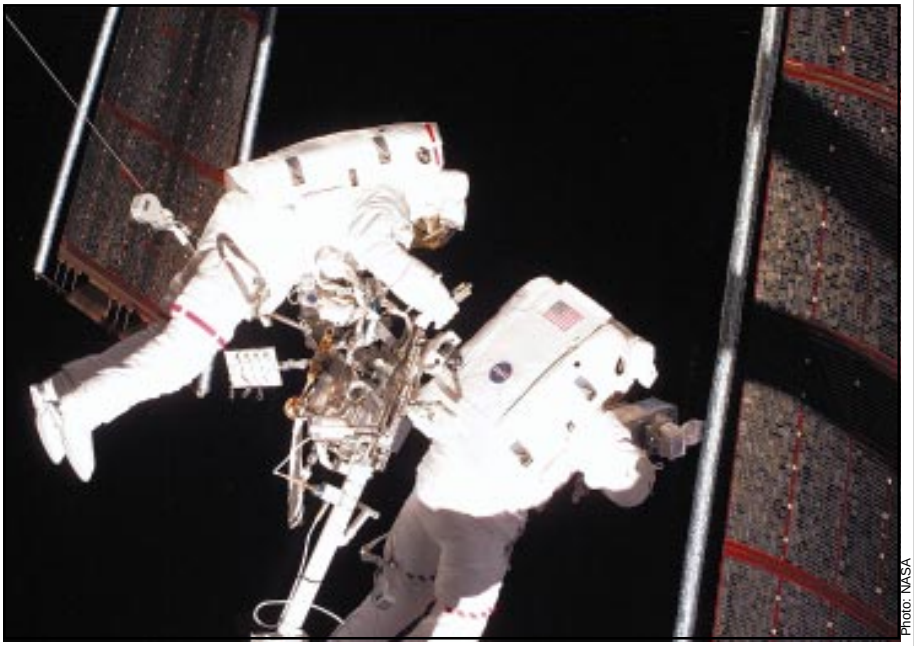

Photo: NASA

Gregory Harbaugh (left) and Joseph Tanner (right) exchanging places on the foot restraint during Day 5 of the servicing mission.

Photo: NASA

HST is released at the end of the second servicing mission.

SPACE TELESCOPE SCIENCE INSTITUTE
Operated for NASA by AURA

STScI NEWSLETTER

The Space Telescope Science Institute publishes a Newsletter 2–4 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:

Space Telescope Science Institute
3700 San Martin Drive
Baltimore, MD 21218
USA

E-mail: help@stsci.edu (Internet)

Requests should also specify whether the subscriber wishes to receive future Calls for Proposals.

Next Generation Space Telescope — design reference mission

In order to match the technical capabilities of the Next Generation Space Telescope (NGST) designs with the scientific drivers, a Design Reference Mission (DRM) has been developed and used to quantify the effects of optical, detector and operational parameters.

Massimo Stiavelli[1,2,3], Pete Stockman[1] & Richard Burg[1,4]

The 'HST and Beyond Committee' was formed to advise NASA on future missions for space astronomy after the nominal end of the HST mission in 2005. Chaired by Alan Dressler, the committee made three recommendations in their report 'Exploration and the Search for Origins: A Vision for Ultraviolet-Optical-Infrared Space Astronomy':

1. A low cost extension of the life of the Hubble Space Telescope beyond 2005.
2. The development of a near-IR optimised telescope of 4m diameter or larger.
3. The development of space interferometry capabilities with emphasis on high resolution imaging and the detection of Earth-like planets in neighbouring planetary systems.

Despite previous discussions—and even scientific workshops—on NGST, the release of the 'HST and Beyond' report represented the real beginning of a number of activities intended to show that NGST was not only desirable but also feasible. Three independent teams led, respectively, by Lockheed Martin Corp., by TRW, and by NASA's own Goddard Spaceflight Center, produced complete designs of the spacecraft with estimated development costs near the cost target of US$ 500M, excluding the launch and operations. Concurrent with these efforts, a volunteer Science Working Group (SWG, chaired by John Mather and Peter Stockman) was set up to further quantify and extend the scientific goals discussed in the 'HST and Beyond' report. A Science Advisory Committee (SAC, chaired by Robert Kennicutt), was also created to review the progress of both the SWG and the technical studies. The SAC, the SWG and the Goddard-led design team included European and ESA scientists. The group lead of the instrument module design team (known as the Instrument Integrated Product team or IPT) was an ESA engineer (Pierre Bely). An artist's view of the Goddard version of NGST is shown in Figure 1.

In the following, we will concentrate principally on one aspect of the activity of the Goddard team in order to illustrate the interplay between the science goals and the instrument design at these early stages of the project. Clearly, astronomers would always prefer a larger telescope to a smaller one. However, in order to build something that will fly and be cheap to operate, we must achieve a compromise between scientific capabilities and technical and financial feasibility. As an example, improvement in certain technical areas, eg, detector performance, might gain significant scientific return for a relatively modest cost. To obtain similar gains in other areas, eg, by increasing the primary mirror size, could be extremely expensive. On the other hand, increasing the main mirror size with all else kept constant would increase the performance for most of the science. Improvements in other areas may have a more limited impact. Since NGST must accomplish a broad range of scientific goals, striking the correct balance is not straightforward. As a tool to achieve this balance, the Instrument IPT and the SWG established a strawman observing program based on the key scientific questions identified in the 'HST and Beyond' report as well as a broad program of astronomical research that requires NGST capabilities.

Because of its importance in the actual design of the mission, the program is termed the Design Reference Mission (DRM). The DRM may be thought of as a *shopping list* of the highest priority observations and a *price list* which represents the time that each observation would require. This *price list* was produced by including all the major attributes of the observatory: primary mirror size, detector noise and quantum efficiency, pixel size, field of view, optics temperature, celestial background, setting time after a major slew, cosmic ray flux, etc. By comparing the time required for each observation with the total time required, we can see how each parameter affects the mission outcome and how various science aspects affect the overall mission.

Science goals

We will focus on one particular DRM as an illustration. About 72% of the time is dedicated to a 'Core program' directly linked to cosmological studies as outlined in the 'HST and Beyond' report. This Core program is the minimum that a mission of this type should achieve. The remainder is devoted to science projects not feasible with other kinds of facility but not included in 'HST and Beyond'. The

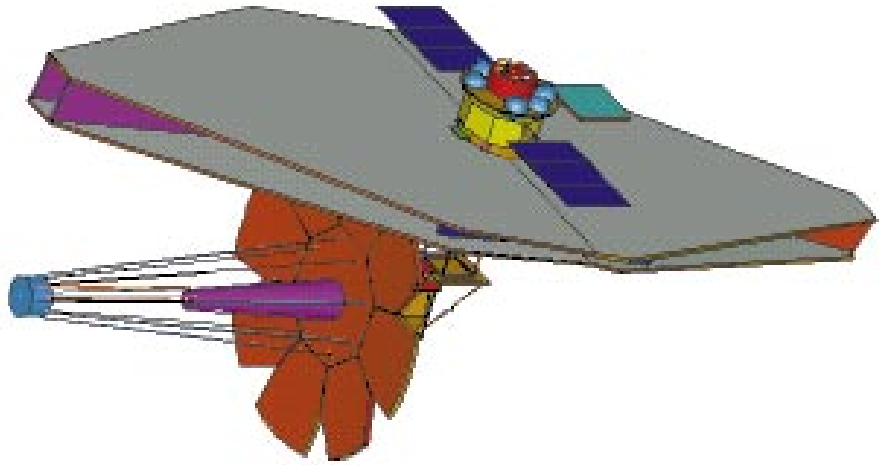

Figure 1: An artist's view of the Next Generation Space Telescope, as designed by the Goddard-led team. The principal elements are a deployable telescope, passively cooled and shaded from sunlight, and a warm service package on the opposite side of the large sunshield.

[1] Space Telescope Science Institute
[2] on assignment by the Space Science Dept. of ESA.
[3] on leave from the Scuola Normale Superiore, Pisa, Italy.
[4] Johns Hopkins University, Dept. of Physics and Astronomy.

selection of the scientific program elements is somewhat subjective and depends on current scientific interests. However, it is broad enough to be representative. A brief explanation of each of the research goals and of the corresponding observational parameters is given below.

Supernovæ (Core). The interest is twofold: one can use the SN as standard candles to improve our knowledge of the geometry of the Universe (q_0 and Λ), and also use them to study the material universe before the birth of galaxies. These goals are achieved by identifying about 100 SN at redshift greater than 2 (ie, down to $K_{AB} \sim 31$), and following them both before and after the maximum for two 'rest frame' weeks. Additional SN will be identified while monitoring the 100 main SN objects.

NGST Deep Fields (Core). One deep field (down to $K_{AB} \sim 32$) and 100 less deep ($K_{AB} \sim 30$) flanking fields will be observed in several broadband filters. Several classes of objects will be identified in these fields. The need for both a very deep survey and a shallower survey covering a very large area arises from our lack of knowledge of how exactly galaxies form: whether as many small subunits or rather as rarer, more luminous aggregations. The deep field will be optimised to investigate the small subunits scheme and will enable us to detect proto-globular clusters in formation up to a redshift of about 10. The large area shallower survey allows us to look for other rare, although important, objects: proto-quasars, primeaval spheroids, proto-disks and is sensitive to L_* objects up to a redshift of 10. At the limit of the flanking survey there are about 1000 galaxies per square arcmin. In order to have significant statistics as a function of redshift on objects such as AGNs and Quasars which appear only in a fraction 10^{-2}–10^{-3} of galaxies, one needs to observe about 10^7 galaxies. To study the early evolution of galaxies and their dark matter content, galaxies at redshift greater than 2 will be studied spectroscopically at low and high resolution to derive their redshift, their spectral energy distribution, and their internal kinematics. These spectroscopic observations are also split into single deep fields, required to obtain data as a function of redshift on the faint end of the galaxy luminosity function and shallower more extended surveys to obtain data on the rarer, brighter objects.

Universe at z > 2 (Core). This includes follow-up studies (pointed observations) of objects identified in the NGST Deep Fields Survey. In particular, primeval spheroids, birth and evolution of disks, origin of heavy elements, and birth and evolution of AGN are all included in this category. The observations include both NIR and T(hermal)IR spectroscopic and photometric studies. High redshift galaxies and star forming regions discovered in the HST HDF and the NGST shallow surveys will often display complex structures due to merging, galaxy-galaxy interactions, spiral-wave star formation, and chance superpositions. We will obtain moderate resolution, imaging spectroscopy of these structures and those of nearby galaxies to study the dynamics of these systems. We can confirm that different elements are bound by gravity if their velocities are identical. Moreover, we can study the mass within each galaxy (mass which may be dark) by measuring the temperature or the collective motions of the stars and gas clouds within the galaxy. Disk structures should show strong velocity shifts with distance from the centre. Imaging spectrometers in the NIR and MIR are required, with resolutions of $R = 1000$–3000.

Gravitational Astronomy. Deep HST images and the NGST SN fields and shallow surveys will discover good examples of gravitational lensing by clusters of galaxies. These chance alignments—approximately 0.1% of all sightlines—provide excellent opportunities to see distant galactic structures at high magnification as well as superb opportunities to study the total mass distribution within the cluster. NGST's NIR sensitivity, wide field imaging, and HST-like resolution can reveal hundreds of background galaxies at moderate redshift, $z = 1$–3, as well as the magnified images of star forming regions at $z = 10$–30. We will study the evolution of cluster potentials and the study of serendipitous ultra-distant galaxies using deep imaging and follow-up spectroscopy of approximately 20 gravitational lenses with the gravitational lens at redshifts between $z = 0.3$–2.0.

Stellar Populations in the Nearby Universe. Our understanding of the fossil stellar record is limited to our own galaxy and a half-dozen satellite galaxies. Using NGST's light gathering power and HST-like resolution, we will extend our understanding of the stellar populations within the local group of galaxies and the Virgo cluster galaxies. Accurate, wide-field imaging of single stars in 30 galaxies can provide the star-formation fossil record for the disks and outer portions of the inner bulge components (spheroids). The exposure times are selected so as to reach the horizontal branch luminosity in the Virgo cluster.

Kuiper Belt Objects. The outer portion of our solar system contains millions of asteroids, with the largest almost 1000km in diameter. Many lie outside the orbit of Neptune and are presumed to be remnants of the formation of our solar system. Before NGST is launched, astronomers will have discovered about ~100 of the brightest and nearest asteroids in the Kuiper Belt. These objects and their distribution are not likely to be pristine, since they lie within or near the orbit of Neptune. We will obtain optical and NIR images in a wide field Ecliptic Survey (about 800 square arcmin). Our goal is to discover an equivalent number of KP belt objects at greater radii from the sun (> 40 AU) and over a wide range in sizes. Mid-infrared signatures, such as silicate features, will be important in linking these objects, our closest *protoplanets*, to the great dust disks seen around young systems in Orion and β-Pictoris stars. Searches will be carried out down to magnitude $AB \sim 30$ in the optical and NIR and $AB \sim 25$ in the TIR. Any object discovered will be studied by followup NIR and TIR imaging and TIR spectroscopy.

Individual Object Classes. A variety of pointed studies in both imaging and spectroscopy that can take advantage of the NGST performance. Included are observations of normal and active galaxies, ISM in galaxies and its evolution, studies of brown dwarfs and stellar evolution. Collectively these projects make up 12% of the program.

Program optimisation

Having defined a strawman science program, the role of observatory parameters on the scientific capability of the mission can readily be studied. The figure of merit being optimised is the completion rate of the program over a given mission lifetime. The parameters to vary are telescope diameter, instrument field of view, optics temperature, optical throughput, parallel use of instruments (several instruments observing the same field either simultaneously or successively if they do not share the same field of view), detector readout noise, and dark current.

In the example discussed here, the time to execute the above program was calculated under the following assumptions:

- ❑ Observations made in a region where zodiacal light and Galactic emission are near the minimum
- ❑ Repointing overhead of 18 minutes following major slews
- ❑ Negligible single exposure overhead (36 seconds)
- ❑ 10% mission time allowance for engineering and calibration
- ❑ Cosmic ray rate of 1 proton cm^{-2} s^{-1}, (resulting in a maximum exposure time of 1000 seconds for 27μm pixels).

The main results of this parametric study are shown in Figure 2, where the fraction of the completed strawman program described previously is plotted as a function of the various parameters being

optimised. The conclusions which can be drawn from these trade-off studies can be summarised as follows:

- The constraint of having the same spatial resolution of HST in the NIR forces one to have a mirror close to 8m in diameter.
- A 6m effective aperture telescope with the proposed set of instruments is adequate to complete all core programs and most of the complementary program in a 5 year mission.
- Below about 5m of effective aperture, the core programs cannot be completed. An effective aperture larger than 5m appears necessary to fulfill the requirements set forth by the 'HST and Beyond' report.
- To some extent, telescope diameter and field of view can be traded against each other. A 6m telescope with a 4×4 arcmin instrument does as well as an 7.2m with a more modest field of view (2.8×2.8 arcmin). This is because the scientific program is dominated by surveys in background limited mode, not by individual targets or high spectral resolution programs. Since instruments are typically less expensive than telescopes, this indicates that instruments should be built with as large a field of view as possible, within the limit allowed by optical aberrations and packaging. That there are obvious limits in the overall size of the observatory also indicates that there is an optimum combination of instrument field of view and telescope size.

In conclusion, a New Generation Space Telescope with 5.5m effective aperture, with large field of view, optimised for NIR imaging and low-resolution spectroscopy, appears to be the minimum requirement for understanding the *Origin of Galaxies*. We should note that a telescope with this minimum size would not be able to carry out a significant, broad-based General Observer (GO) science mission until after the first 4–5 years of its mission. As experience with HST forewarns us, our knowledge of astronomy may have improved in unexpected ways by the time NGST is launched. Also, it is clear that a significant, if not the most important, fraction of the scientific results come from the GO science program. We feel, therefore, that the 8m diameter goal for the primary mirror is appropriate and better addresses the intent of the 'HST and Beyond' Committee recommendations.

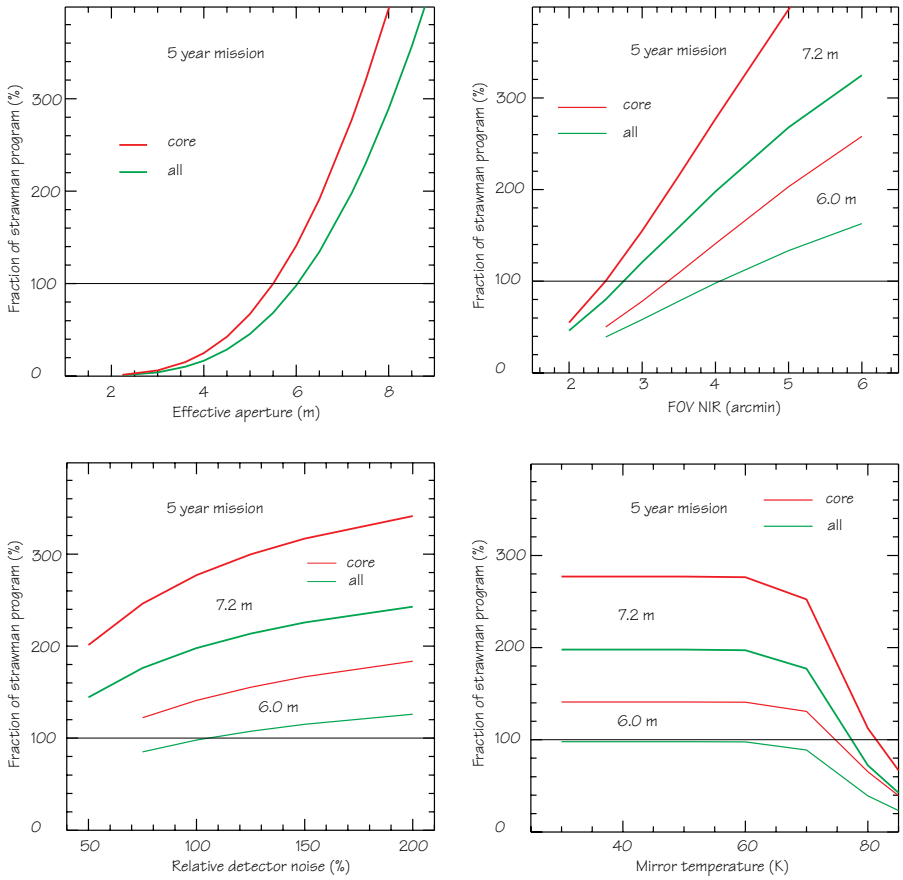

Figure 2: Completed fraction of the Strawman program as a function of the various parameters. Red curves represent the Core program, and green curves the complete program. In the upper left panel we show the dependence on the telescope effective aperture. The upper right shows the effect of field of view both on a 6m and a 7.2m telescope. In the lower panels we show, also for a 6m and a 7.2m telescope, the effect of detector noise and mirror temperature. The detector noise includes both dark current and read-out noise and is given relative to the one in the baseline design.

SCIENCE WITH THE NGST

Goddard Space Flight Center, Greenbelt, Maryland, USA

April 7–9, 1997

The Next Generation Space Telescope is a new facility for space astronomy being considered by NASA in collaboration with ESA and other Space Agencies and planned for launch in the first decade of next century. The telescope is optimised for Near-IR observations. The meeting will address the science feasible with such a facility.

Main Topics: Status of the NGST project, Precursors to Galaxy Formation, Galaxy Evolution and High Redshift objects, Observational cosmology, Nearby Galaxies and their Stellar Populations, Star and Planet Formation, Solar System Science

Scientific Organizing Committee: R. Kennicutt (U. Arizona, chair), J. Mather (GSFC, co-chair), J. Bahcall (IAS/Princeton), S. Beckwith (MPIA/Heidelberg), A. Cochran (U. Texas), A. Dressler (OCIW, Pasadena), R. Ellis (U. Cambridge), R. Giacconi (ESO), M. Hauser (STScI), G. Illingworth (Lick, Santa Cruz), J. Knapp (Princeton U.), J. Ostriker (Princeton U.), M. Rowan-Robinson (Imperial College), P. Stockman (STScI), H. Thronson (NASA, Washington DC), V. Trimble (U. Maryland), M. Werner (JPL, Pasadena), S. White (MPIA, Garching), R. Williams (STScI).

Local Organizing Committee: P. Bely (STScI), E. Dwek (GSFC), D. Fahey (GSFC), M. Hauser (STScI), M. Hurlbut (Jorge Sc.), A. Koratkar (STScI), S. Maran (GSFC), J. Mather (GSFC), A. Michalitsianos (GSFC, chair), E. Smith (GSFC), M. Stiavelli (ESA/STScI), P. Stockman (STScI).

Contributed papers are invited in the form of posters.

Contact Address: Mary Hurlbut mhurlbut@pop200.gsfc.nasa.gov (301) 220-1701

Registration Deadline: March 24, 1997: Registration Fee: sessions: $45, banquet: $25, proceedings: $40.

Detailed information on meeting logistics and registration can be obtained at WWW URL http://ngst.gsfc.nasa.gov/~ngst/science/meetings/NGSTmeeting1.html

NICMOS grism spectroscopy — software development at the ST–ECF

As part of a collaboration with the NICMOS IDT and with the STScI, software is being developed for handling data from the NICMOS grism spectroscopy modes.

Wolfram Freudling

A unique capability of NICMOS, the near-IR camera which was installed during the 2nd servicing mission in February, is the grism spectroscopy mode. Camera 3 (NIC3) is fitted with three grisms giving slitless spectroscopy in the 0.8 to 2.3 micron range at a spectral resolving power of 200. The image area is 51 × 51 arcsec with 0.2 arcsec pixels. The three grisms cover the wavelength ranges 0.8–1.2μm (grism A), 1.1–1.9μm (grism B) and 1.4–2.5μm (grism C). In the 1.0–1.8μm range, the NICMOS grism has unsurpassed sensitivity in comparison with much larger aperture groundbased facilities due, principally, to the very low background above the atmosphere. The sensitivity in the longest wavelength range will, however, be compromised by thermal emission from the warm HST optics. At 1.4μm for example, a signal-to-noise of 10 can be achieved in a 1000 second exposure on a source of 0.07 mJy (H = 18). See the NICMOS Instrument Handbook for details (also available at http://www.stsci.edu/instrument-news/handbooks/nicmos/NIH.html).

Typically, one or more direct images are taken in conjunction with the grism images for the wavelength calibration. Both direct and grism images are routinely calibrated by the standard STSDAS pipeline (*calnica* and *calnicb*). However, there is currently no NICMOS-specific software within STSDAS to extract 1-dimensional spectra from such image sets. Two IDL programs are being developed at the ST–ECF for that purpose. The first of these, called *NICMOSlook*, is an interactive program to extract spectra for individual sources imaged with one set of grism and direct images. The second one, called *calnicc*, is a non-interactive program which automatically detects and extracts spectra from a set of image pairs.

In addition, a program *GRISMdecon* is being developed to allow the deconvolution of NICMOS grism data taken at a number of distinct roll angles.

NICMOSlook

NICMOSlook is an interactive program using an IDL widget. It relies on the presence of the Xmanager and has been tested under Linux and Solaris versions of IDL. The program reads a pair of user-defined NICMOS images which are

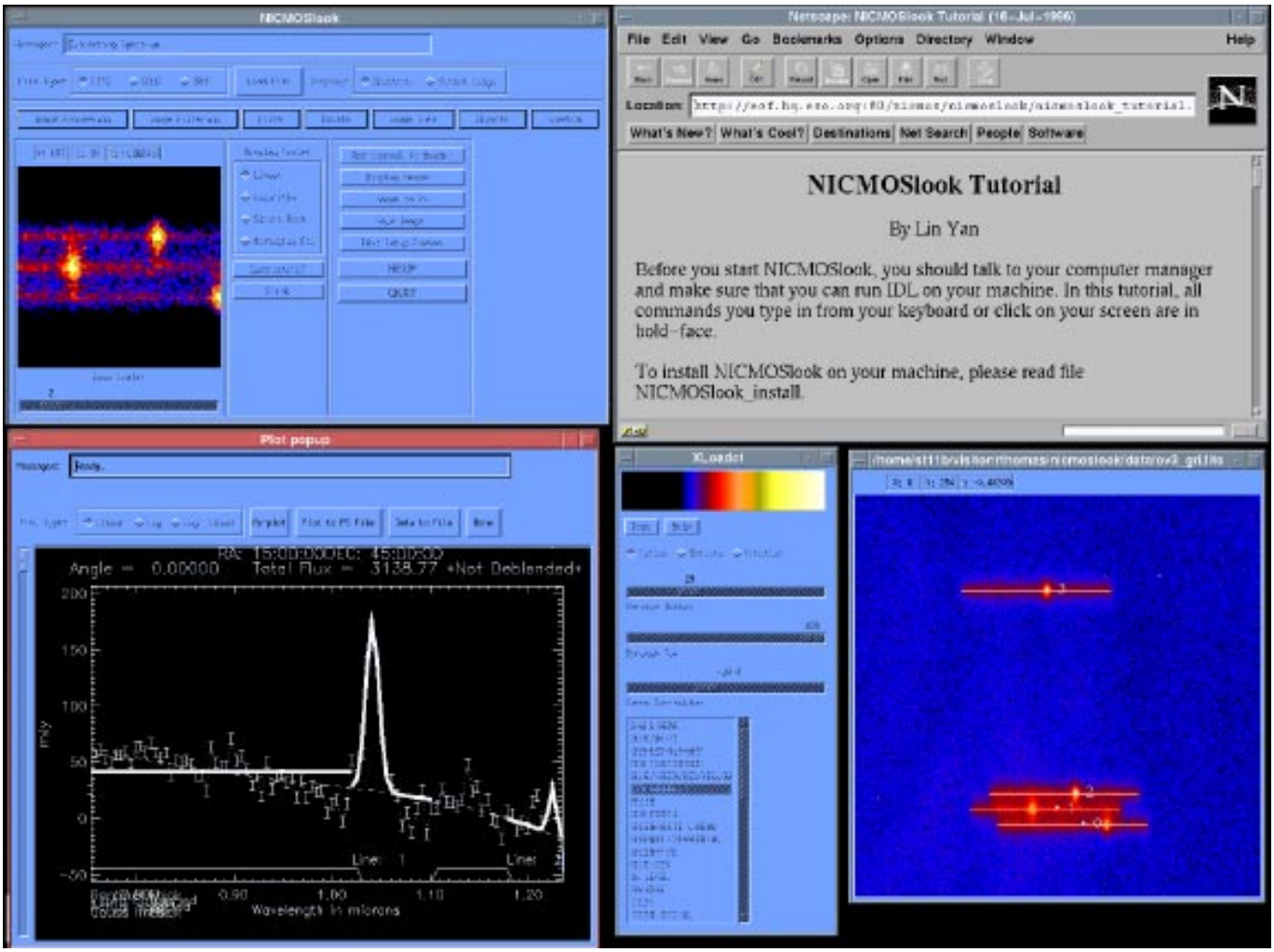

Figure 1: Screen layout of a typical NICMOSlook session. This is the interactive version of the program developed at the ST–ECF for the extraction of spectra from NICMOS grism data. In this session, the direct image and a zoomed region are displayed along with an extracted spectrum. Also visible is the tutorial which is provided in html format.

assumed to be calibrated by the STSDAS pipeline. From the image header, the image type (grism or direct) is identified and the frame placed into the appropriate buffer. There are a number of options for the display of the images and simple image manipulation. Objects can be identified on the direct image either automatically (using DAOPHOT) or through user interaction. Subsequently, spectra for individual objects, or for all identified objects, can be extracted. Several options for the weighting of the extraction are available. The weights for point sources used by *NICMOSlook* have been computed from *TinyTim* point spread functions (see Richard Hook's article in this Newsletter). The extracted spectra can be saved in an output file, displayed on the screen or printed as a PostScript file. Figure 1 shows a screen snapshot of a NICMOSlook session.

The extraction of the spectra is controlled by a calibration database in which properties of the grisms and flatfields are stored. This database is easily maintainable. It currently contains pre-flight calibrations and will be updated as new information becomes available during the course of SMOV. On-line documentation and a tutorial, written by Lin Yan, are available.

calnicc

NICMOSlook is a convenient tool to extract spectra from a single pair of images. Since it is interactive, it can be used to experiment with different strategies such as weighting methods and object detection as well as different calibration files. However, for large data sets with large numbers of images, a more automatic approach is frequently desirable. Such a need may arise from large survey-type grism programmes, for archival research or for programmes where grism images contain a larger number of objects which are not the primary target(s) of interest. Ideally, such a grism extraction could be run at the same time as the STScI pipeline data reduction so that extracted spectra can be provided as a standard data product. This need is addressed by *calnicc*. Like *NICMOSlook*, *calnicc* is written in IDL, but it is non-interactive. Some modules of the program are written in C. Therefore, the program needs an IDL version which allows external functions to be called. Currently, the program has only been tested under SunOS 4 and Solaris. Linux users will need IDL version 5.0.

The capabilities of the program are similar to *NICMOSlook*, with all aspects of the extraction controlled by setup files. Objects are identified on a direct image and classified as stars or galaxies using a neural network approach implemented as the SExtractor program (Bertin & Arnouts, 1996). The positions of the objects are used to extract spectra from the grism image. The wavelength calibration of the extracted spectra is performed using the position of the objects as determined by the SExtractor program as the zero point, and using parameterised dispersion relations. After extraction, the spectra are corrected for the wavelength dependence of the quantum efficiency of the detector. The flux scale is then computed using the same calibration database as *NICMOSlook*. The extracted spectra are corrected for contamination by nearby objects under the assumption that the shape of extended objects does not change with wavelength. Subsequently, the extracted spectra are automatically searched for emission and absorption lines. In addition, the continuum emission is automatically determined. The final data products are binary FITS tables with the spectra, error estimates, object parameters derived from the direct image and details of the spectrum extraction process. PostScript files with plots of the individual spectra are also provided.

Grism deconvolution

For crowded fields where the object spectra overlap, the spectral information on a single grism image for a given spatial position is not unique since there is a degeneracy between the flux at a given wavelength from one position and the flux at a different wavelength from another position. *calnicc* tries to correct extracted spectra for contamination of neighbouring objects by assuming that the spatial shape of extended objects is independent of wavelength. This strategy fails when this assumption is not valid (such as for an AGN with a continuum nucleus and an extended emission line region) or when the overlap between two or more objects is such that there is not enough independent information in each of the spectra. However, this degeneracy can be broken if several grism images are obtained with different roll angles of the spacecraft, giving rise to differing directions of the dispersion. Other constraints can be obtained with direct images of the same field without the grism. A program *GRISMdecon* has been developed which performs such a deconvolution based on a Lucy-Richardson restoration. The program is written in IDL and is non-interactive. However, a sufficient amount of memory and a fast computer are necessary to run it efficiently.

Availability of programs

All programs described in this article have been tested on simulated data. They will be further developed and tested on real NICMOS data as they become available. Soon afterwards, official releases of the programs and their progress will be announced. For up-to-date information, check the ST–ECF NICMOS page at: http:/ecf.hq.eso.org/nicmos/nicmos.html

Acknowledgments: Most of the code for both *calnicc* and *NICMOSlook* was written by Robert Thomas. Lin Yan prepared the flat-fields and background estimates used in both programs. Other people involved in the software development are: Rudolf Albrecht, Hans-Martin Adorf, Alberto Micol and Benoît Pirenne.

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Drizzling dithered WFPC frames

Originally designed for processing the Hubble Deep Field, a method has been developed for combining dithered WFPC images using Variable Pixel Linear Reconstruction. It is known, for reasons which have become obscure, as 'drizzling'.

Richard Hook & Andrew Fruchter[†]

A series of articles in the February 1995 issue of this Newsletter presented some methods by which dithered WFPC images can be combined to recover some of the information lost by the undersampling of the image by the large pixels of the camera CCDs. These are non-linear, iterative techniques which work well for small areas of images. Unfortunately, such methods cannot readily be used for large-scale combination because they are computationally demanding and can handle neither the significant geometrical distortion of the WFPC optics, nor rotations between dithered frames. They also cannot handle PSFs which vary across the image and give resultant images in which the noise properties are very different from those of the input images and hard to quantify for subsequent photometric analysis.

For these reasons, a new method—formally known as Variable Pixel Linear Reconstruction, but usually called drizzling—was developed by us to handle the major image combination problem posed by the Hubble Deep Field project. We wished to preserve resolution while obtaining the highest possible signal-to-noise on faint galaxies. Drizzling is a non-iterative, linear, direct technique which may be considered to be an enhanced, fully flexible, generalisation of the familiar 'shift-and-add' method widely used in infrared imaging and elsewhere. Instead of simply shifting the large input pixels into the correct position on the output and adding them, the drizzling method shrinks the input pixels before mapping onto the output and hence minimises the effects of an additional convolution with the pixel-response function (see Fig. 1). In the extreme case, where the input pixel is shrunk to a point, this method becomes equivalent to pixel interlacing which is an optimum strategy but rarely practical because the fractional shifts required cannot normally be executed to an adequate accuracy. Furthermore, geometric distortion prevents interlacing from being applied when there are large shifts between images. The degree of pixel shrinking is normally limited by a desire to avoid empty pixels in the output or, in the less extreme case, large variation in the weights of adjacent output pixels.

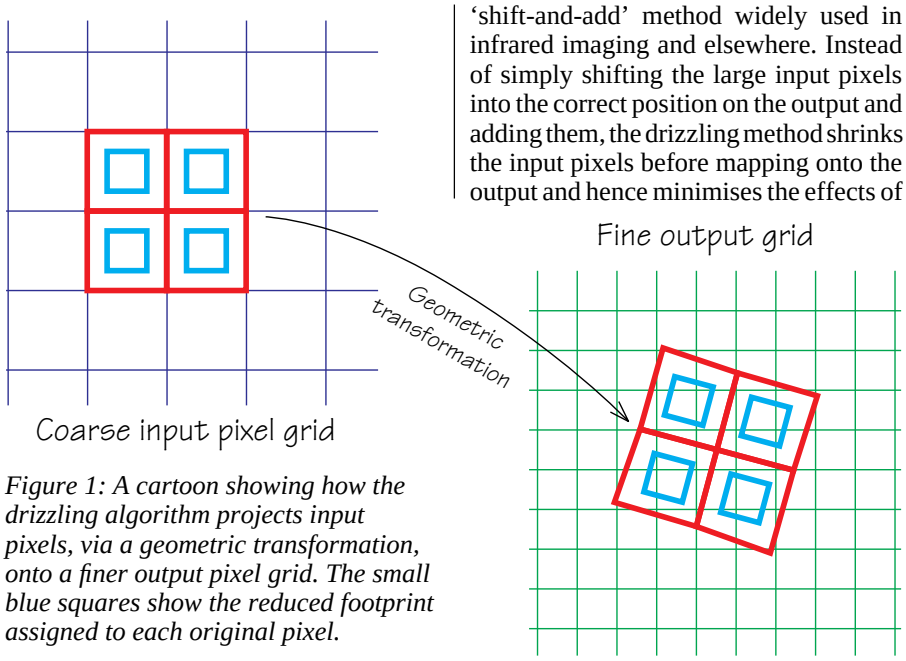


Figure 1: A cartoon showing how the drizzling algorithm projects input pixels, via a geometric transformation, onto a finer output pixel grid. The small blue squares show the reduced footprint assigned to each original pixel.

Drizzling can handle bad pixel masks, geometrical distortion, rotations and shifts and combines images in a statistically optimum way with minimum loss of resolution. Since its application to the HDF, the software has been considerably enhanced and has subsequently been used on many datasets including ISO imaging of the HDF as well as WFPC 2 imaging. A full description along with the current implementation of the software (easily installed to run under IRAF) is available at:
http://www.stsci.edu/~fruchter/dither/
and an example of its use is shown in Fig. 2. A detailed published description of the method will appear in the near

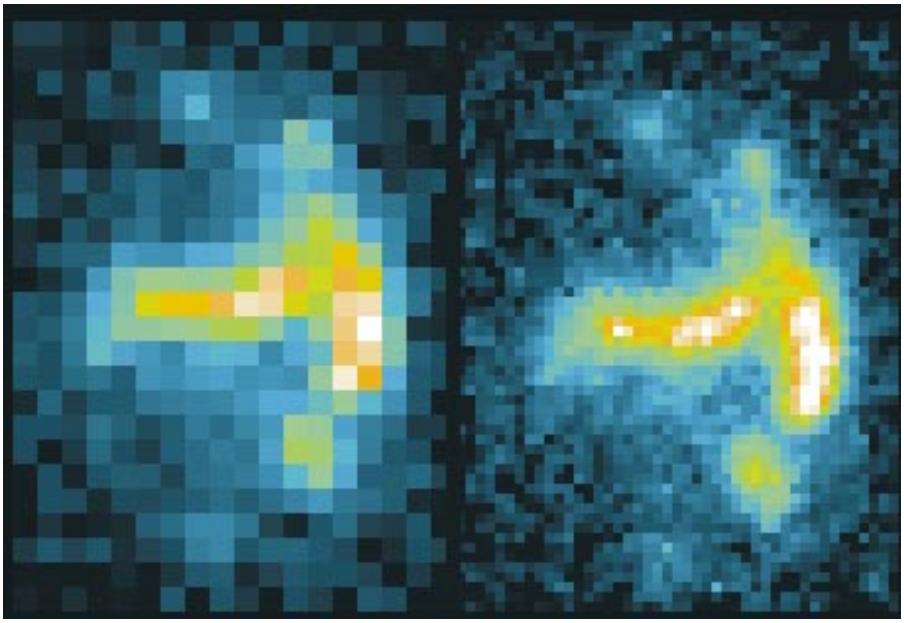


Figure 2: A small subset of the Hubble Deep Field showing a peculiar disturbed or interacting galaxy. The left-hand image was produced by 'shift-and-add' on the original pixel grid. The right-hand image was produced using drizzling and has 2.5 times finer pixels.

[†] Space Telescope Science Institute

future and this brief note is to alert interested observers of the code's availability and to encourage anyone with dithered data to down-load the software and try it out.

The drizzling task will form a part of a more comprehensive software package being developed at STScI by Andrew Fruchter, Ivo Busko and others which will also address issues such as the accurate measurement of the shifts and possible rotations between dithered images. This dither package will appear in a future release of STSDAS. There is also very promising work in progress in adapting drizzling to be able to detect and flag cosmic-ray events in small sets of dithered images which do not have the multiple exposures at each telescope pointing which are required for traditional CR rejection schemes (Fig. 3). As such sets are common in typical GO programs it is hoped that this method will become a valuable tool.

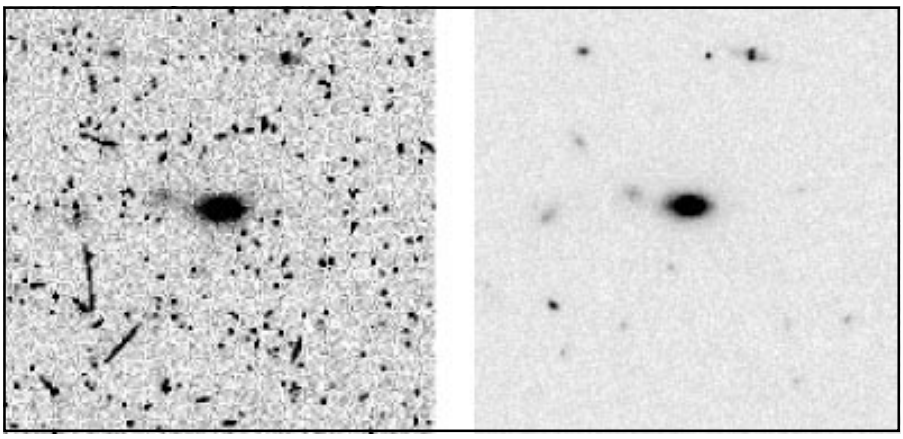


Figure 3: An example of the use of drizzling to combine dithered images and simultaneously detect and suppress cosmic-ray events. The left-hand frame shows a small part of a single input image, one of 12 public ones extracted from the archive for this work. The right-hand image shows the result of combining all twelve images using cosmic-ray detection and image combination procedures currently under development at STScI.

NICMOS point spread functions now available from *Tiny Tim*

Richard Hook & John Krist[†]

Point-spread functions (PSF) are required for many aspects of HST data flow. These include simulations and exposure time estimation during proposal preparation, image restoration and optimum weighting for grism spectral extraction. The *Tiny Tim* program, designed and written by one of us (JK), has proved convenient for PSF simulation as it is easy to install and use, quick to run and produces PSFs which are close enough to empirical ones for most purposes. As a collaboration between the ST–ECF and STScI, facilities for creating PSFs for the three NICMOS cameras have now been added to the latest version of *Tiny Tim* (V4.2) which is available for downloading via the Web at:

http://ecf.hq.eso.org/~rhook/nicmos-tinytim.html

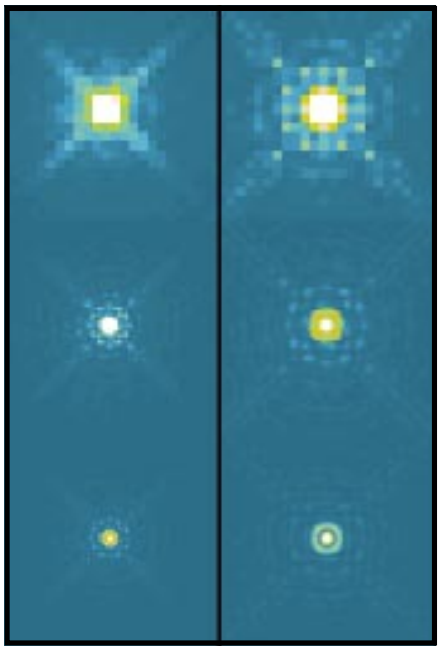
There is also a general *Tiny Tim* page at:

http://scivax.stsci.edu/~krist/tinytim.html

The model of the NICMOS imaging system used by this version of *Tiny Tim* includes the current best values for the orientation and position of the NICMOS apertures in the HST focal plane, the focal ratios of the cameras and the geometry of the coldmasks. No aberrations of the final beam are currently well known (although they are known to be small) and none are included. More precise information will be available after the instrument has been in orbit for some time, although pre-launch optical tests and phase-retrieval suggest that the PSF produced by this version of the software are good approximations.

This version of *Tiny Tim* does not include filter curves for NICMOS. For the other cameras, the spectral energy distribution to be used in the construction of a weighted, polychromatic PSF is determined by the choice of a stellar spectral type. In the infrared, where few objects have a black-body spectrum corresponding to typical stars, this makes little sense. Instead there is a new option, which may also be used with the other cameras, whereby the user can supply *Tiny Tim* with a list of wavelengths and weights which are used to create a polychromatic 'bespoke' PSF. It is planned to include NICMOS filter curves along with several options for SED definition (black-body, power-law, user-defined, etc.) in a future release. Unfortunately the coronagraphic mode of NICMOS cannot be properly modeled by *Tiny Tim* (which assumes that all the obscurations are in a single pupil plane and hence cannot model the apodizing effects). Another factor which is not currently included is the NICMOS pixel-response function—the pixels are known to be less sensitive at the edge than in the centres and this will have some effect on the PSF.

It should be stressed that this is a preliminary release and, although initial comparisons with actual NICMOS data are good, there will need to be significant revisions after orbital verification.



Examples of monochromatic PSFs for NICMOS produced by Tiny Tim V4.2. The left column is for 1μm and the right for 2μm. The bottom row is for camera 1, the centre for camera 2 and the top for camera 3. For each PSF, an area of 5" on a side is shown. The intensity scaling is such that the maximum scaling value is the same fraction of the total intensity of the PSF in each case. Because the pixels of camera 3 are larger than camera 2 or 1 they contain a larger fraction of the total, the fainter outer structure is more prominent in these images.

[†] Space Telescope Science Institute

More reflections on the TAC

A second commentary on the HST time allocation process with special reference to European proposers. More details derived from the comments of European members of the Cycle 7 subject panels and allocation committee will be given on the ST–ECF Web site before the Cycle 8 deadline.

Leon Lucy

Following the allocation of HST time for Cycle 5, I wrote an article (ST–ECF Newsletter No. 22, February 1995) under a similar title summarising the operations of the Proposal Review Panels (PRPs) and of the Telescope Allocation Committee (TAC). I also explained the circumstances under which otherwise scientifically excellent proposals ended up with no time.

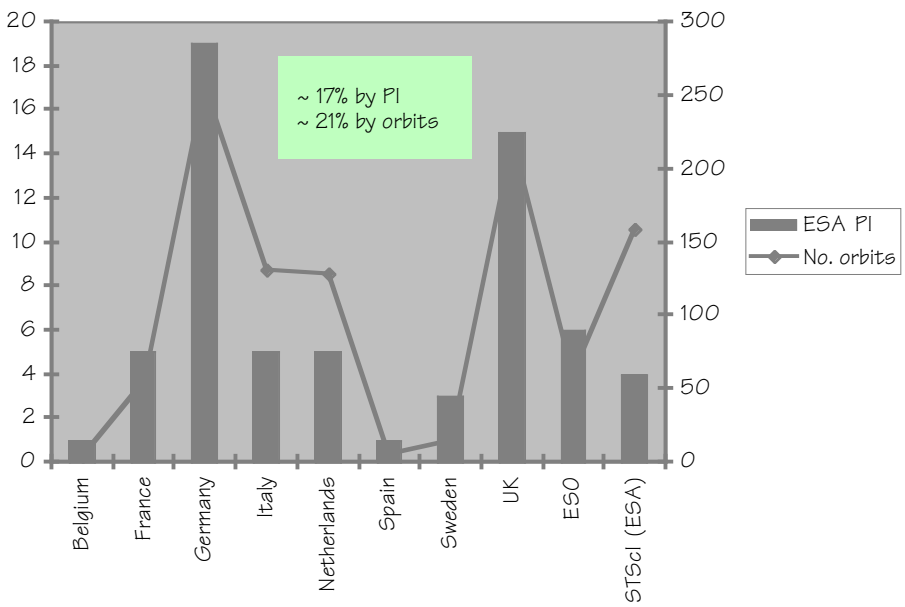
In view of favourable comments on the usefulness of that article, following the meetings of the PRPs and the TAC for Cycle 6, I asked the European Panellists to debrief themselves and summarize for us what they learned about the do's and don't's of successful proposal writing for HST. These make fascinating reading and, at the urging of the ST–ECF's Users' Committee, a lightly edited version was made available via our Web site (http://ecf.hq.eso.org/tacomments.html) for the benefit of proposers for Cycle 7. A new version of this material, organized by topic and including input from our Cycle 7 Panellists, will be put on the Web well before the Cycle 8 proposal deadline.

Following the allocation of time for Cycle 7, I again asked the European Panellists to debrief themselves. However, instead of do's and don't's, I asked them to focus on the proposed use by the world community of NICMOS and STIS and, in particular, to alert us to any generic scientific opportunities opened up by these new instruments that are being neglected by European astronomers. Gratifyingly, the Panellists are essentially in unanimous agreement that the scientific quality of the European proposals was fully competitive with those from US-based PI's. Moreover, these admittedly subjective impressions are resoundingly confirmed by the hard statistics of orbits allocated to proposals with ESA PI's and CoI's (see below).

A second topic on which I requested comments is that of current research possibilities available using the HST archive. As most readers will know, US-based researchers can submit proposals purely for research with archived data. If approved, such proposals get financial support, often at a level allowing a postdoc to be hired to do most of the actual work. Having participated in the reviewing of such proposals, several of our Panellists are convinced that cutting-edge science can now be done with archived data, and that the lack of comparable financial support in Europe puts us at a disadvantage in exploiting this increasingly valuable resource. Note that these qualitative comments on the scientific quality of the best archival proposals are decisively supported by their being ranked in among the best of the proposals for new telescope time.

Though funding in Europe for postdocs to mine the HST archive is undoubtedly desirable and is being sought, European researchers would be well-advised not to be inactive in the interim. In this regard, they should inform themselves of powerful software tools developed at the ST–ECF by Benoît Pirenne and colleagues that greatly facilitate HST data retrieval, recalibration and combination (see the article about WFPC 2 combinations and on-the-fly recalibration in this Newsletter). Quite possibly, a reader's first guess of the effort required to complete an HST archive project would in fact prove a gross overestimate.

Given the severe oversubscription for HST time, many excellent proposals are inevitably rejected. Not unnaturally, the PI's of such proposals are upset, and a handful (no more) complain to the ST–ECF that, judging from the comments received from the STScI, their proposals were not understood by the reviewing Panel. I find it hard, if not impossible, to believe that this could happen to a clearly-argued proposal. Since each Panellist is required to submit electronically a grade for each proposal before the Panel meets, they reach their understandings of the proposals independently, and so the probability that all fail to grasp the point of a well-written proposal is surely miniscule. Disappointed PI's with lingering doubts should look at the list of Cycle 7 Panellists in the recent STScI Newsletter (January 1997) and ask themselves if the expertise was indeed present to understand and evaluate their proposals. If the answer is yes, as I would confidently expect, then the point of failure must lie in the proposal itself. With increasing specialization, there are some topics with only 2 or 3 real experts in the whole world. If you are one of them, you should not assume that the STScI will have the foresight to recruit one of the others as a Panellist. Accordingly, proposals must be written to be understood by colleagues with adjacent expertise: after all, each Panel deals with a considerable diversity of topics.



Summary of the Cycle 7 allocations to ESA member state Principal Investigators (PI). The ESO and the (ESA) STScI PIs have been counted separately.

WFPC 2 images of the Lagoon nebula

In a dramatic demonstration of the wealth of high quality data now publicly available from the HST archives, these colour-composite pictures reveal new features in the familiar Lagoon nebula.

Adeline Caulet

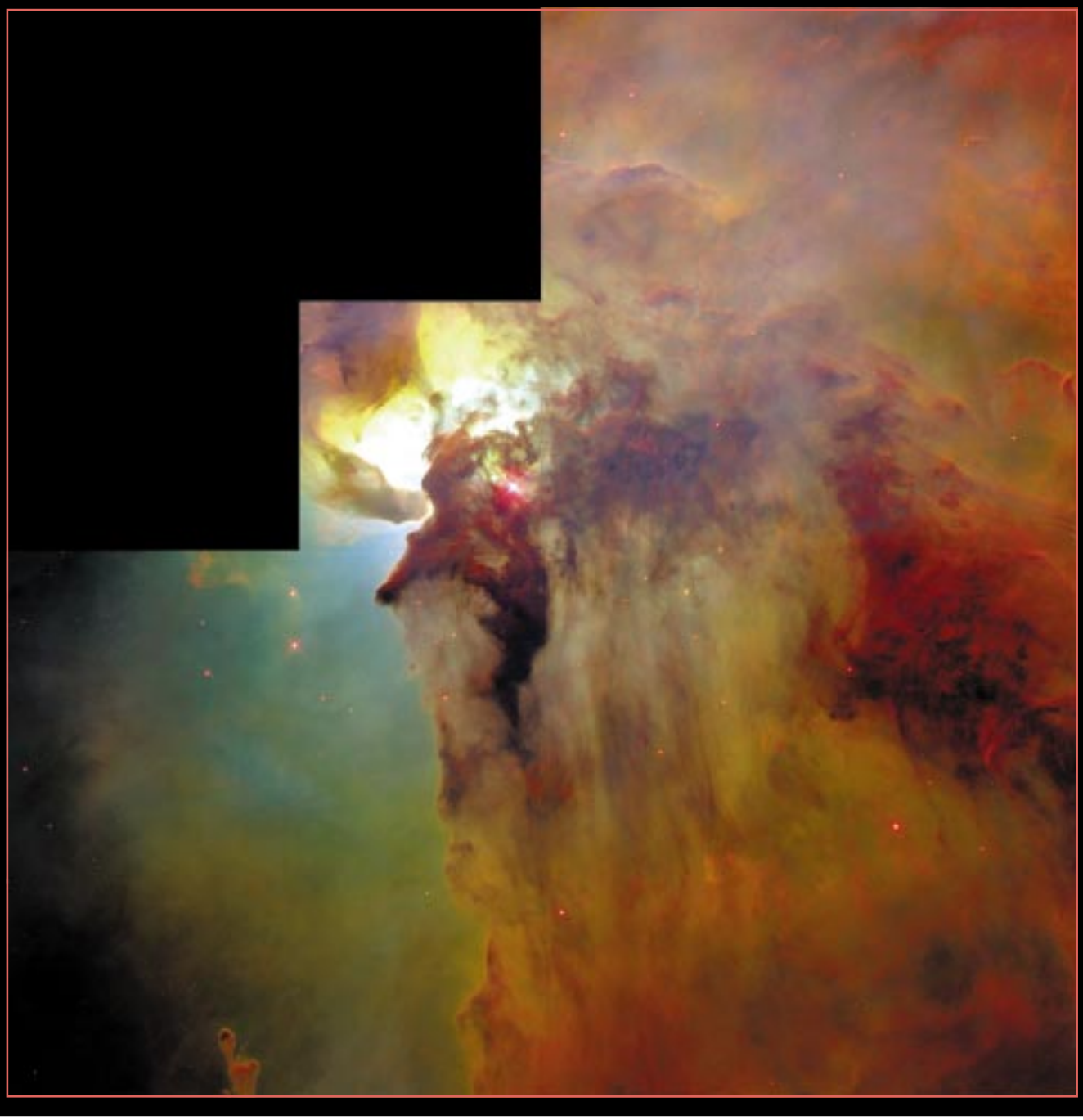
The Lagoon Nebula (Messier 8) is a well-studied H II region in our Galaxy. It is 1.5 kpc from us and appears a few degrees northwest of the Great Sagittarius Star Cloud. This H II region is, like the well-known Orion Nebula, a site where new stars are being born from dusty molecular clouds. The HST picture reveals, in great detail, the small-scale structures in the interstellar medium: Bok globules, bow shocks around stars, ionized wisps, rings, knots and jets. The images here are constructed from archival observations taken in filters which select ionized sulphur (red colour), hydrogen (green) and doubly-ionized oxygen (blue). This choice of colour assignment is extremely valuable for revealing the different levels of excitation in the clouds. This type of image presentation was applied before on other nebulæ imaged with WFPC 2 (see STScI press releases and published articles on the Helix Nebula and the Orion Nebula). By comparing the morphology and the flux of extended features in different emission lines and also in the continuum at blue and red

wavelengths, it is possible to identify objects which appear to be circumstellar disks around young forming stars like those seen in the WFPC 2 images of the Orion Nebula nicknamed 'proplyds' in the literature. For example, among them is the bright blueish blob seen close to the brightest star, Herschel 36.

The HST images have sufficient spatial resolution to reveal the different positions of the ionization fronts that penetrate the parent cloud giving birth to the star. Here, the images have clearly revealed the high excitation [O III] front on the nearside (facing Herschel 36), followed by the hydrogen and sulphur fronts. Those fronts have a characteristic arc/moon shape which is a small cross-section of the illuminated cloud. The new-born star embedded in the cloud is identified in the continuum light by a stellar object surrounded by scattered light. It is not always possible to detect the newborn stars in the optical because of heavy dust extinction. Near-infrared images help to identify the obscured stars and are complementary to the optical identifications of circumstellar disks.

These colour-coded images show the distribution of the interstellar molecular clouds in much more detail than before. In particular one can see the smoothness of several cloud surfaces and the very thin dark ridges aligned almost vertically in the middle of the image. Their widths can be as thin as 0.004 pc (recall that the whole field or 1600 WF pixels corresponds to 1.2 pc). With the finer sampling of the Planetary Camera (0.0455 arcsec/pixel = 3.4×10^{-4} pc), the structure of the clouds of the Hourglass region shows details never seen before. It shows the processes of the wrapping of an ionization and heating front around the clouds. As the gas gets ionized, it is heated from some 30 K to about 10,000 K with a correspondingly sudden jump in pressure, inducing what is called photoevaporation of the clouds. This is seen directly in the HST image as the blue haze in the upper-right WF quadrant.

These public images were retrieved from the HST archive at the ST–ECF and have been processed with IRAF and STSDAS tasks. The processing used for scientific analysis included the combination of all data in the archive in different filters, two series having being taken at different pointings. Removal of artifacts, cosmic rays, hot and dead pixels was carried out and saturated pixels were flagged using STSDAS tasks such as *crrej*. Image combination was carried out using the drizzling technique described elswhere in this Newsletter by Andy Fruchter and Richard Hook.



Predictive calibration using instrument models

By constructing instrument models whch incorporate as full as possible a knowledge of optical and detector physics, the calibration of astronomical data can be placed on a firmer footing than is currently the norm. Ultimately, the comparison of observations with models can take place in the raw data domain. This article describes a methodology, developed jointly at the ST–ECF and ESO, which is designed for application to HST and VLT instruments. It is now implemented in the form of a software library.

Michael Rosa

In some respects, HST has become a paradigm for planning, executing, calibrating and archiving astronomical observations. Astronomers are now accustomed to receiving data which are calibrated to high accuracy. Here, I discuss some new concepts for data calibration based on a physical understanding of the instruments and the detection process. The operational advantages are outlined and the interrelation between this predictive calibration strategy and model-based data analysis is shown. Finally, reference is made to working implementations for HST instruments as well as ground based equipment in use or under construction at ESO.

The classical calibration concept

With ever more complex instruments entering service at telescopes accessible to the worldwide astronomical community, an increasing importance is assigned to 'calibration' tasks. However, the concepts currently employed for the calibration of observational data derive from the historical development of instrument and detector technology. In order to assess whether we employ the best possible method of analysing the precious data from large groundbased telescopes and space observatories, it is necessary to take a careful look at the calibration concept currently in use.

When the only detector was the human eye, calibration basically consisted of the proper transfer of some linear readings (eg. from micrometers) into angles on the sky and the determination of the so called 'personal equations' for timings and brightness estimation (ie, calibration by comparison with empirical readings from 'standards'). Since that time, most calibration strategies have been based on that very same principle. Admittedly, computational tools have become much more elaborate, so that the 'standard' readings can be filtered, statistical analysis can be performed, and long term trends can be studied with the help of archives. Still, at the heart of the process are empirical relations which are based on noisy data. A typical example is the fitting of low-order polynomials to the observations of wavelength calibration lamp spectra with data taking and analysis usually repeated for each new target night after night.

The calibration strategies currently adopted in most of optical astronomy are an adaption of empirical methods aimed at 'cleaning' data from the effects of instrumental and environmental (eg, atmosphere, particle radiation in orbit) processes. One of the most obvious signs of the empirical nature of this calibration concept is the linearised decomposition of the calibration process into individual tasks which are designed to correct for just a single effect at each step. The transformation of detector-based units to astrophysical units is usually done separately as a final step at the boundary between calibration and data analysis.

This whole sequence makes it difficult to arrive at a physical understanding of variations in instrumental characteristics which could direct the subsequent efforts at maintenance or algorithmic design. It further requires a long learning process to determine the optimum deployment of resources in the form of observing time for calibration observations and manpower for subsequent analysis. While the link between the calibration of individual observations and the monitoring of instrument performance can be strengthened by adopting improved operational procedures, the calibration process itself is still not seen as an entity requiring a comprehensive gathering of instrument knowledge and observed data.

From raw data to astrophysical parameters

Figure 1 depicts the generic information flow in observational astronomy. During data gathering an operator that describes the telescope/instrument combination projects a sub-volume of the Universe's parameter space onto the raw data domain. In the classical interpretational approach, we attempt to apply the 'calibration' operator in order to re-project onto the physical parameter space (eg, a flux scale) to obtain the 'true' spectral energy

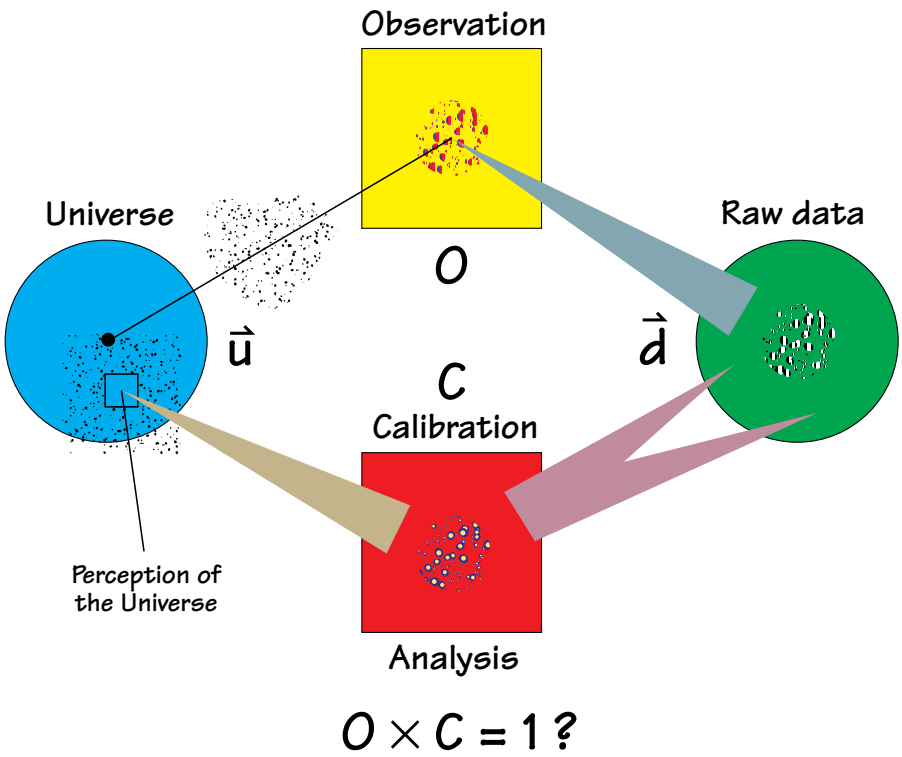


Figure 1: The generic data gathering and analysis scheme in astronomy.

distribution of a source or its 'true' morphology and surface brightness distribution. Were it not for the presence of noise (photon shot noise and detector noise), we could in principle find an inverse of the 'observation' operator which would perform an exact re-projection. Radio interferometry, which is not limited by photon noise, comes very close to achieving exactly that. At optical wavelengths, however, direct inversion is out of question because of the limited number of photons that can be collected and the characteristics of most detectors.

The usual procedure therefore is to decompose the inversion process into a sequence of instrument signature removal steps. In imaging this might be bias and background subtraction, flat fielding, photometric correction and possibly deconvolution. In spectroscopy one has to deal, in addition, with dispersion relations and the wavelength dependence of efficiencies. Cross-dispersed and long-slit spectra require additional complexity. Major efforts have been expended in obtaining more accurate and less noisy empirical calibration relations.

The classical concept takes noisy raw data back through the 'calibration' operator which is only an approximation of the inverse 'observation' operator because of the sequential treatment of effects and because of the presence of noise. However, Figure 1 reveals a different route for arriving at statistically sounder estimates of the astrophysical parameters. It rests on the ability to simulate the observational process in all its (relevant) detail on noise-free models of targets (eg, theoretical surface brightness and energy distributions). The range of acceptable model targets that could result in the observed raw data can then be explored using, for example, Monte-Carlo optimisation procedures.

Concepts based on instrument models

It is well known that even software models that address only one aspect of the instrument in question greatly help to recognise adverse characteristics of the design and the impact of various solutions on the later performance at the telescope. Such models, often in the form of exposure time estimators, also support the preparation and planning of observations. However, most of these models are linear and empirical, ie, inverted versions of the classical calibration process.

Yet we know much more about our instruments and about the observational process than is usually incorporated into the data calibration and analysis process. Already during the design phase we employ physical concepts to optimize the layout—for example by using ray tracing software. In contrast, when dealing with wavelength calibration, all we do is to repeatedly re-use polynomial approximations to very basic optical trigonometric equations.

Instrument models which are based on first principles clearly have the predictive power required to make substantial progress in the areas of calibration and data analysis. In the road map of Figure 1, they can be applied at 'calibration', where such models will provide noise-free calibration relations that can be projected even into 'uncalibrated' modes of the instrument: this is the concept of predictive calibration. A preferred alternative for the physical models is at 'observation', where they enable the full simulation of the observation process on synthetic targets. The astrophysical data analysis is then performed by comparing actual raw data with simulations of the expected appearance of raw data for the instrument configuration being used. This is the concept of model-based data analysis. Such a scheme has been familiar to X-ray astronomers for a long time, a procedure driven in their case by the relatively small number of photons collected in a normal observation.

Practical considerations

Before implementing the two concepts of 'predictive calibration' and 'model based data analysis', two questions must be answered:

- ❑ Can one construct from first principles 'physical' software models of astronomical instruments which
  - i. are able to predict observations of 'standards', ie, calibration relations, to a sufficient degree of accuracy, and
  - ii. work reasonably fast so that they can be embedded into routine calibration and data analysis procedures?
- ❑ Are such implementations
  - a) affordable in comparison with the effort needed to maintain the classical calibration scheme, and
  - b) do they bring any additional benefits for the operation of common-user instrumentation?

The ST–ECF has long experience with the transfer of such concepts from ideas into working software packages. The first coherent database of HST instrument characteristics, with the associated tools to simulate observations, was created as the STMODEL package in the MIDAS environment at the ST–ECF in 1985. This tool and the data served as a basis for the SYNPHOT package in IRAF/STSDAS which has been widely used by the HST community ever since. In a mathematical sense, the various methods for image deconvolution that blossomed in the early years of HST operation and in particular those developed by Lucy and Hook at the ST–ECF (eg, ST–ECF Newsletter No. 19, 6, 1993), are implementations of the 'model-based data analysis' concept.

An established application of the 'instrument model' concept in HST data analysis is the development of the

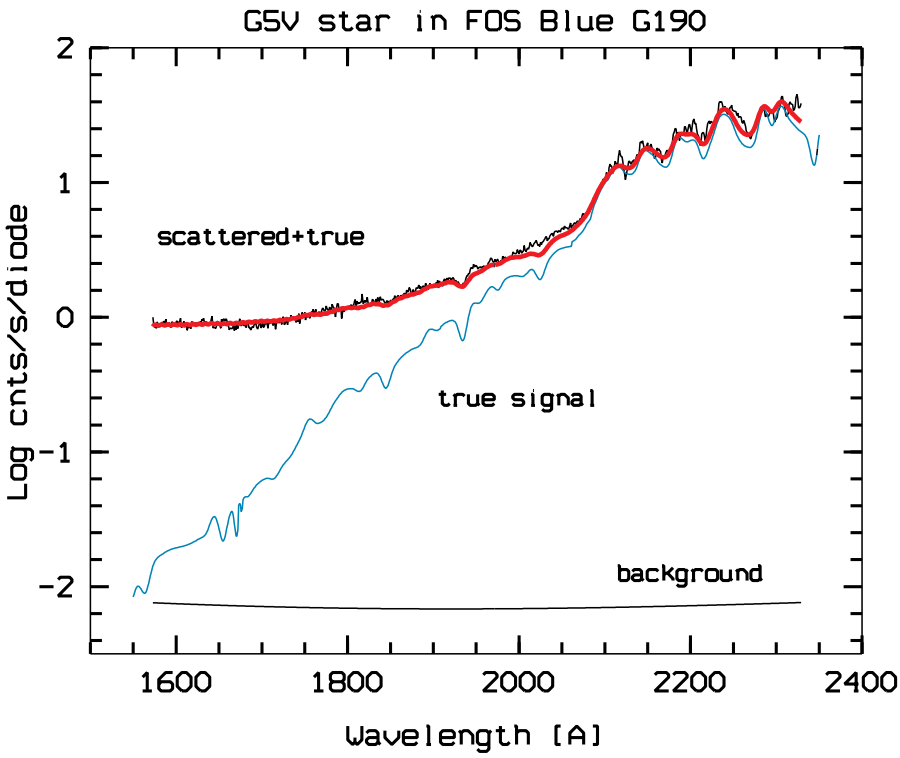


Figure 2: The observed count rate for the star 16 Cyg B (in black)—which is very similar to the Sun. The blue spectrum shows the expected signal observed with an ideal instrument and the red line shows the way this is affected by the scattered light predicted from the model.

understanding of scattered light in the FOS. The initial analysis (Rosa 1993, 1994a) identified as the causes the combination of broad wavelength range sensitivity of the detectors and the non-zero light levels in the far wings of the line spread function of this spectrograph for red targets. The resulting spectra show veiling of the scarce UV photons by the abundance of red photons present in the LSF wings. It is obvious that the intrinsic UV properties of such targets can only be recovered via a software model that simulates to a precision of better than one part per million the dispersion and image formation of the aperture-collimator-grating-detector combination. This software model is available in MIDAS (Rosa 1994b) and IRAF/STSDAS (Bushouse, Rosa & Müller 1995). The simulation of an FOS/BLUE G190H observation of a solar type star with actual data is shown in Figure 2 (see also FOS Instrument Handbook V5.0 or 6.0, Appendix C).

This example demonstrates that a software model going beyond a simple throughput calculation, ie, correctly describing all relevant physical effects, can be very powerful in solving problems encountered during the scientific analysis of data. Used in this way, the model appears simply as an additional data analysis tool in support of the calibration process. Ultimately, the goal is to go one step further, ie, to advance from the calibration strategy of 'signature removal' currently in use.

There are operational benefits to be gained from the use of instrument models with high predictive power. Instruments built and tested in the laboratory according to detailed performance specifications can be understood in all aspects of their performance before and during commissioning. The physics of optical elements and the interior workings of detectors and electronics are known to a degree that is usually much better than can be deduced from the analysis of noisy data from astronomical 'standards'. During routine operations, the model—fed by updated calibration databases—provides the reference for the nominal performance of the instrument. Large deviations from the anticipated behavior will signal the necessity of maintenance, while small deviations will usually be easily recognised as parameters not yet properly accounted for in the coded model.

The Model Project at ST–ECF and ESO

With the experience gained during actual case studies and with the recognition that there is a large overlap in requirements for the operation of the pipeline calibration between HST and VLT instrumentation, the ST–ECF has started a joint project with ESO to study, implement and exploit the 'predictive calibration' and the 'model based data analysis' concept. This effort is three-fold: to further develop the general modelling concept; to construct instrument models based on first principles for specific instruments and modes; and to establish a generic model software library. Thus code generated to handle the 2D geometry (order location and shape, dispersion relations) of a particular ESO 2D-echelle spectrograph (CASPEC) can easily be re-used to provide the same functionality for HST's STIS and ESO's VLT instrument UVES (cf. Ballester & Rosa 1997, A&A in press).

Short-term goals for HST are the capability to support HST observers by predicting calibration data for STIS modes not covered in the early stages of in-orbit calibration and the development of advanced methods for echelle data extraction based on model-predicted order location and inter-order background profiles. For NICMOS, the impact of models on the extraction and analysis of grism data is being studied. Long-term goals are to bind such models into the calibration processes and ultimately implement 'model based data analysis' as a general methodology. An important aspect will be the routine use of models to provide calibration reference data.

Users of both the new HST instruments, particularly STIS, and the archival data of the previous generation instruments FOS and GHRS are likely to see the impact of the instrument models soon. The finalising of the FOS and GHRS archives (see article in this Newsletter) will rely heavily on such models. The ESO La Silla community already makes use of the model software library any time one of the new exposure simulators is activated on the World Wide Web (eg. http://www.eso.org/ntt/susi/simulator.html), and extensions are in preparation for the first generation of VLT instruments.

Acknowledgments: It is a pleasure to acknowledge the continued support and encouragement from Riccardo Giacconi for this project. The outstanding collaboration with Pascal Ballester (ESO/DMD) has resulted in mutual benefits for HST and the ESO VLT.

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Final archives for the FOS and GHRS

Michael Rosa

This February, the first generation spectrometers aboard HST were returned to the ground at the end of a very successful second servicing mission. The FOS and GHRS data collection is therefore complete and it is appropriate to consider the production of final archives

At the ST–ECF we are preparing for reprocessing versions of these data under the project 'The FOS and GHRS final archives'. This is in close consultation with the planning group at STScI, where activities have concentrated on closing out the FOS and GHRS cycle 6 proposals. The aim here is to avoid any duplication, to provide mutual support in these activities within the HST project and, most importantly, to arrive at products which result in an increased scientific value of FOS/GHRS data for the user community.

Why should one bother with 'oldies'? STIS is a new HST spectrograph which combines the resolving powers and wavelength ranges of FOS and GHRS, while providing large spatial and spectral multiplex gains from 2D detectors. The total time available for UV-visible spectroscopy on HST is, however, unlikely to increase substantially as imaging in the infrared (with NICMOS) and later deep imaging on wider fields (with ACS) compete for observing time. It is clear that precious time will not be made available to re-observe targets in modes that would simply duplicate observations already

secured with FOS or GHRS. Therefore the FOS and GHRS science data sets will remain as valuable as they are now. Similarly the IUE project is preparing its final archive, which will provide a unique resource of observations that cannot be made from the ground.

The processed data currently accessible from the FOS/GHRS part of the HST archive span the period from cycles 0 to 6. Both instruments underwent secular changes in sensitivity and both were fed with a greatly improved HST PSF from cycle 4. The presence of COSTAR resulted in smaller projected aperture sizes and modified ultraviolet sensitivity curves. The calibration procedures used in the pipeline have also seen a continuous improvement throughout these seven cycles.

We can now take a global look at the calibration of these data and can produce a more homogeneous archive than could be produced by simply applying the 'best' calibration reference files to the previous cycles of observations. In particular, a global recalibration can make use of the predictive power of instrument models (see the article in this issue) for the dispersion curve analysis, the background determination and the scattered light in FOS.

Most of the information and the tools required to optimise the recalibration are already available. A substantial building block is 'on-the-fly' recalibration scheme implemented in the ST–ECF HST archive user interface a year ago and described in this issue. An area calling for a rather large effort, however, is the exploitation of information contained in the engineering data stream which is currently not readily accessible. Several items, such as jitter information, instrument temperatures and magnetometer readings, are required in order to improve the current pipeline calibration.

Given the appropriate manpower for this level-of-effort project, we are planning to make available a self-contained volume for each of the two instruments, FOS and GHRS, on CD-ROM. These final archives will contain:

- ❑ The (publicly available) raw data sets, accompanied by a re-calibrated version from the standard pipeline using the best available reference data. This is essentially the version derived from the current HST archive by requesting re-calibration with the best reference files.

The value-added items planned are:

- ❑ All calibration reference data ever produced to that date for both instruments.
- ❑ All software items required to run the latest pipeline on the raw data, assuming the presence of IRAF/STSDAS on a UNIX platform.
- ❑ All publicly available records of Phase I and II proposals with SMS logs, so that the exact sequence of observing events can be reconstructed, eg, the location of an aperture on a target galaxy.
- ❑ All relevant documents in electronic form. These will include all versions of the Handbooks, the data analysis guides, the Phase II instructions, technical documents and Instrument Science reports.
- ❑ The procedures, reference data and documentation for the model-based recalibration, along with copies of the resulting data products.

The initial release of such an instrument archive should be viewed as a first installment. A delivery date late this year can only be met if some sacrifices are made. A number of data sets will still be proprietary at that time and the first issue could contain only the core of the items listed above. The exercise itself will provide us with the insights to devise improvements to calibration items and tools. Not least, the response and suggestions from users will be incorporated into enhancements, enabling a truly final archive to be produced.

esa SPACE TELESCOPE European Coordinating Facility

The 1997 HST Calibration Workshop

— with a new generation of instruments

22–24 September, 1997

SPACE TELESCOPE SCIENCE INSTITUTE
Operated for NASA by AURA

The Space Telescope Science Institute will host the third *HST Calibration Workshop* on September 22–24, 1997.
The workshop will be organized by STScI with the collaboration of the ST–ECF.

Topics will include:

Preliminary results of the calibration of the new instruments (STIS, NICMOS, and the new FGS)
Closure information on the calibration history of FOS and GHRS
Up-to-date calibration results for the continuing instruments (FOC and WFPC 2)
New pipeline and post-processing software
An advance look at future instruments

The format will include invited talks, contributed posters, and splinter sessions for more detailed technical discussions.

If you are interested in participating, please complete the form at
http://www.stsci.edu/stsci/meetings/cal97/CalibWSForm.html
or send email to cal97@stsci.edu.
Registration information will be sent to all respondents, and the information you provide will be very helpful in our planning.

The Archive column

Benoît Pirenne & Alberto Micol

In the past year, the archive has been active both in operations and development. We have seen the archive usage increase by a substantial factor: see fig. 1 for accesses to the database services and fig. 2 for the evolution of the distributed data volume. The on-the-fly recalibration scheme has been released and user requests can be delivered on CD-ROM. In addition, a Web interface for retrieval of the best calibration files has been implemented.

On-the-fly recalibration

This novel approach to archive data distribution is described in a separate article in this newsletter. In brief, it allows one to submit a request for HST archive data as before, but allows one extra option. The data files can be re-calibrated at the time of the request using the best available calibration reference files together with the most up-to-date pipeline software applying at the instant of the request submission.

The system, developed in collaboration with the CADC, has been undergoing heavy testing in the past few months and has just been released for wider use. It can be accessed on the Web using the following URL:

http://archive.eso.org/wdb/wdb/hst/science/form

To support the reprocessing exercise, we have added extra hardware power to the archive system such that we achieve a recalibration time of about 3–5 minutes per WFPC(2) dataset.

The overall service time (from submission to reception of results) should also be greatly reduced due to the presence of all the raw data on CD-ROM located in a jukebox. This setup allows for a very fast data access. The calibration reference files are all on direct access magnetic disk.

HST data now also on CD-ROM

In addition to FTP, Exabyte and DAT tapes, we now offer HST and ESO/NTT data on CD-ROM. This facility is limited to requests involving between 300 MB and 1200 MB of data. For larger and smaller datasets and special requests, please send email to 'catalog@eso.org'.

Retrieval of best calibration files

This new Web interface has been designed principally for HST users willing to calibrate the observations themselves even though the on-the-fly recalibration service is available.

Using a web form, users can enter a list of datasets and/or calibration files. If available, the requested files for the given dataset(s) are retrieved and made available for immediate downloading through the user's web browser.

The Hubble Deep Field

The archive currently offers versions 1 and 2 of the HDF data products. Please have a look at:

http://ecf.hq.eso.org/hdf/hdf.html

for current information on availability or send email to 'catalog@eso.org' to request the collection of processed/raw data on tape or CD-ROM. Fig. 3 shows a very small section of the *'BVI'* and *'UBV'* colour composites.

The Digitised Sky Survey

The northern part of the Digitised Sky Survey has been available for public access without restriction since early February 1996. The entire sky can now be accessed from:

http://archive.eso.org/dss/dss

To improve the speed with which regions of the southern sky can be retrieved, we have copied over 60 CD-ROM entirely onto large, fast-access magnetic disks. The new setup has been available since July 1996 and reduces the time to get any random image of the southern sky from 30 to about 5 seconds.

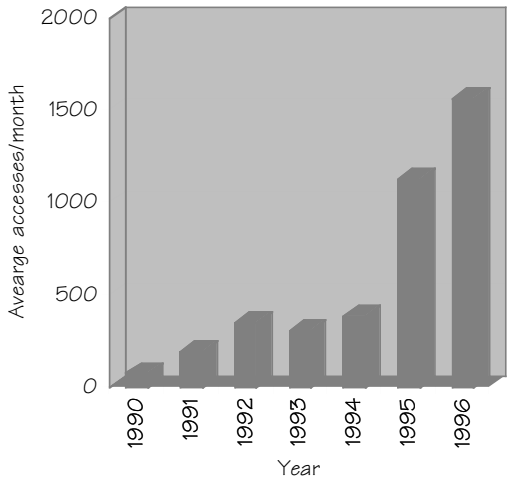

Figure 1: Average number of accesses per month to the archive services.

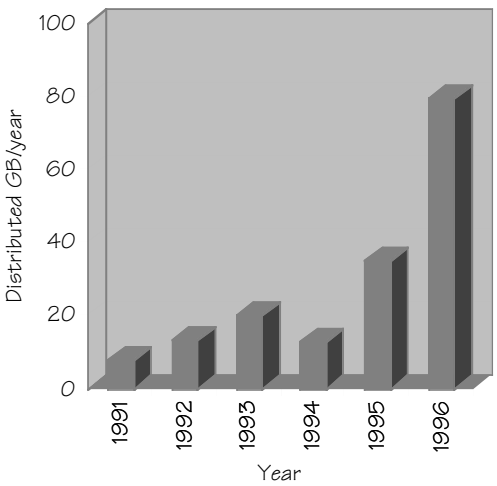

Figure 2: Evolution of the distrubuted data volume.

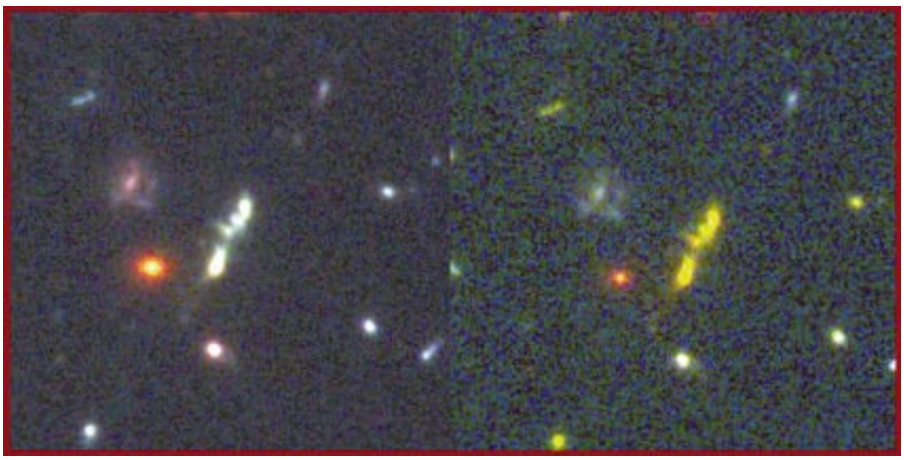

Figure 3: A small section of version 2 of the Hubble Deep Field data product with the BVI image on the left and the UBV on the right, each coded with blue, green and red respectively.

Astrocat at the CDS

The CDS has developed a Web interface to a large collection of astronomical catalogues (Vizier: see a description under http://vizier.u-strasbg.fr/). This service, which was not available from our own WWW interface, is now offered directly by the CDS. It offers all the nice features of a Web form query interface such as WDB, but also allows for the step-by-step selection of catalogues to query as well as the combination of several catalogues to be searched together. Search by (solid angle) cone, with astronomical name translation, is also available from the query screens.

Automatic recalibration — a new archive paradigm

The concept of 'on-the-fly' recalibration means a smaller archive and better quality calibrated products.

Dennis Crabree†, Daniel Durand†, Norman Hill†, Séverin Gaudet† & Benoît Pirenne

The CADC and ST–ECF have together implemented a pipeline which automatically recalibrates data as it is requested from the archive. This process uses the latest recalibration software and the recommended calibration reference files, which may be different than the calibration files used in the original calibration. The service is now available through the World Wide Web.

Background

HST science data are automatically calibrated when they are received at the STScI and are subsequently included in the archive. The calibration software, which is contained in the IRAF/STSDAS hst_calib package, takes as input the raw data and any necessary calibration reference images or tables if they are already available. The software determines which calibration steps to perform by checking the values of the calibration switches in the header. It selects which reference files to use in the calibration by examining the reference file keywords. The values of these switches and keywords depend upon the exact configuration of the instrument, the date of the observation and any other constraints. The values are set in the headers of the raw data in the RSDP (Routine Science Data Pipeline).

Until now, when users requested calibrated data from the HST archive, they received the data produced by the RSDP pipeline. However, instrument properties change with time and better approaches for the calibration of some instruments have been introduced and there have been other general improvements to the HST calibration procedures. So what is a user to do?

Fortunately, the same, or improved, software which runs in the calibration pipeline at STScI is also available in the released version of IRAF/STSDAS. One can recalibrate data from the archive by starting with the raw data, editing the appropriate header keywords to activate the new calibration files and then running the appropriate software. The STScI maintains a database which contains the recommended calibration reference files for each observation. However, this is not the most convenient approach for users and this has led us to develop an automatic recalibration process for HST data which essentially duplicates what a user would do manually.

Automatic recalibration of HST data

In order to offer automatic, quasi-on-line recalibration of HST data, several components need to be in place:

- ❑ the raw science data need to be available on-line
- ❑ the required calibration reference files and tables need to be on-line
- ❑ a pipeline to recalibrate the data needs to be in place.

Unlike the STScI, we do not have the resources to store the large 12 inch optical disks in jukeboxes. The approach we have taken for this recalibration effort is to store the compressed raw data for all science observations on-line on CD-ROM. Using standard 'gzip' compression, the raw data for a typical WFPC 2 observation occupies less than 1 MB. The raw data for all public HST data currently fit on fewer than 70 CDs which are stored in a Pioneer 500 CD jukebox. Data are copied to CD-ROM as they become public at the CADC where a second disk is made for the ST-ECF.

In order for the recalibration to work properly, all of the necessary calibration files and tables need to be on-line. The CADC maintains a directory structure containing all of the necessary files by querying the 'bestref' tables each night to identify the distinct reference files which are needed. By comparing this list to the ones currently on-line, a report is generated of which files need to be installed. Currently, there are approximately 13 GB of reference files on-line. Often a reference file is not available at the CADC, ie, it has not yet been distributed and must be retrieved from STScI using Starview. A process at the ST–ECF copies the reference files regularly over the network from CADC to ensure that both sites have all of the needed reference files on-line.

While there are tasks within IRAF/STSDAS for changing the header keywords associated with recalibration, they must be run manually. We have developed a small IRAF/STSDAS

† Canadian Astronomy Data Centre, Dominion Astrophysical Observatory, Herzberg Institute of Astrophysics, National Research Council of Canada, Victoria, BC

pipeline to automate this process and to perform the complete 'recalibration pipeline'. One of the key steps in this process is a script which queries the database to identify the recommended calibration reference files and tables. The output from this script is a small IRAF script which updates the necessary IRAF parameters needed to update the raw data headers.

The process which occurs when a request is received is the following:

1. the raw data are copied from CD-ROM to a staging area and decompressed
2. an IRAF process is started which runs the recalibration pipeline. This pipeline does the following:
   a. it reads the data into IRAF/STSDAS (converts from FITS to internal format)
   b. runs the script to find out the recommended reference files
   c. updates the raw headers to represent the new calibration information
   d. runs the appropriate calibration pipeline and writes the results back as FITS files
3. copies the recalibrated data to the anonymous ftp area for retrieval.

Our automatic process duplicates what a user would do manually. That is: get the raw data, update the header to reflect the current information on which reference files to use and run the standard calibration pipeline.

Developments in progress

There are several improvements to be made to this system. Some of the possibilities being addressed at the moment are:

- ❑ inclusion of the pipelines for the new instruments (STIS and NICMOS)
- ❑ addition of extra calibration steps for the WFPC2 (like cosmic ray removal, co-addition of frames). This however, entails the need to create the currently unavailable notion of 'products' or groups of observations (see the article in this Newsletter)
- ❑ addition of more 'experimental' calibration steps with eg, improved background treatment (FOS)
- ❑ the instrument physical models now being developed at the ST–ECF for FOS and STIS
- ❑ interactive recalibration for expert users where processing steps can be turned off or on, and user-specified calibration files used.

Other archives have also shown interest in this new archive paradigm and one could imagine the final archive of IUE being operated in this manner with the addition of a physical model of its instrument. The ESO VLT observatory will also consider this approach for its own data archive.

Access to recalibrated data

Although automatic re-calibration does not necessarily guarantee better results than the original pipeline calibration, we expect better results in almost all cases. It is always advisable, however, to carefully examine the results and, when in doubt, to compare both old and new calibration results. We will do our best to keep checking the re-calibration results ourselves but it would understandably be difficult to make an exhaustive examination of all results.

Access to recalibrated HST data is offered though the CADC and ST–ECF Web interface. Typical processing time for a WFPC 2 dataset is 3–5 minutes while for the FOS and HRS it is approximately 1 minute. Users are notified automatically and can monitor the progress of the job.

The relevant URLs are:
http://cadcwww.dao.nrc.ca/hst
and
http://arch-http.hq.eso.org/cgi-bin/wdb/hst/science/form

Recent ST–ECF staff changes

Caulet, Adeline:
Contract ended on 3 March,1997

Dolensky, Markus:
Took up duty on 3 February 1997

Tolstoy, Eline:
ESA External Research Fellow from 1 June 1996

Murtagh, Fionn:
Contract ended on 14 October 1996

Villar-Martin, Montserrat:
DFG studentship ended, Spring 1996

Editorial note (see pages 12,13):

A paper entitled *"The ultracompact HII region G5.97–1.17 — an evaporating circumstellar disk in M8"* by B. Stecklum et al. has been accepted for publication in the Astronomical Journal and is also the subject of a forthcoming ESO press release. This paper makes independent use of the same public archival HST WFPC 2 data illustrated and described on pages 12 and 13 of this Newsletter. The research utilises NIR high-resolution imaging with the ADONIS instrument at ESO in addition to the HST data and it reports the discovery of the M8 proplyd.

IRAF
Image Reduction and Analysis Facility

Mirror of NOAO IRAF Archive now available at ST–ECF

The IRAF system and its layered packages such as STSDAS and PROS are now widely used in Europe and within ESO. When new versions of such packages are required, or documentation about the current ones needs to be consulted, it is normally necessary to contact NOAO in Tucson or access the Web pages there. This typically means that multiple copies of many things cross the Atlantic unnecessarily.

In order to make access to this information easier for local ESO users and European users in general, a 'mirror' of the NOAO IRAF ftp directory tree, including all the Web pages, has been established at the ST–ECF. This mirror is automatically updated each night to keep it identical to the Tucson version. This means that the latest information about IRAF will be available here at the ST–ECF within a day of the changes being made in Tucson and can be accessed directly over fast internal network connections.

The Web pages which contain most of the information of interest to users can be accessed at:

http://ecf.hq.eso.org/iraf/web

The IRAF ftp archive, which contains the software distributions for many platforms and also many layered products, is available at:

http://ecf.hq.eso.org/iraf/ftp

or via anonymous FTP at:

ftp://ecf.hq.eso.org/iraf

Another mirror has already been established at the Rutherford Laboratory in England and been found very useful. We hope that the ST–ECF one will also be of help. I am very grateful for help and encouragement from Mike Fitzpatrick (NOAO) and Dave Terrett (RAL) who did most of the work the first time around when they set up the RAL mirror.

Richard Hook

WFPC 2 data associations

A project at the ST–ECF to group positionally associated WFPC 2 images from the archive.

Paul Bristow, Benoît Pirenne & Alberto Micol

The data reduction procedure required to obtain a final observation from WFPC 2 datasets is an arduous task, particularly so for some archival research projects. The implementation of on-the-fly re-calibration at the ST–ECF and CADC goes some way towards alleviating this problem. The data access paradigm remains, however, to consider each exposure individually, re-calibrate it and then offer the set of results to users for subsequent data processing.

The archive stores each of the files generated by individual exposures (raw data, calibration files, calibrated data, anciliary data) but does not store cosmic ray cleaned or co-added exposures, nor does it currently have the capacity to handle these data. The process of cosmic ray removal can be rather time consuming, requiring the identification of the relevant exposures, application of CR-removal algorithms to only those exposures which are appropriately aligned. Further combination possibly involves complex techniques such as the 'drizzling' of dithered data (see Dickinson & Fosbury 1995, Fruchter & Hook 1996 and the article by Hook & Fruchter in this Newsletter).

Ideally, a more user-friendly situation would be preferred where users can request the 'product' of any given observation. A similar system is currently being prepared for the new HST instruments (NICMOS and STIS) where the ground system will actually produce 'observation products' rather than individual exposures in a semi-finished state as is currently the case.

To tackle this problem and provide a more complete service to archive researchers, the ST–ECF recently started a which project aims to:

- ❑ Group together into 'associations' those WFPC 2 images which form a logical entity. This is the case for perfectly aligned or dithered exposures.
- ❑ Subject these associations to CR-removal using appropriate algorithms such as STSDAS *crrej*.
- ❑ With suitable software, it should be possible to offer automatic co-addition of dithered images.

This scheme is intended to retrofit existing and future WFPC 2 exposures into observation products.

CR rejection and construction of exposure groups

The most straightforward, and therefore most reliably automated, algorithms for CR-rejection perform a comparison of corresponding pixels in several well-aligned exposures. If a pixel from one exposure contains an anomalously high flux then it is disregarded and replaced by a scaled average derived from the other exposure(s). Hence it is essential that the input exposures are very closely aligned to avoid degrading the spatial resolution. Moreover, a small shift in the position of the pixel grid with respect to the centroid of a star may confuse the comparison for the pixels involved.

In principle, one would expect to find many such perfectly aligned exposures in the archive. After all, most observing strategies will implicitly allow for this kind of CR-removal and also dynamic range considerations necessitate multiple exposures of any target (though observers frequently choose to dither these exposures). However, our initial attempts to identify such associations were thwarted by the unreliability of the recorded positional information for many exposures. This stems not from a lack of precision (*relative* offsets can be accurately measured to within a fraction of a PC pixel) but from inconsistently recorded positions, usually for one of the following reasons:

- ❑ A set of consecutive exposures is carried out for a given target and dithering is requested for some of this set. In some cases, exactly the same co-ordinates are recorded in the headers for all of the exposures and no indication as to the dithering offset is recorded.
- ❑ A target is re-acquired at a later epoch for further examinations, the re-acquisition may not be precise, but the recorded co-ordinates reflect the desired position (ie, that of the earlier exposure) not the actual position.

These problems were more frequent early on. Nowadays, the reliability of these parameters has improved. In both cases exposures which should not be grouped together for CR-removal will be if the header information is trusted.

In order to avoid this we have opted to extract the mean *RA* and *Dec* as recorded in the so called 'Jitter' files which contain information concerning HST's pointing and other physical characteristics extracted from the engineering data. We are currently updating the ST–ECF database to incorporate this information.

We are currently investigating the most suitable set of parameters for the *crrej* task, however, the resulting images are not critically dependent upon them. Nevertheless, some users may still prefer to carry out this step for themselves, tweaking the parameters to suit their preference or even using preferred algorithms. Such users will still benefit from the information we will be supplying concerning accurately aligned exposures and may find our CR-removed image useful as a comparison. In most cases though, we expect that our CR-removed images will be sufficient.

Future possibilities

We want only to provide CR-removed images which we are confident will be scientifically useful and reliable, hence the stringent criteria for grouping exposures for CR-removal reflect a conservative approach. However, this means that an observation of a given object remains a collection of CR-removed images with the addition, perhaps, of some individual exposures which could not be grouped for CR-removal. Therefore, we intend to group these images together and present them as observation products. These groups will contain images deliberately dithered relative to one another and those acquired at different epochs. They will come with the jitter position information which will aid subsequent co-addition.

At present we are studying the problem of co-adding these images using various techniques, including drizzling. However, for optimum reconstruction of dithered data (Hook 1995), an interactive approach remains essential. The implementation of an automated 'shift and add' type co-addition remains a possibility but will only be offered where the products can be expected to be of the same standard as achieved by an interactive approach.

References

Dickinson, M. & Fosbury, R.A.E. 1995, ST–ECF Newsletter, 22, 14

Fruchter, A.S. & Hook, R.N., 1996, http://www.stsci.edu/~fruchter/dither

Hook, R. N., 1995, ST–ECF Newsletter, 22, 16

The WFPC 2 exposure time calculator — a retrospective

The WFPC 2 exposure time calculator (ETC for short) has served its purpose well in the past two proposal submission Cycles and is now operated and maintained at the STScI. Here I review its origin and some of the salient features which have made it the model for other exposure time calculators which can be found on the WWW.

Hans-Martin Adorf

The Wide Field and Planetary Camera 2 was the first of HST's science instruments to offer an on-line exposure time calculator accessible on the World Wide Web (WWW). Its development was triggered during 1994 by Mark Johnston, who—then still at the STScI—sensed that the time had come to revive an old idea which had been lying dormant for several years.

Mark was familiar with some work, which had been pursued at the ST–ECF in 1987/88—years before the HST launch—under the umbrella of the so-called 'Artificial Intelligence Pilot Project' (Adorf & Johnston 1987), and to which the history of the present WFPC 2 ETC can be traced. One of the developments at the time was a fully-fledged exposure time calculator (Adorf & di Serego Alighieri 1989a, b) for all first generation science instruments on-board HST (ie, WF/PC, FOC, GHRS, FOS, and HSP). This tool had been used at the ST–ECF to aid astronomers in the first proposal Cycle.

This first-generation ETC was designed according to quite advanced software engineering principles which can still be called 'modern' by today's standards. No paper manual should be required for using the software; instead a self-explanatory graphical (WIMP) user interface was offered along with an on-line help facility using 'hypertext'—a word virtually unknown at the time within the astronomical community.

Using the characteristics of the object, the background and the chosen instrument as a generic input, the first-generation ETCs allowed the estimation of the exposure time from a given signal-to-noise ratio, and vice versa. Underlying this ETC was a simplified instrument database derived from HST's Calibration Database System (CDBS). The exposure time and signal-to-noise algorithms for the original ETC were devised by Sperello di Serego Alighieri (di Serego Alighieri & Adorf 1988).

While the first-generation ETC software was conceived without prior exposure to spreadsheets, it implemented the important concept of data-driven 'forward-chaining' (which is lurking behind the scenes in the automatic update-mechanism of every spreadsheet). The computational dependencies are explicitly recorded, and the result—typically the exposure time—is updated in near real-time, whenever any of the input values (eg, filter, star brightness, etc.) changes.

The major disadvantage of the original ETC implementation, severely restricting its wider use, was that the software only executed on dedicated LISP workstations, of which the ST–ECF had one and the STScI had several.

Software technology

The first-generation ETCs were implemented in Common Lisp and used some non-standard graphics extensions. (Recall that no universally accepted graphics standards existed at the time, neither within the Lisp community, nor outside.) In addition, KEE-rules (KEE = Knowledge Engineering Environment) were used for data-driven 'forward-chaining' leading to the near-real time updating of the result, as explained above.

In the six years from 1988 to 1994, when the idea of an ETC was revived for WFPC 2 (then a new HST instrument), software and hardware technology had advanced significantly, particularly in the area of graphical screens and networks. When the original suite of ETCs was implemented, they excecuted on one of ESO's first workstations equipped with a full-scale graphics screen. By 1994, however, workstations with graphics screens were abundant at ESO as elsewhere in astronomy. The astronomical community had also moved away from DEC VAXes and the DECnet based SPAN network towards UNIX workstations and to the universally accepted TCP/IP-based Internet. The concept of client-server computing was becoming widely accepted.

Not least in importance, the WWW was about to bury several costly user interfaces, such as that of STARCAT developed by the ST–ECF, that of ADS developed by NASA, and that of STARVIEW, developed at the STScI. The question naturally arose of how to revive the ETC, considering the enormous changes in the software environments now common in the astronomical community.

Using the instrument models

At some stage, consideration was given to using the fully-fledged SYNPHOT instrument model software as the back-end compute engine of the WFPC 2 ETC. In the end, however, it turned out to be too complicated and to require too much co-ordination within too limited a time period. While SYNPHOT was not excluded as a long-term solution, the quick fix required for Cycle 6 effectively ruled it out.

Implementation language

During the design phase in 1994 it was contemplated to revive the ETC in Lisp, which is such a beautiful, well-engineered language and so much fun to work with. This choice was not so completely out of the question as it may appear, since there are now robust commercial Lisp interpreters/compilers for UNIX-workstations and , using an Internet-based client-server approach, the compute engine could reside on the server machine, together with the simplified instrument and object databases. Only the user-interface had to be exported to the client machine at the user's institution.

The major drawback of the Lisp-approach appeared to be the long start-up time required before a Lisp-based server process becomes fully operational upon request by a remote client. Thus, in the end, a decision was made to re-implement the compute engine in Tcl which, apart from its LISP-likeness, is one of the most prominent languages for WWW CGI-bin scripts, but with a less arcane syntax than Perl.

User interface

Having chosen the implementation language for the compute engine, a decision still had to be made concerning the user-interface (UIF). Two choices were contemplated. One was to establish a dedicated UIF using the Toolkit language 'Tk'. This clearly had the advantage of allowing the implementation of a completely unconstrained UIF. However, the potential user would always have first to download the current UIF code before being able to run the ETC.

The other option was to base the UIF on HTML and so be ready for use via the WWW. Since the user interactions with the ETC's UIF were not too complicated, the options offered by an HTML-based UIF appeared to be marginally sufficient. Such an implementation had the advantage

that the current UIF code would be downloadable transparently from the server by simply clicking on the link (the URL) pointing to the ETC compute engine on the server. In the end, the reasons favouring the latter solution outweighed the concerns that it might be too inflexible and the decision was taken to go with an HTML-based UIF to be interfaced to the Tcl-based compute engine.

While a single UIF or 'spreadsheet', usable for both point sources and extended sources, would have had some virtues, the desire for reducing the apparent complexity to the user combined with the restrictions of the HTML implementation language enforced a split into two. (At the STScI the split was later carried further when four such 'spreadsheets' were created by adding two which included a stellar background.)

The algorithms

For the second generation WFPC 2 ETC, support was sought from the STScI, and delivered by Anatoly Suchkov, who at the time was working in the WFPC 2 instrument team. Anatoly's algorithms were based on those originally devised by Sperello, but enhanced at various points.

Implementation

After the algorithm design was completed, the implementation languages chosen and the go-ahead given by ST–ECF and the STScI management for the second-generation version, the actual coding could proceed, and the initial version was finished within about two days.

Subsequently, the software was successfully exported to the STScI where it was welcomed by John Biretta from the WFPC 2 team who quickly familiarised himself with the code and started incorporating substantial enhancements.

A few bugs were weeded out, some features added, and the results checked against SYNPHOT. The modified code was eventually returned to the ST–ECF. Thus, the WFPC 2 ETC was put into operation on both sides of the Atlantic just in time for the Cycle 6 proposal deadline in 1995.

Usage

The acceptance of the ETC by proposers was overwhelming. The log-records showed that the ETC was invoked 300 times per week, apparently without overloading system resources, totalling around 12,000 calculations during the weeks immediately preceding the 1995 proposal deadline. (Actually, the many requests occasionally caused an overflow in the system log, which therefore had to be deleted daily.)

The use of the WFPC-2 ETC was quoted in many proposals. One of the most missed features was the batch-processing capability which was actually implemented and available to local users at the ST–ECF and the STScI but, due to the restrictions of the HTML-based UIF, was not offered to remote users. Some people wanted to import the whole ETC to their home machines. A questionnaire was sent out by the STScI to sample user opinions more systematically.

Conclusion

After its early experimental evolution, the WFPC-2 ETC eventually came to life in 1995 largely due to the foresight and persistent encouragement of Mark Johnston. Since then the ETC has served as a forerunner for other exposure time calculators, such as those for STIS and NICMOS on HST and the ESO SUSI imager.

For us at the ST–ECF, it was possible to quickly recognise the power and potential of the WWW which the ST–ECF had started using already in 1993 (Adorf 1994). This was due in part to our experience with the 'Artificial Intelligence Pilot Project', advanced user-interface technology, data-driven forward-chaining feature and hypertext help system. For the same reason we were able to quickly realise the virtues of a simple exposure time calculator accessible via the WWW and, having had prior experience of all the above techniques, could offer it in a timely fashion.

In addition to HST's long-term scheduler called SPIKE, which was partially implemented while Mark Johnston was visiting the ST–ECF on leave from the STScI, the 'AI Pilot Project' had the effect of spawning the current generation of ETCs.

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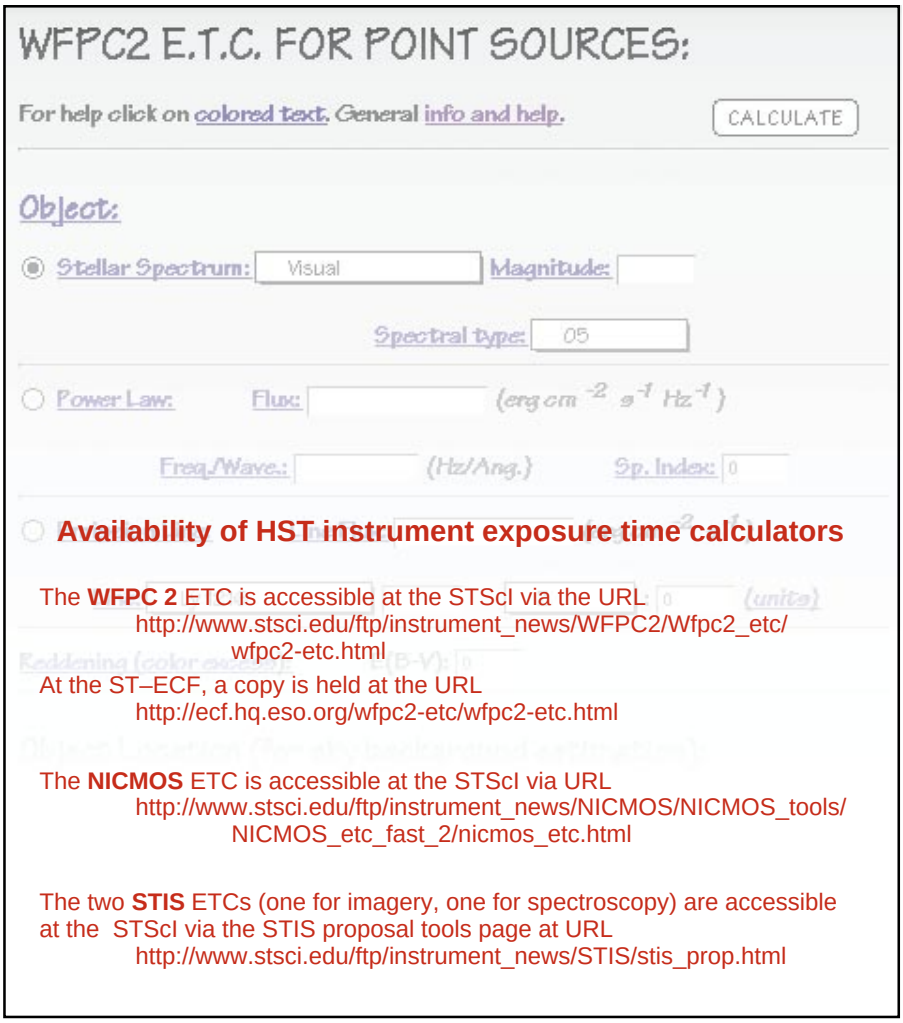

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Cover picture: Shorly before liftoff on the morning of the 11th February for the second Hubble Space Telescope servicing mission, Discovery — with two new instruments, a new fine guidance sensor and various other pieces of harware aboard — is illuminated by floodlights on pad 39A at the Kennedy Space Center in Florida.

Below: NASA photograph of liftoff. The same event, seen by the editor from 3.5 miles, is shown on page 2. It must be assumed that NASA employs a braver photographer!

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.

Contacts at ST–ECF

Head: P. Benvenuti
Tel. +49–89–320 06 290
Computer: PBENVENU

Science Data and Software: R. Albrecht
Tel. +49–89–320 06 287
Computer: RALBRECH

Science Instrument Information: R.A.E. Fosbury
Tel. +49–89–320 06 235
Computer: RFOSBURY

Computer hot-line and information
Hot-line: stdesk@eso.org (for e-mail)
WWW: http://ecf.hq.eso.org/

Editor: Robert Fosbury
Sub-editor: Jeremy Walsh
Editorial assistant: Britt Sjöberg
Production: Robert Fosbury

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Space Telescope–European Coordinating Facility
European Southern Observatory
Karl-Schwarzschild-Str. 2
D–85748 Garching bei München
Germany
Telephone: +49–89–320 06 291
Telefax: +49–89–320 06 480
Internet: <user>@eso.org

esa SPACE TELESCOPE
ESO
European Coordinating Facility