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HST Data Handbook for WFPC2

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Preface

Introduction to Reducing HST Data

This data handbook provides an introduction to the process of retrieving and reducing Hubble Space Telescope (HST) data. The reduction procedures, calibrations, and sources of error specific to each active HST instrument (WFPC2, STIS, NICMOS and ACS) are explained in detail in their respective instrument data handbooks. However, we recommend a careful reading of this handbook before proceeding to the instrument data handbooks and before starting to work on your HST data. The present document is an updated version of chapters 1-3 of the HST Data Handbook, v.3.0, and is based on the information available as of December 2001. In particular, it is written under the assumption that the ACS and NICMOS instruments will be fully functional following HST Servicing Mission 3B (SM3B).

Many changes in the HST Data Archive and HST data reduction software have occurred since v. 3.0 of the Hubble Data Handbook. These differences are covered in this document and include, but are not limited to:

1. Expansion of the HST Data Archive into the Multimission Archive at Space Telescope (MAST), which currently includes 14 satellite mission archives as well as ground-based survey data.
2. The ability to retrieve MAST data using the World Wide Web.
3. New capabilities of the StarView program for searching for and retrieving HST and other MAST data.
4. The introduction of PyRAF, a new Python-based alternative to the IRAF cl shell, and
5. A new distinction between waiver FITS format, used to archive data from the older HST instruments such as WFPC and FOS, and the FITS extension format used for the newest instruments (STIS, NICMOS and ACS).

Future changes in this handbook are anticipated as MAST expands to cover additional missions, and as StarView and PyRAF evolve. The reader is advised to consult the STScI web site at http://resources.stsci.edu for the latest information. Moreover, as the present revision comes before SM3B, important revisions to the ACS file structure and data handling may be necessary after the installation of this instrument.

Bahram Mobasher (Chief Editor, HST Data Handbook)
Michael Corbin (Editor, Chapter 1)
Jin-chung Hsu (Editor, Chapters 2 and 3)

PART I:

Introduction to Reducing HST Data

The chapters in this part provides an introduction to the process of retrieving and reducing Hubble Space Telescope (HST) data.

CHAPTER 1:

Getting HST Data

In this chapter. . .

This chapter describes how to obtain Hubble Space Telescope (HST) data files. All HST data files are stored in the Hubble Data Archive (HDA), which forms part of the Multimission Archive at STScI (MAST)[1]. HST Guaranteed Time Observers (GTOs), Guest Observers (GOs) and Archival Researchers can retrieve data in either of two ways:

- Electronically over the Internet from the HDA, where data are stored immediately after they pass through HST pipeline processing.
- On data storage media written at STScI from the HDA. The options are Exabyte and DAT tapes, and will include CDs and DVDs in the future.

To retrieve data electronically you must first register as a MAST user[2]. HST Principal Investigators (PIs) are ***not*** automatically registered. If you have not recently retrieved data, you should register or renew your registration before retrieving data from the HDA. PIs should register before their observations are made. GTO and GO observations normally remain proprietary for a period of one year, which means that during this period

1. MAST currently includes data from HST, FUSE, IUE, EUVE, ASTRO, HUT, UIT, WUPPE, ORFEUS, BEFS, IMAPS, TUES, Copernicus and ROSAT. Data from the FIRST radio survey, Digital Sky Survey (DSS) and Sloan Digital Sky Survey (SDSS) are also available.

2. By 2002, registration will no longer be required for public (non-proprietary) data.

other registered users cannot retrieve them without authorization from the PI. All calibration observations as well as observations made as part of the Public Parallel programs are immediately public. All observations made as part of the Treasury Programs begun in Cycle 11 will either be immediately public or have only a brief proprietary period. The HST section of MAST also contains several Prepared (fully reduced) data sets, including the Hubble Deep Fields, the Hubble Medium Deep Survey Fields, and a composite quasar spectrum, which are also public.

This chapter describes how to search the HDA, how to electronically retrieve files from it, and how to request and read tapes and disks containing HST data. As an aid to retrieving their data, PIs will automatically receive e-mail notification of the status of their observations two times: first, when the first datasets for their proposal are archived, and second, when all the datasets for their proposal and all necessary calibration files have been archived.

Note for Advanced Camera for Surveys (ACS) Users: Calibrated ACS images are approximately 168 MB in size, larger than those of any other HST instrument. Therefore, electronic retrieval of ACS data is enabled only for those with broadband (> 100 KB/s) Internet connections, in order to ensure uninterrupted transmission of individual files. Users retrieving large numbers of ACS files should also consider requesting them on tape or disk.

1.1 Archive Overview

The HDA contains all HST observations ever made. It also contains a database that catalogs and describes these observations. There are currently two ways to search and retrieve data from the HDA. The first is a program called StarView, which acts as an interface to the HDA. StarView currently runs as Java-based, stand-alone application that can be downloaded from the web site http://starview.stsci.edu. Previous versions of StarView, such as XStarView, are no longer available. The second search and retrieval method is through the HST section of the MAST web site, http://archive.stsci.edu. StarView is the more powerful of the two methods, and in particular allows an examination of the calibration files applied to a given data file. StarView also provides an interface to the Visual Target Tool (VTT) in the Astronomer's Proposal Tool (APT) suite of programs. The VTT interface can display archive observations on a Digital Sky Survey (DSS) image alongside planned observations. StarView is thus recommended for observation planning, duplication checking, calibration file review, investigation of On-The-Fly Reprocessing flags and proprietary status. It is also recommended for those needing to retrieve large numbers of datasets, and those needing to examine calibration files. The MAST web site interface to the HDA has the same basic capabilities as StarView, and may be preferable for those requiring simple retrievals of datasets. Both StarView and the MAST web site allow simultaneous searches of the other MAST mission archives for all HDA searches. They also offer simple preview of the capabilities of HST datasets when available, as well as links to literature references citing a given dataset, using the Astrophysics Data System (ADS). In later sections we discuss StarView and the MAST web site in more detail.

1.1.1 Archive Registration

The simplest way to register and retrieve HST data is to complete the form on the Web page at: http://archive.stsci.edu/registration.html.

Registration requests may also be sent to the HDA hotseat, at: archive@stsci.edu.

The PI of each HST proposal must request proprietary access for their data, and for anyone else whom the PI wants to have access to it. PI retrieval permission is not granted automatically, for security reasons. PIs wishing to allow others access to their proprietary data should make that request to archive@stsci.edu.

When registration is granted, your account will be activated within two working days, and you will receive your username and password via e-mail.

1.1.2 Archive Documentation and Help

The MAST web site provides a wealth of useful information, including an online version of the HST Archive Manual available at http://archive.stsci.edu/hst/manual/. Investigators expecting to work regularly with HST and other datasets supported by MAST should also subscribe to the MAST electronic newsletter by sending an e-mail to archive_news-request@stsci.edu and putting the single word *subscribe* in the body of the message. Questions about the HDA can be directed to archive@stsci.edu, or by phone to (410) 338-4547.

1.2 Getting Data with StarView

1.2.1 Downloading and Setting Up StarView

The latest version of StarView runs under versions 1.2.2 and later of Java and may be downloaded from http://starview.stsci.edu.

This site also includes a FAQ page and news on releases and updates. StarView will automatically update itself to the latest version, so users do not have to worry about additional installations. Following its installation on computers running Unix and Linux, begin StarView by typing

```
> StarView
```

at the system prompt. Under Windows and MacIntosh systems, StarView will appear as an icon. The StarView session then begins, first with an Information window explaining navigation within StarView, and a request for the user to specify an object name resolver (SIMBAD or NED) for use in HDA searches. The first-time user are asked to supply their e-mail information in order to allow StarView to communicate the results of its attempts to retrieve the files requested from the HDA. This e-mail information includes the user's SMTP host, or the computer from which e-mail messages are routed. If unsure of your SMTP host, ask your system administrator. These queries can be turned off for future sessions once this information has been supplied.

1.2.2 Simple Use of StarView

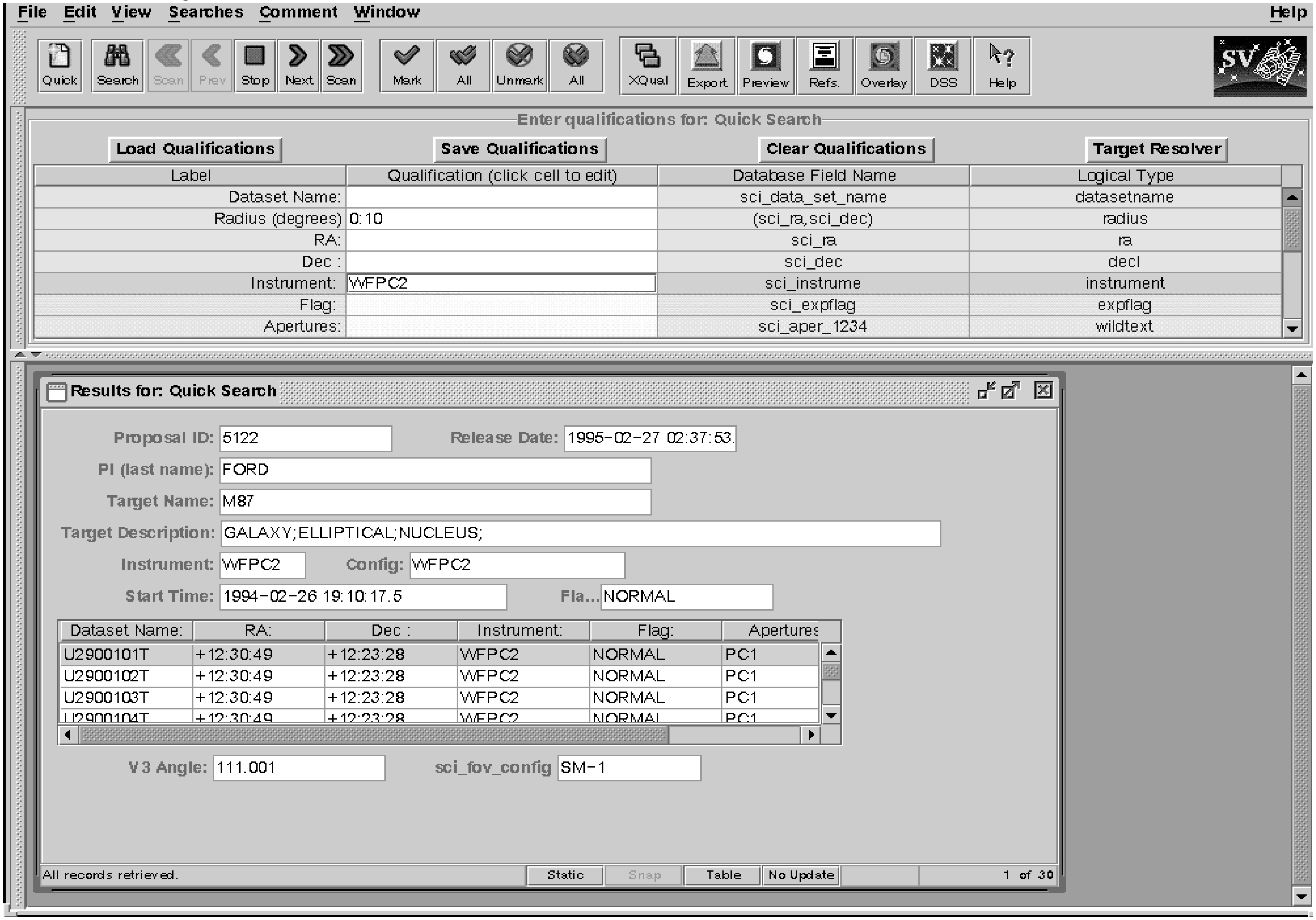
We now proceed to an introduction to the use of StarView. A more detailed description of its capabilities is provided at the web site above, which should also be consulted for more advanced topics such as its Table Exportation and Cross-Qualification functions.

The basic function of StarView is to enable the user to first search the HDA (and the other mission archives in MAST) for data files matching criteria such as object name, position, or proposal number, then allow the user to navigate through the set of files matching those criteria, and finally to let the user retrieve some or all of the files found in the search. Several options for the type of search that can be performed (e.g. by a particular instrument) will be discussed later.

The design of StarView is similar to that of a Web browser. At its top are pull-down menu bars including File, Searches, and Help. The Help menu offers links to documents including the StarView FAQ page. Beneath these menu bars is a row of buttons that run StarView's basic functions, such as searching, marking files for retrieval, and previewing images. A Help button allows users to display pop-up windows describing the function of the different StarView buttons and windows, by first clicking the Help button, then the item of interest. Beneath the row of buttons is the Qualifications table, which is displayed when a search is begun. It consists of several cells corresponding to the search parameters the user wishes to use, e.g., object name, proposal I.D., or instrument. Below this window will appear the Results table, displaying the datasets found to match a given set of search parameters entered into the Qualifications table. For the purpose of introduction, we will describe the use of the most basic search option, called "Quick Search," which can be started by clicking the "Quick" button at the top left of StarView.

As an example of the use of the Quick Search option, we will request all available WFPC2 data for the galaxy M87. This is done by typing "WFPC2" and "M87" in the Instrument and Target Name cells of the Qualifications section, then clicking the "Search" button at the top left of the StarView window. The results of the search will then be displayed in the bottom panel of StarView, as shown in figure 1.1. These results include the dataset name, instrument name, R.A. and Dec of the target, and the instrument aperture used. Note that these parameters could also have been specified in the Qualifications section, as can other parameters including proposal I.D. number, proposal P.I. name, and image central wavelength (corresponding to particular instrument filters or gratings).

Figure 1.1: Results of StarView Quick Search for WFPC2 files of M87

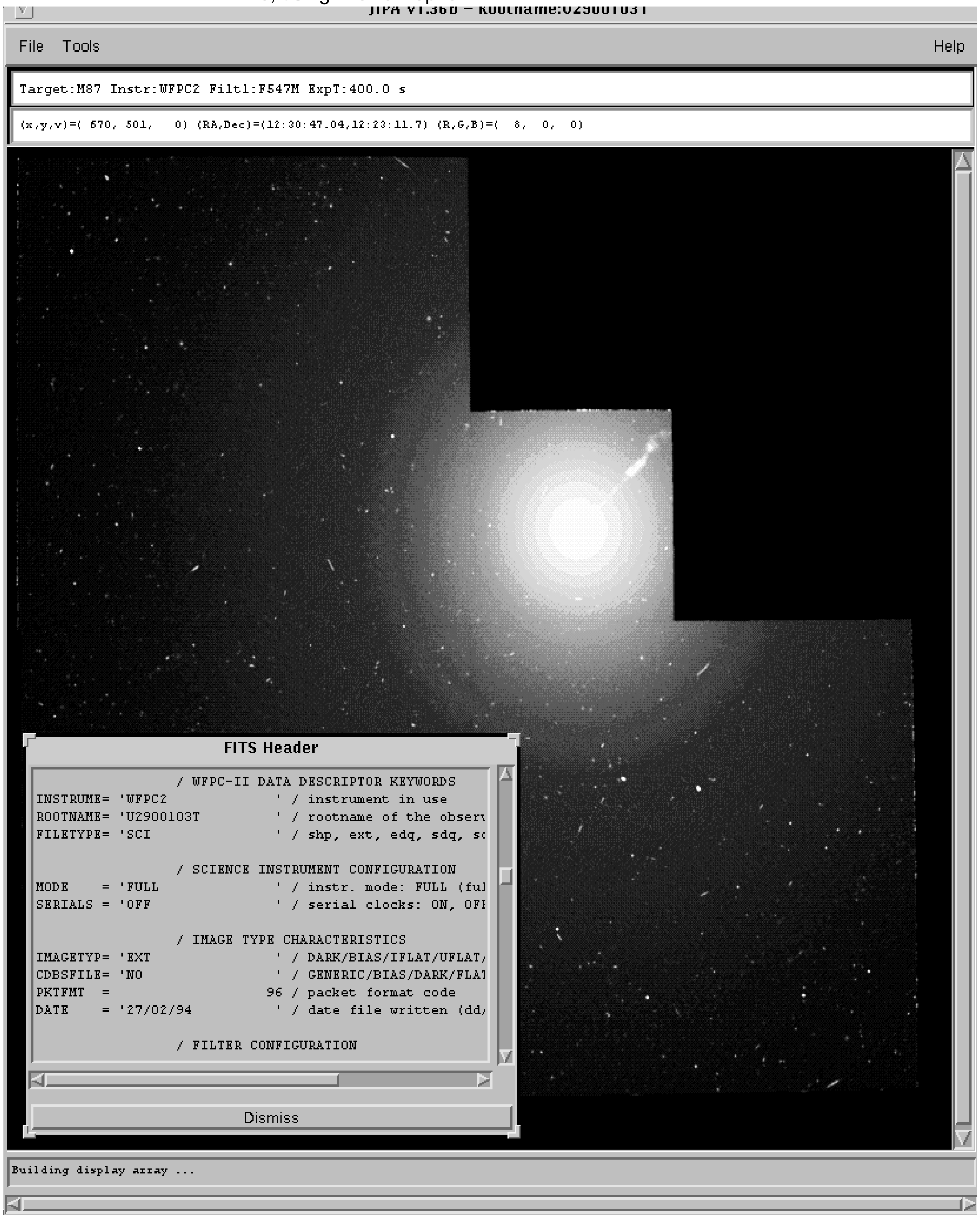


Clicking on a given dataset in the Results table will display the information shown in the cells above it (Proposal ID, Release Date, P.I., etc.). You may browse through the retrieved datasets either by using the mouse and scroll bar, or by using the navigation buttons (Scan, Previous, Next) in the top row of mouse buttons. The Scan option will automatically step through all of the files retrieved in the search, provided that the right most button at the bottom of the Results window is toggled to “Update.” If this button is toggled to “No Update,” the Scan option will go straight to the end of the list of files.

The ability to obtain a preview is available for many, but not all, of the datasets in the HDA (e.g., previews are not available for many FOC datasets). This is done with the “Preview” button, if it is enabled. For images, this will display a re-sampled version of the image using the Java Image Preview Application (JIPA) tool that is part of StarView. For spectra, a simple GIF image of the calibrated spectrum will be displayed. JIPA and VTT can also display an image's FITS header, under the JIPA “Tools” menu. The JIPA preview of the WFPC2 image U2900103T retrieved in the previous search for WFPC2 images of M87 is shown in figure 1.2, along with the window displaying part of the FITS header file of this image.

Other display options with StarView include “DSS,” which will display a 20' x 20' Digital Sky Survey image at the target coordinates, while the “Overlay” button will display the same DSS image with outlines of the HST instrument apertures at the target coordinates superimposed on it, at the orientation of the observation selected. The “References” button provides a link to any known published papers citing the dataset, as listed in ADS. Note that the HST images displayed by the Preview are of reduced quality compared to the actual data files, and cannot be downloaded. They are only meant to provide a quick check that the datasets found by the search met the search criteria, i.e., contained the object(s) of interest, and are of the desired quality.

Figure 1.2: JIPA preview of WFPC2 image U2900103T, along with image header file, using Preview option



1.2.3 Marking and Retrieving Data with StarView

Datasets are marked for retrieval by first clicking on them, then using the "Mark" button at the top of StarView. There is also the "All" button, which will mark all the datasets retrieved in the search. Marked datasets will be displayed in the Retrieval window. Datasets still within their proprietary period will be displayed in yellow, and users other than the proposal PI and those authorized by the PI will not able to retrieve them. The release date of files still within their proprietary period will also be indicated on the search results form.

If satisfied with the marked datasets, choose "Submit" in the Retrieval window to retrieve them. You will then be queried for both the type of data files associated with the dataset(s) to be retrieved, and for the method of delivery of these files. The options for type of file include files calibrated with the On-The-Fly-Recalibration (OTFR) pipeline for the WFPC2, NICMOS, STIS and ACS instruments. OTFR applies the best available calibration files (i.e., dark current and flat field images taken closest in time to the observations) to the uncalibrated data files. You may also request the uncalibrated (raw) files and calibration files separately. For some of the earlier instruments, e.g., WFPC and FOS, you may request both the calibration files actually applied to the images, as well as those that should provide the best calibration of them, if recalibration is desired. You may also request Data Quality and Observation Log files.

Options for data delivery include ftp transfer by the user from the HDA staging disk, automatic transfer from the HDA via the Internet to a directory specified by the user, and the mailing of tapes or disks. If Internet delivery is specified, you will be queried for the name of the computer and directory in which the files are to be placed, as well as your user name and password on that computer (these requests are encrypted, so there is no danger of your login information being stolen). Upon final submission of the request, you will receive an e-mail message acknowledging its receipt, and another message after all the requested files have been transferred. The status of the request, i.e., how many files have been transferred and any errors that have occurred, can be checked on a Web page that will be given in the acknowledgment message.

1.2.4 Using StarView to Retrieve Calibration Files and Proposal Information

StarView allows several additional types of searches of the HDA besides the Quick Search option described above. These can be selected from the Searches menu bar at the top of the StarView screen. One such search option is by instrument. This is necessary for identifying calibration reference files. As an example, selecting the option "WFPC2 OTFR" under the Instrument and WFPC2 sub-menus of the Searches menu, and then entering "M87" under Target Name in the qualifications box, brings up the screen shown in figure 1.3. This screen shows all the calibration images and files applied by OTFR to the first file in the set of WFPC2 images of M87, as well as whether the application of these files was performed or omitted in the calibration pipeline. This is the same set of images found by the Quick Search query described above, and the same information for the other datasets from this search can be found using the Previous, Next and Scan buttons. Once these calibration images have been identified, further information on them can be obtained. For example, taking the name of the flat field file found in the above search and entering it into the "WFPC2 Calibration Data" Searches option will retrieve information on when and where this file was taken, and the date after which its use is recommended. This will help users decide if they would prefer to recalibrate their data using different files.

StarView can also be used to search for and view the abstracts of accepted HST proposals. Like the Preview capability of StarView, this provides additional information about a given dataset and whether it may be useful for your science goals. Viewing proposal abstracts is an option under the Searches menu, and an example is shown in figure 1.4. The Qualifications window again offers several parameters by which this search can be constrained, including proposal I.D. number, HST cycle, P.I. name, and combinations thereof. In the example shown only the proposal I.D. number was used.

Finally, StarView can be used during the Phase I proposal process to see whether or not HST observations of a given object or object class have already been made, or else are scheduled for execution. Specifically, the Duplications option under the Searches menu allows users to check a database containing both HDA files and a list of queued observations in order to see if a given object has been or will be observed. Similarly, under Duplications the user may also query the database of proposal abstracts for a given object or object class, to check for archived or scheduled observations.

1.2.5 Advanced Features of StarView

In addition to its basic search and retrieval function, StarView allows users to cross-qualify results from separate searches of the HDA, and to export the results of searches to disk as ASCII files. These operations are performed with the "XQual" and "Export" buttons, respectively. As an example of cross-qualification, a user might want to identify all the spiral galaxies for which both WFPC2 images and STIS spectra have been obtained. This could be accomplished with the Cross-Qualification feature by first doing two separate Quick Searches, in which these respective instruments are specified in the query box, and in which "Galaxy;Spiral" is typed in the Target Description box for both searches. Clicking the XQual button, specifying "Target Name" as the common field in the two sets of search results (as shown in figure 1.5), and clicking the "X-Qualify" button then identifies the galaxies occurring in both lists. StarView then places these galaxy names in the Target Name box of a new Quick Search window. Clicking the Search button with "WFPC2,STIS" entered for Instrument then gives a list of all the WFPC2 and STIS datasets for these galaxies. The Cross-Qualification function can also be performed on the files produced by the Export feature.

Figure 1.3: Results of StarView search for WFPC2 OTFR calibration files for M87

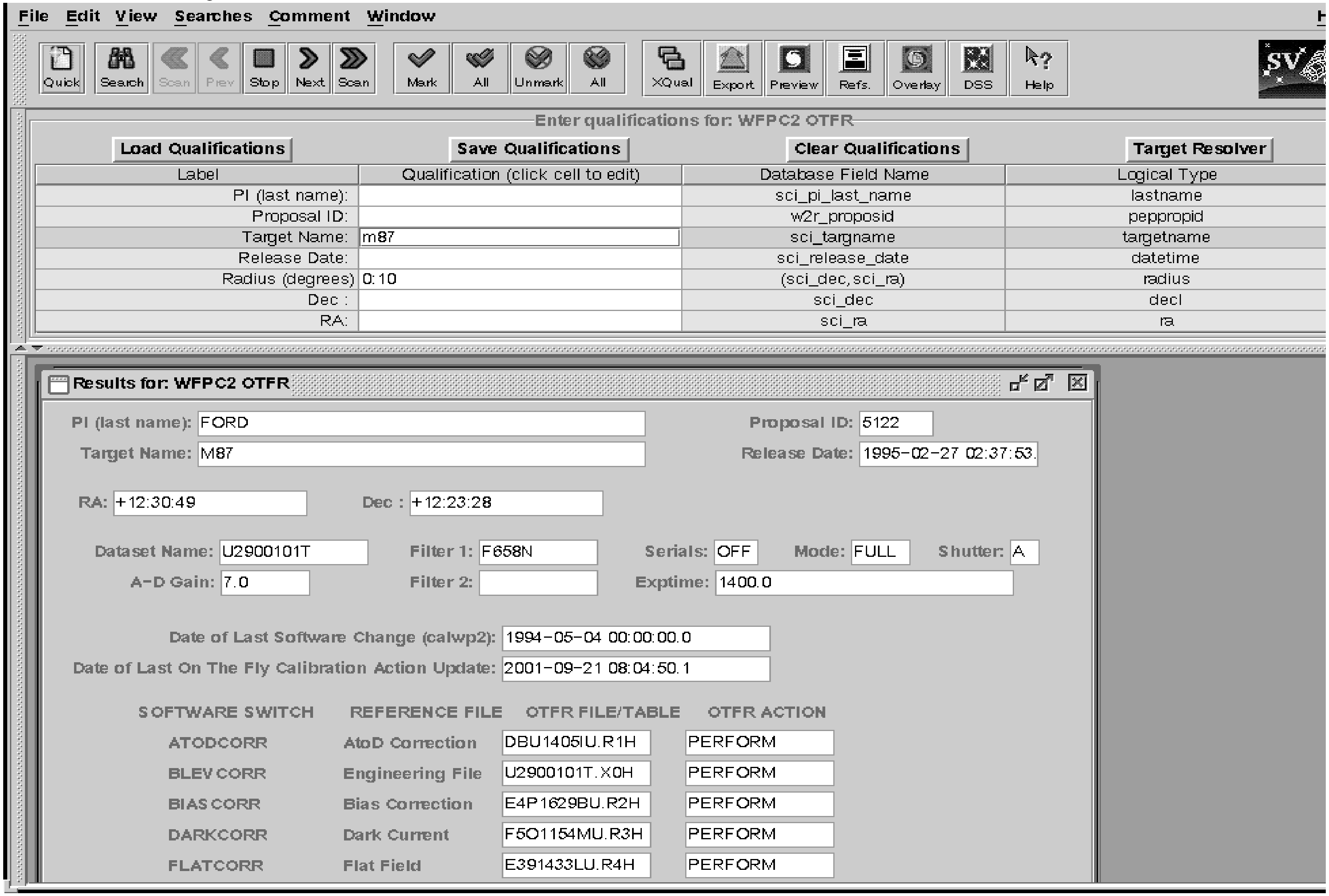


Figure 1.4: Results of the StarView search for the abstract of Proposal 8725

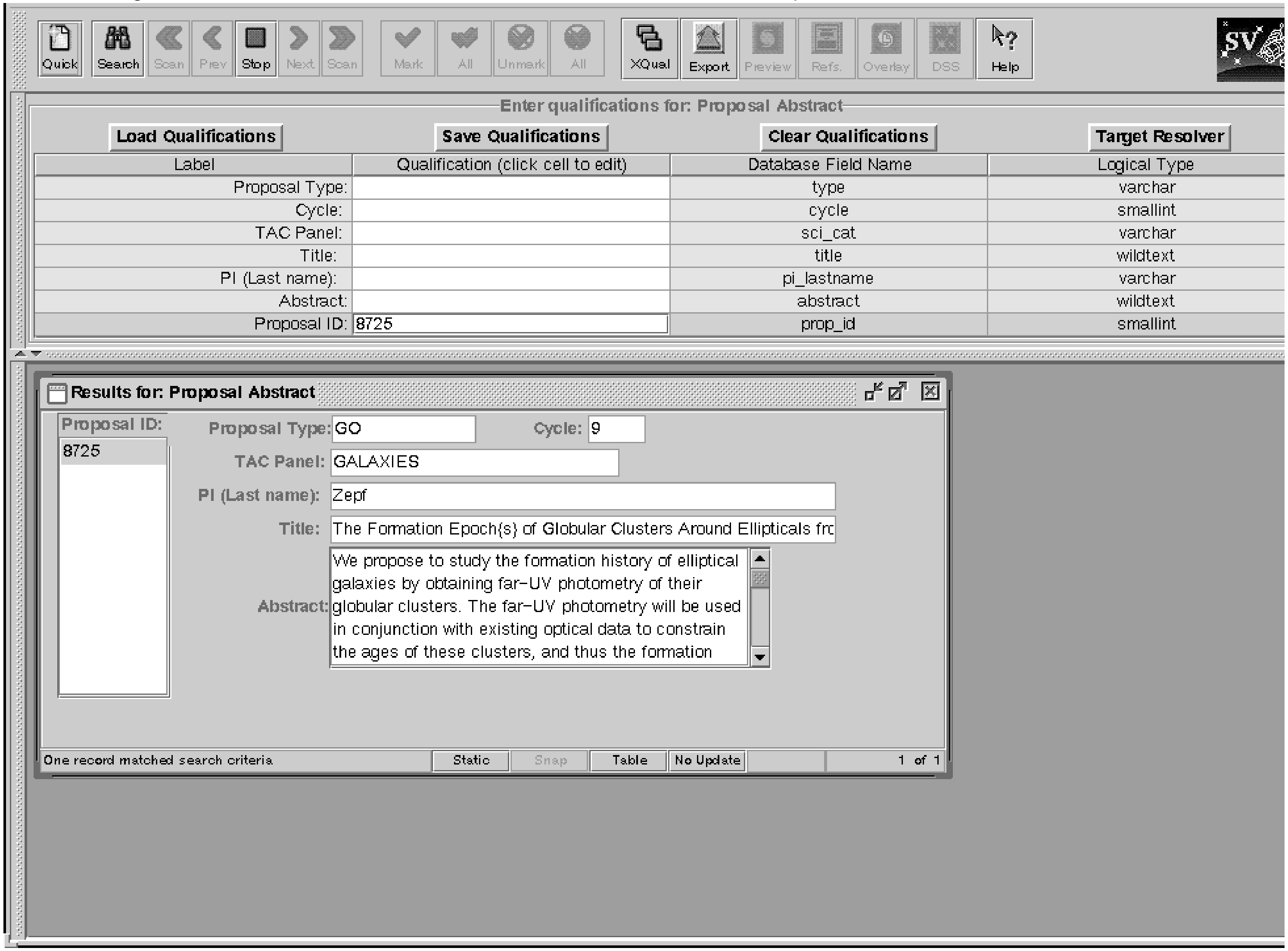
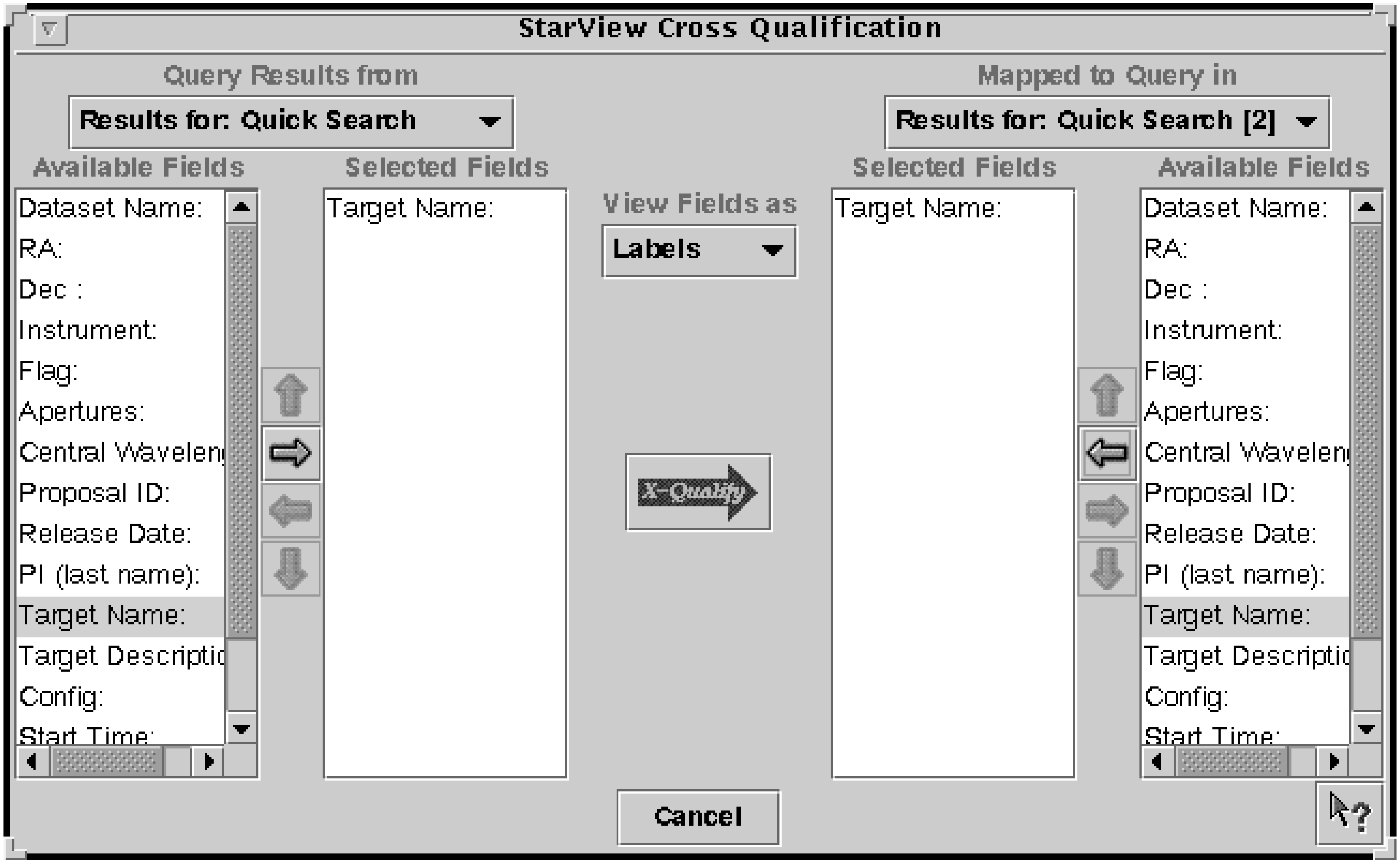


Figure 1.5: Example of Cross Correlation Feature, in which Target Name has been chosen as the common feature to search for in two Quick Search result lists.



1.2.6 StarView and the Visual Target Tuner

The Visual Target Tuner (VTT) is part of the Astronomer's Proposal Tool (APT) package, which has been created to aid astronomers in planning their HST observations during the Phase I and Phase II proposal stages (see http://apt.stsci.edu). VTT is an image display tool which allows the user to display DSS images or local FITS images with proper World Coordinate System keywords in the headers. It offers more features than JIPA, which is the default StarView display tool. However, for a limited number of operating systems, the VTT can be used with StarView. VTT offers the particular advantage that it can overlay the instrument apertures of multiple observations on a single DSS image. Clicking on these apertures will also highlight the associated datasets in StarView.

Currently, to combine StarView and VTT requires downloading and installing APT from the above Web site. APT is only available for those operating systems with the Java Virtual Machine 1.3 (JVM 1.3). You can download the StarView/VTT package with JVM 1.3 included (a large download), or if you already have JVM 1.3 installed, you can get the smaller APT/VTT package. To make StarView use VTT, you must change your Viewer options from JIPA to VTT. Go to the Environment sub-menu of Edit in StarView, and change JIPA to VTT in the Viewers section. If VTT is not listed here, you should reinstall the two programs. Following this change, the Preview, DSS and Overlay buttons of StarView should all bring up VTT.

Once VTT has been installed, you can also bring up StarView from it. Enter in to StarView mode by clicking on the StarView button in the lower left hand menu of VTT. Clicking on a DSS image will then spawn a Quick StarView screen with the R.A. and Dec of the position you clicked loaded into the search fields. You can enter other constraints into these fields as usual. Search results can be displayed on the VTT screen by selecting the results in StarView, and pressing the Overlay button.

1.2.7 Quick Data Retrieval with StarView

The following steps summarize the basic process that PIs need to go through to retrieve their data with StarView. These steps follow registration as a MAST user, notification from STScI that the observations for a given proposal are complete, and providing StarView with your e-mail information. They are intended as a quick reference for this process.

1. Start StarView.
2. Click the “Quick” button.
3. Enter your PI name and/or proposal ID number in the appropriate cell.
4. Click the “Search” button.

5. Use the “Scan” button to step through the retrieved files, after toggling the right most button at the bottom of the Results window to “Update,” to verify that all datasets have been retrieved.
6. Preview some or all of the datasets if desired, to verify data quality and target acquisition.
7. Click “All” to mark all datasets for retrieval, or “Mark” to mark individual datasets for retrieval.
8. Click “Submit” in the window that will be spawned by marking the files.
9. Enter your MAST username and password and specify the means of data delivery. StarView remembers your name and password from past searches so it does not have to be entered each time.
10. Click “Done”, and your data are on their way. You will receive an e-mail message when your retrieval has been queued, and another when the transfer is complete.

1.3 Getting Data With the World Wide Web

HDA datasets can be searched for, previewed and retrieved via the World Wide Web in very much the same way as with StarView. As noted in section 1.1, StarView offers more capabilities for this process, including cross-qualification, the use of VTT, and more information about instrument calibration files. However, Web retrievals may be preferable in some cases, particularly when information on calibration files is not needed, and the hypertext on the Results pages makes it easy to access all the information they contain. The starting point for Web-based searches of the HDA is the MAST web site at: http://archive.stsci.edu[3]

This web page is shown in figure 1.6. A powerful feature of MAST is that all of its mission archives, including the HDA, can be searched simultaneously. This is done with the Cross-Correlation Target Search option shown on the MAST home page. This search will return all datasets for all missions available for a given object or coordinates, according to the search constraints specified by the user (based on the wavelength region of interest), and will provide hypertext links to these datasets. If only HST datasets are desired, they can be accessed separately by clicking “HST” on the MAST home page.

3. European archive users should generally use the ST-ECF Archive at http://archive.eso.org. Canadian users should request public archival data through the CADC web site at http://cadcwww.dao.nrc.ca. Proprietary data are only available through STScI.

The HST section of MAST offers tutorials about the HDA as well as a FAQ page and HDA news. It also provides links to HST Prepared datasets such as the Hubble Deep Field images. Clicking on the “Main Search Form” option of the HST section brings up the page shown in figure 1.7. Here the user is queried for the same search parameters as requested by StarView, e.g., Object Name, Instrument and Proposal I.D. Once these are entered, clicking the Search button returns a page listing the datasets found, which can then be selectively marked for retrieval. The data type and retrieval options remain the same as those for StarView. Previews of GIF files of the datasets are also available.

1.4 Reading HST Data Tapes and Disks

If you request HDA files on tapes or disks, you will receive them within a few weeks of your request. The tapes will contain **tar** files containing the requested datasets. The datasets will all be in FITS (Flexible Image Transport System) format[4]. You should thus first create a directory where you want your data to reside, e.g., /home/myname/myhstdata, go to that directory, then read the tape or disk using the Unix/Linux **tar** command to read the FITS files into it.

Currently, datasets obtained with HST's original instruments (FGS, FOC, FOS, GHRS, HSP and WFPC) as well as WFPC2 must have their FITS files converted to GEIS (Generic Edited Information Set) format in order to work on them with IRAF/STSDAS. Further information on HST file formats is presented in chapter 2. STSDAS is the package analysis software for HST data, and is discussed further in chapter 3. Datasets obtained with the other current HST instruments (ACS, NICMOS and STIS) should be reduced in FITS format without conversion to GEIS. STSDAS support for the analysis of WFPC2 data in FITS format is currently planned.

The steps for reading and converting FITS files to GEIS files are as follows:

First bring up IRAF/STSDAS in your IRAF home directory by typing

```
> cl
```

4. A description of FITS format and various supporting documents can be found at the Web site http://fits.gsfc.nasa.gov/fits_home.html

This will start an IRAF session. IRAF and STSDAS are organized into *packages*. To load a package, type its name. To begin with, you must load the **stsdas** and **fitsio** (FITS Input/Output) packages:

```
cl> stsdas
st> fitsio
```

The IRAF prompt (such as st>) shows the first two letters of the most recently loaded package. The **fitsio** package contains the STSDAS programs (called *tasks* in the IRAF/STSDAS environment) required to read and write FITS files to and from tapes and disks. The two principle tasks are **strfits** for reading files, and **stwfits** for writing them.

Next, set the IRAF environment variable *imtype* to specify that your data files are to be written in GEIS format. This is done by typing

```
fi> set imtype="hhh"
```

You should then move to the directory containing the FITS files.

The last step is to use **strfits** to read the data. Like most IRAF/STSDAS tasks, **strfits** has several parameters that control its function. You can either edit these tasks using the IRAF “epar” command, or specify them on the command line. For the purpose converting FITS files to GEIS files, the important parameter is *oldirafname*, which needs to be set to “yes” in order to keep the file rootname the same. To convert all the FITS files in a directory to GEIS files, type

```
fi> strfits *.fits "  " oldirafname=yes
```

Figure 1.6: MAST Home Page

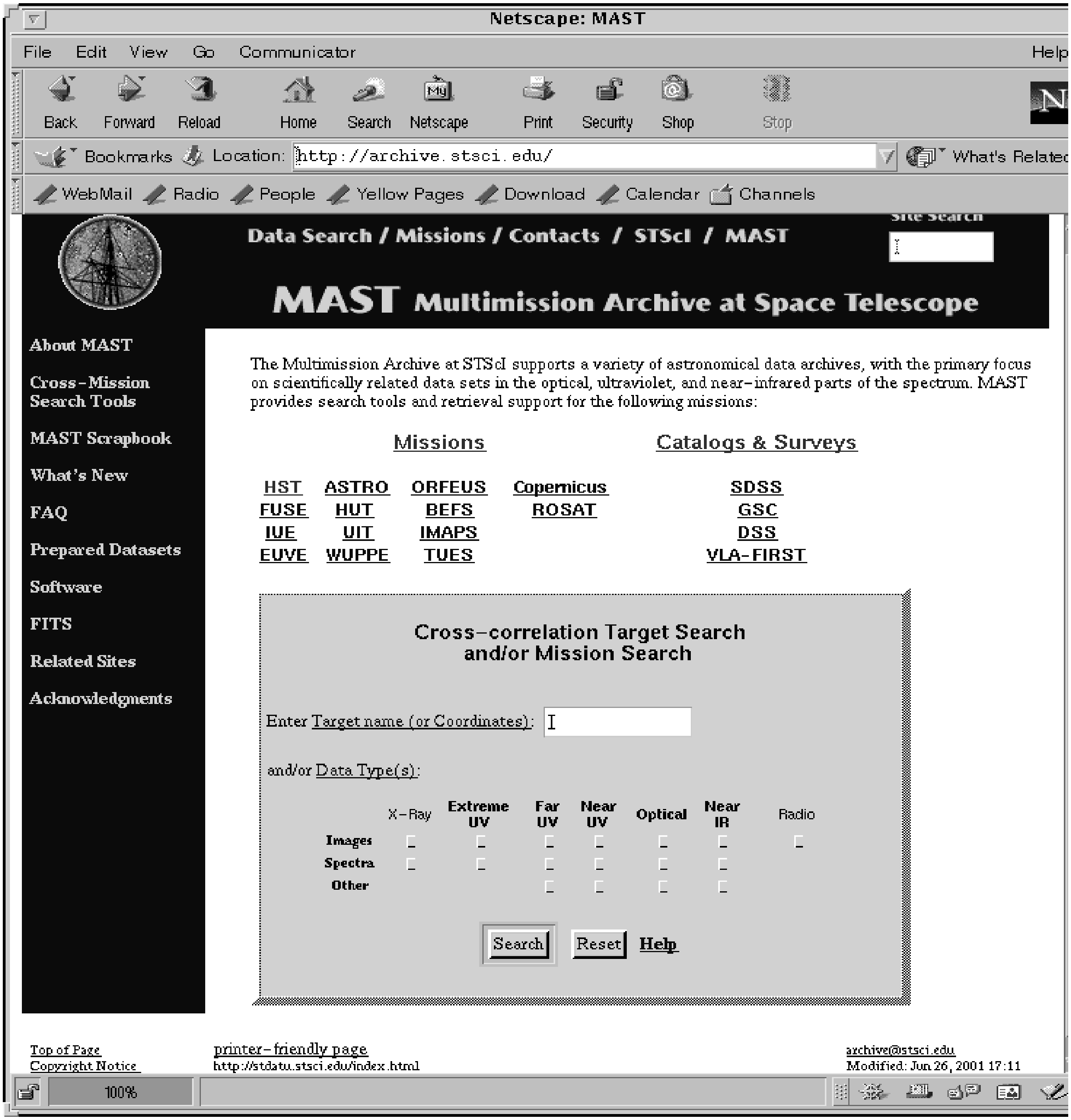
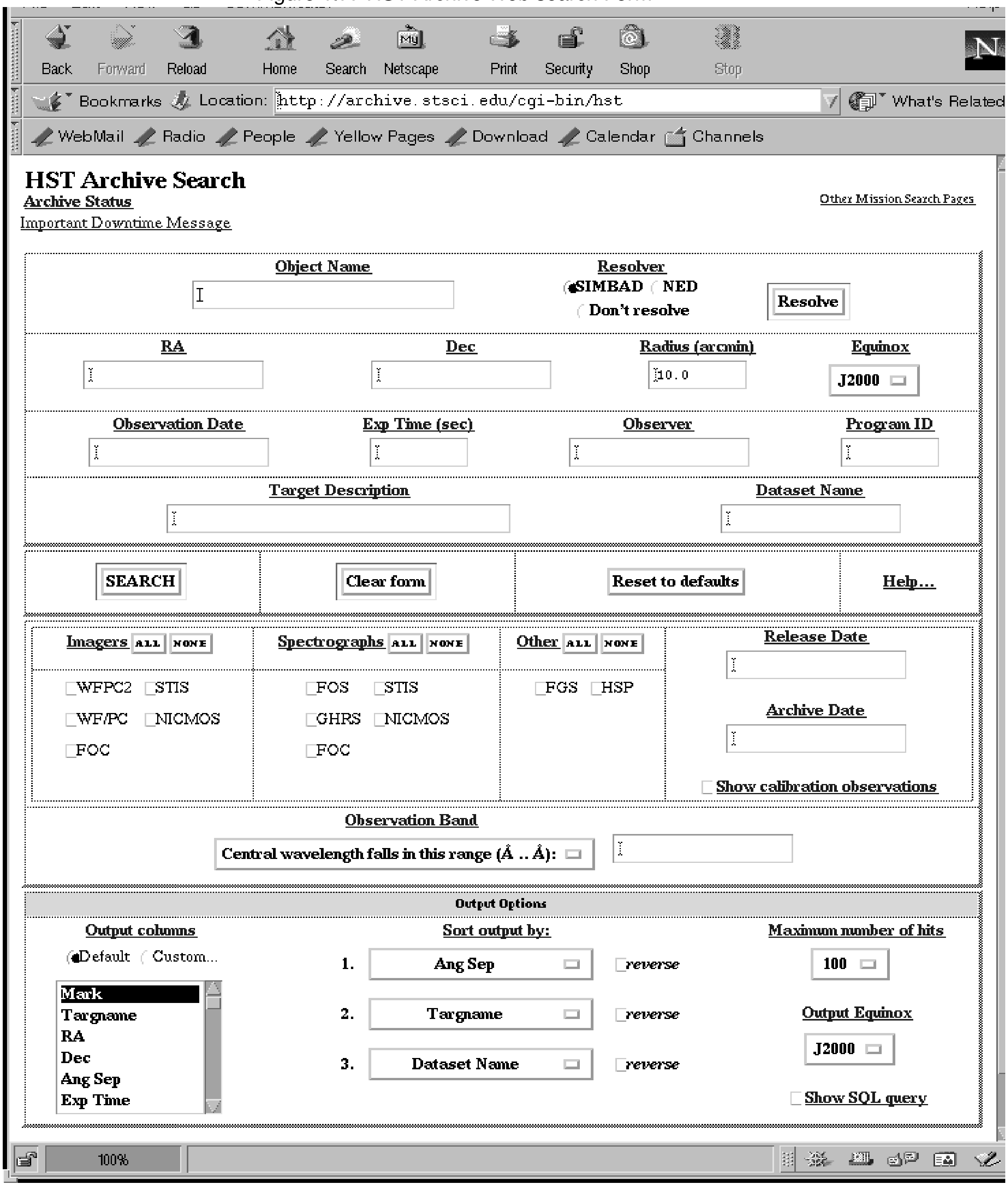


Figure 1.7: HST Archive Web search Form



This command will make GEIS format copies (having extension ".hhh") of all the FITS files in the directory, with the same rootname. Following reduction and analysis of the GEIS files with the IRAF/STSDAS tasks, they may be written back into FITS format, on hard disk or to a tape or other storage media, with the **stwfits** task.

CHAPTER 2:

HST File Formats

In this chapter. . .

STScI automatically processes and calibrates all the data received from HST. The suite of software programs that performs this processing—part of a system known as OPUS—is frequently called the *pipeline*, and its purpose is to provide data to observers and to the HST Data Archive in a form suitable for most scientific analyses. Pipeline processing assembles data received from HST into *datasets*, calibrates the data according to standard procedures described in the instrument sections of this handbook, and stores both calibrated and uncalibrated datasets in the Archive.

Pipelines of older instruments (FOC, FOS, FGS, GHRS, HSP, WF/PC-1, and WFPC2) generate files in the so-called GEIS (stands for Generic Edited Information Set) format. Since GEIS is a machine dependent format, these files are converted to a specific kind of FITS file format, sometimes referred as "waiver" FITS, before being archived. We'll explain the structure of this "waiver" FITS format later in this chapter. Since the "waiver" FITS format is only designed for archival purpose, it is necessary to convert it back to the GEIS format before further data processing and analysis using IRAF/STSDAS tasks.

Instruments installed after the 1997 servicing mission (STIS, NICMOS, ACS, and most likely all future instruments) have pipelines which generate FITS files directly. They are ready to be used by relevant IRAF/STSDAS tasks and, unlike the "waiver" FITS files, do NOT need to (and indeed, should not) be converted to GEIS format. Sometimes FITS files for the newer instruments are referred to as "FITS with extension" or "extended"

FITS files. But this can be misleading, since a "waiver" FITS file also has one (ASCII table) extension.

Much confusion has occurred about the two kinds of FITS files been archived at STScI. So we like to repeat one more time:

Older instruments (FOC, FOS, FGS, GHRS, HSP, WF/PC-1, and WFPC2) generate files in GEIS formats, but are stored and delivered as "waiver" FITS format in the archive, and need to be converted back to GEIS format before processing. Newer instruments (STIS, NICMOS, ACS) generate and store files in FITS format and should not be converted to GEIS.

This chapter describes these two HST file formats, first giving some historical perspective on the reasons why they were selected, then explaining the FITS and GEIS formats in more detail. STIS,ACS, and NICMOS observers should pay particular attention to the section on FITS files, which shows how to identify and access the contents of these files and covers some important conventions regarding header keywords. Veteran observers with the other instruments will find little new in the section on GEIS files, but newcomers to the older HST instruments should consult the material on data groups and conversion from FITS to GEIS before proceeding to chapter 3 of the HST Introduction.

2.1 Historical Perspective

In the early 1980's, when GEIS was selected as the standard format for HST data files, it held several advantages over both FITS and the original IRAF format (OIF):

- GEIS allows floating-point data. The early incarnations of FITS accommodated only integer data, and this restriction to integers would have made data reduction and storage of calibrated data rather cumbersome.
- GEIS files can hold multiple images, each with associated parameters. This feature allowed the packaging of images from the four WF/PC-1 chips into a single unit, as well as the packaging of multiple FOS or GHRS readouts into single files. OIF files and early FITS files could contain only single images.

- GEIS data are stored in two parts, an ASCII header and a binary data file. The separation of these two pieces and the restriction of the header to ASCII made these headers easier to read and print in the days when computers were less powerful and tasks for reading header information were less numerous. OIF headers combine ASCII and binary information, and FITS headers come packaged with the data in a single file.

GEIS was also the standard format for archiving and distribution of HST data until September 1994, when the Space Telescope Data Archive and Distribution Service (ST-DADS) came online. This new system stores and distributes HST data files in machine-independent FITS format, but observers with FOC, FOS, FGS, GHRS, HSP, WF/PC-1, and WFPC2 still must convert their files to machine-dependent GEIS format as described in section 2.3.1 before using IRAF/STSDAS software (see chapter 3 in the HST Introduction) to reduce their data.

Since the selection of GEIS as HST's standard data format, FITS has added features that have dramatically increased its flexibility. In particular, FITS files can now contain multiple *image extensions*, each with its own header, size, and datatype, that allow multiple exposures to be packaged into the same file, along with associated error and data quality information. The FITS image kernel in IRAF version 2.11, released in August 1997, enables users to access FITS image extensions in ways similar to how they would access GEIS data groups.

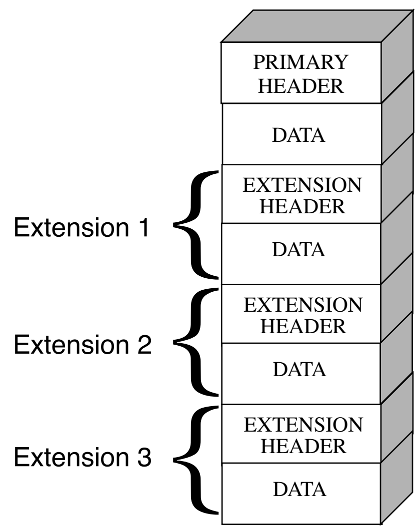
Because of these advantages, FITS was chosen as the standard reduction and analysis format for STIS and NICMOS. The STSDAS tasks written for these instruments expect FITS files as input and produce FITS files as output. *You cannot convert STIS and NICMOS files to GEIS format*. Observers using these instruments should therefore read the following section, which explains how to work with these new FITS files.

2.2 FITS File Format

Flexible Image Transport System (FITS) is a standard format for exchanging astronomical data between institutions, independent of the hardware platform and software environment. A data file in FITS format consists of a series of Header Data Units (HDUs), each containing two components: an ASCII text header and the binary data. The header contains a series of *header keywords* that describe the data in a particular HDU and the data component immediately follows the header.

The first header in a FITS file is known as the *primary header*, and any number of *extensions* can follow the primary HDU. The data unit following the primary header must contain either an image or no data at all, but each extension can contain one of several different data types, including images, binary tables, and ASCII text tables. The value of the XTENSION keyword in the extension's header identifies the type of data the extension contains. Figure 2.1 schematically illustrates the structure of a FITS file and its extensions.

Figure 2.1: FITS File Structure



The three-letter identifier (e.g., d0h) that follows the rootname of an HST data file (see appendix B for more on HST file names) has often been called an "extension" in the past. However, because of the potential for confusion with FITS extensions, this handbook will refer to these three-letter identifiers as "suffixes."

2.2.1 Working with FITS Image Extensions

The FITS image kernel included in IRAF version 2.11 is designed to read and write the images in FITS extensions and their associated headers. Once IRAF has ingested a FITS image and its header, it treats the header-data pair like any other IRAF image. The following discussion describes how to specify the image extensions in FITS files that you would like to process with IRAF/STSDAS tasks and presumes that you are using IRAF 2.11 or higher. It covers how to:

- List a FITS file's extensions.
- Access data in particular FITS extensions.

- Inherit keywords from the primary header.
- Append new extensions to existing FITS files.

Retaining the .fits at the end of every FITS file name in your file specifications will ensure that IRAF both reads and writes these images in FITS format.

If you want to work with STIS and NICMOS data, you will need to upgrade to IRAF 2.11 or higher and STSDAS 2.0.

Generating a FITS File Listing

Once you have downloaded STIS,ACS, or NICMOS FITS files from the Archive, you may want an inventory of their contents. To generate a listing of a FITS file's extensions, you can use the **catfits** task in the **tables** package. The following example, in table 2.1, illustrates the first 11 lines generated by **catfits** from a NICMOS MULTIACCUM FITS file containing images only.

The first column of a **catfits** listing gives the extension numbers. Note that the primary HDU is labeled extension number zero. The second column lists the extension type, given by the keyword XTENSION (IMAGE = image, BINTABLE = binary table, TABLE = ASCII table). The third column lists the extension name, given by the keyword EXTNAME. In STIS, ACS, and NICMOS image files, the EXTNAME values SCI, ERR, and DQ indicate science, error, and data quality images, respectively. NICMOS image files contain samples and exposure time images as well, with EXTNAME values SAMP and TIME.

Each STIS or NICMOS readout generates an image set or *imset*. STIS and ACS imsets comprise three images (SCI, ERR, DQ), while NICMOS imsets comprise five (SCI, ERR, DQ, SAMP, TIME). All images belonging to the same imset share the same integer value of the EXTVER keyword, given in the fourth column of a **catfits** listing. Several STSDAS tasks can work with entire imsets (see section 3.3.3), but most operate on individual images. See the Data Structure chapters of STIS, ACS, and NICMOS Data Handbooks for more information on the contents of imsets.

Table 2.1: NICMOS MULTIACCUM Listing from catfits

```
tt> catfits n3t501c2r_raw.fits

EXT#  FITSNAME      FILENAME              EXTVE  DIMENS     BITPI OBJECT

0     n3t501c2r_raw n3t501c2r_raw.fits                      16    n3t501c2r_raw.f
1       IMAGE       SCI                   1      256x256    16    n3t501c2r_raw.f
2       IMAGE       ERR                   1                 -32
3       IMAGE       DQ                    1                 16
4       IMAGE       SAMP                  1                 16
5       IMAGE       TIME                  1                 -32
6       IMAGE       SCI                   2      256x256    16
7       IMAGE       ERR                   2                 -32
8       IMAGE       DQ                    2                 16
9       IMAGE       SAMP                  2                 16
10      IMAGE       TIME                  2                 -32
```

Accessing FITS Images

After you have identified which FITS image extension you wish to process, you can direct an IRAF/STSDAS task to access that extension using the following syntax:

fitsfile.fits[*extension number*][*keyword options*][*image section*]

Note that all the bracketed information is optional. However, the only time it is *valid* to provide only a file name without further specification is when the file is a simple FITS file that contains a single image in the primary HDU.

Designation of the extension number is the most basic method of access, but it is not necessarily the most helpful. Referring to an extension's EXTNAME and EXTVER in the `[keyword options]` is often more convenient. If a number follows an EXTNAME, IRAF interprets the number as an EXTVER. For example, if extension number 6 holds the science image belonging to the imset with EXTVER = 2, as in the **catfits** listing on the previous page, you can specify it in two equivalent ways:

```
fitsfile.fits[6]
fitsfile.fits[sci,2]
```

Designations giving an EXTNAME without an EXTVER refer to the first extension in the file with the specified value of EXTNAME. Thus, `fitsfile.fits[sci]` is the same as `fitsfile.fits[sci,1]`.

The syntax for designating image sections adheres to the IRAF standard, so in the current example the specifications

```
fitsfile.fits[6][100:199,100:299]
fitsfile.fits[sci,2][100:199,100:299]
```

both extract a 100 by 200 pixel subsection of the same science image in

```
fitsfile.fits.
```

Header Keywords and Inheritance

STIS, ACS, and NICMOS data files use an IRAF image kernel convention regarding the relationship of the primary header keywords to image extensions in the same file. In particular, IRAF allows image extensions to *inherit* keywords from the primary header under certain circumstances. When this inheritance takes place, the primary header keywords are practically indistinguishable from the extension header keywords. This feature circumvents the large scale duplication of keywords that share the same value for all extensions. The primary header keywords effectively become global keywords for all image extensions. The FITS standard does not cover or imply keyword inheritance, and while the idea itself is simple, its consequences are often complex and sometimes surprising to users.

Generally keyword inheritance is the default, and IRAF/STSDAS applications will join the primary and extension headers and treat them as one. For example, using **imheader** as follows on a FITS file will print both primary and extension header keywords to the screen:

```
cl> imheader fitsfile.fits[sci,2] long+ | page
```

Using **imcopy** on such an extension will combine the primary and extension headers in the output HDU, even if the output is going to an extension of another FITS file. Once IRAF has performed the act of inheriting the primary header keywords, it will normally turn the inheritance feature off in any output file it creates unless specifically told to do otherwise.

If you need to change the value of one of the global keywords inherited from the primary header, you must edit the primary header itself (i.e., "extension" [0]).

Keyword inheritance is not always desirable. For example, if you use **imcopy** to copy all the extensions of a FITS file to a separate output file, IRAF will write primary header keywords redundantly into each extension header. You can suppress keyword inheritance by using the NOINHERIT keyword in the file specification. For example:

```
im> imcopy fitsfile.fits[6][noinherit] outfile.fits
im> imcopy fitsfile.fits[sci,2,noinherit] outfile.fits
```

Both of the preceding commands will create an output file whose header contains only those keywords that were present in the original extension header. Note that in the second command, the `noinherit` specification is bracketed with the EXTNAME and EXTVER keywords and not in a separate bracket of its own, as in the first command where an absolute extension number is used. For a complete explanation of FITS file name specifications, see:

http://iraf.noao.edu/iraf/web/docs/fitsuserguide.html.

Appending Image Extensions to FITS Files

IRAF/STSDAS tasks that produce FITS images as output can either create new FITS files or append new image extensions to existing FITS files. You may find the following examples useful if you plan to write scripts to reduce STIS, ACS, or NICMOS data:

If the specified output file does not yet exist, a new output file is created containing only a primary HDU if no specification is appended to the output file name. For example, to copy the contents of the primary header of `fitsfile.fits` into the primary HDU of the FITS file `outfile.fits`, type the command:

```
cl> imcopy fitsfile.fits[0] outfile.fits
```

If the specified output file already exists and you want to append a new extension to it, you need to include the APPEND option in the output file specification. The following command appends extension `[sci,2]` of `fitsfile.fits` onto the existing file `outfile.fits`, while retaining the original EXTNAME and EXTVER of the extension—the `noinherit` specification inhibits the copying of the primary header keywords from the input file into the output extension header:

```
    cl> imcopy fitsfile.fits[sci,2,noinherit] \
    >>> outfile.fits[append]
```

If you want to change the EXTNAME or EXTVER of the appended extension, you can specify the new values of these keywords in the output extension, like this:

```
cl> imcopy fitsfile.fits[sci,2,noinherit] \
>>> outfile.fits[sci,3,append]
```

For obvious reasons, it is not generally advisable for two file extensions in the same FITS file to share the same EXTNAME and EXTVER values. However, if you must append an extension to an output file already containing an extension with the same EXTNAME/EXTVER pair you can do so with the DUPNAME option:

```
cl> imcopy fitsfile.fits[7] \
>>> outfile.fits[append,dupname]
```

If you need to replace an existing extension with a new output extension, you can use the OVERWRITE option as follows. Overwriting can cause a lengthy rewrite of the whole file to insert the new extension, if its size is not the same as the extension it replaces.

```
cl> imcopy fitsfile.fits[sci,2,noinherit] \
>>> outfile.fits[sci,2,overwrite]
```

2.2.2 Working with FITS Table Extensions

STIS and NICMOS use FITS tables in two basic ways. Both instruments produce association tables (see appendix B.3) listing the exposures that go into constructing a given association product. In addition, STIS provides certain spectra, calibration reference files, and time-tagged data in tabular form . Here we describe:

- How to access and read FITS table extensions.
- How to specify data arrays in FITS table cells.

This discussion assumes you are using STSDAS 2.0 or later. (The IRAF FITS kernel deals only with FITS images. The **tables** package installed with STSDAS handles FITS table extensions.)

Accessing FITS Tables

You can access data in FITS table extensions using the same tasks appropriate for any other STSDAS table, and the syntax for accessing a specific FITS table is similar to the syntax for accessing FITS images (see section 2.2.1), with the following exceptions:

- The FITS table interface does not support header keyword inheritance.
- FITS tables cannot reside in the primary HDU of a FITS file. They must reside instead in a FITS table extension, in either ASCII form (XTENSION=TABLE) or binary form (XTENSION=BINTABLE).
- If the first extension in a FITS file is a TABLE or a BINTABLE, you can access it by typing the file name with no extension specified. It is not sufficient for the table to be just the first BINTABLE or TABLE; *it must actually be the first extension*.

For example, running **catfits** on the NICMOS association table `n3tc01010_asn.fits` provides the following output:

```
fi> catfits n3tc01010_asn.fits


EXT#  FITSNAME      FILENAME              EXTVE ...

0     n3tc01010_asn N3TC01010_ASN.FITS ...

1      BINTABLE    ASN                   1 ...
```

Extension number 1 holds the association table, which has EXTNAME=ASN and EXTVER=1. You can use the **tprint** task in the STSDAS **tables** package to print the contents of this table, and the following commands are all equivalent:

```
tt> tprint n3tc01010_asn.fits
tt> tprint n3tc01010_asn.fits[1]
tt> tprint n3tc01010_asn.fits[asn,1]
```

STSDAS **tables** tasks can read both FITS TABLE and BINTABLE extensions, but they can write tabular results only as BINTABLE extensions. Tasks that write to a table in-place (i.e., **tedit**) can modify an existing FITS extension, and tasks that create a new table (i.e., **tcopy**) will create a new extension when writing to an existing FITS file. If the designated output file does not already exist, the task will create a new FITS file with the output table in the first extension. If the output file already exists, your task will append the new table to the end of the existing file; the APPEND option necessary for appending FITS image extensions is not required. As with FITS images, you can specify the EXTNAME and EXTVER of the output extension explicitly, if you want to assign them values different from those in the input HDU. You can also specify the

OVERWRITE option if you want the output table to supplant an existing FITS extension. For example, you could type:

```
tt> tcopy n3tc01010_asn.fits out.fits[3][asn,2,overwrite]
```

This command would copy the table in the first extension of `n3tc01010_asn.fits` into the third extension of `out.fits`, while reassigning it the EXTNAME/EXTVER pair `[asn,2]` and overwriting the previous contents of the extension. Note that overwriting is the only time when it is valid to specify an extension, EXTNAME, and an EXTVER in the output specification.

Specifying Arrays in FITS Table Cells

A standard FITS table consists of columns and rows forming a two-dimensional grid of cells; however, each of these cells can contain a data array, effectively creating a table of higher dimensionality. Tables containing extracted STIS spectra take advantage of this feature. Each column of a STIS spectral table holds data values corresponding to a particular physical attribute, such as wavelength, net flux, or background flux. Each row contains data corresponding to one spectral order, and tables holding echelle spectra can contain many rows. Each cell of such a spectral table can contain a one-dimensional data array corresponding to the physical attribute and spectral order of the cell.

In order to analyze tabular spectral data with STSDAS tasks other than the **sgraph** task and the **igi** package, which have been appropriately modified, you will need to extract the desired arrays from the three-dimensional table. Two new IRAF tasks, named **tximage** and **txtable**, can be used to extract the table-cell arrays. Complementary tasks, named **tiimage** and **titable**, will insert arrays back into table cells. To specify the arrays which should be extracted from or inserted into the table cells, you will need to use the *selectors* syntax to specify the desired row and column. The general syntax for selecting a particular cell is:

```
intable.fits[extension number][c:column_selector][r:row_selector]

or

intable.fits[keyword options][c:column_selector][r:row_selector]
```

A *column selector* is a list of column patterns separated by commas. The column pattern is either a column name, a file name containing a list of column names, or a pattern using the IRAF pattern matching syntax (type `help system.match`, for a description of the IRAF pattern matching syntax). If you need a list of the column names, you can run the **tlcol** task (type `tlcol infile.fits`).

Rows are selected according to a *filter*. The filter is evaluated at each table row, and the row is selected if the filter is true. For example, if you specify:

```
infile.fits[3][c:WAVELENGTH,FLUX][r:SPORDER=(68:70)]
```

IRAF will extract data from the table stored in the third extension of the FITS file, `infile.fits`, specifically the data from the columns labelled WAVELENGTH and FLUX, and will restrict the extraction to the rows where the spectral order (SPORDER) is within the range 68–70, inclusive. Alternatively, if you specify:

```
infile.fits[sci,2][c:FLUX][r:row=(20:30)]
```

IRAF will obtain data from the table stored in the FITS file extension with an EXTNAME of SCI and EXTVER of 2. The data will come from the column FLUX and be restricted to the row numbers 20–30, inclusive. Eventually, all STSDAS and TABLES tasks will be able to use row and column selection. For a complete explanation of the table selector syntax, `type help selectors`.

2.3 GEIS File Format

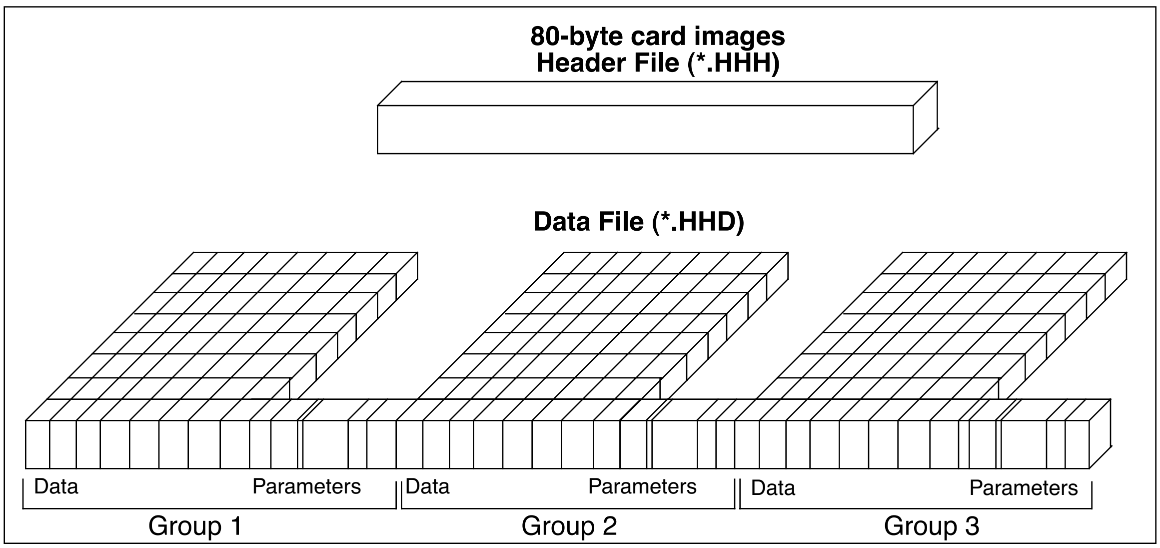
The HST-specific Generic Edited Information Set (GEIS) format[1] is the standard format for reducing data from FOC, FOS, FGS, GHRS, HSP, WF/PC-1, and WFPC2. All HST images in GEIS format consist of two components: a *header file* and a separate *binary data file*, both of which should reside in the same directory. GEIS header files, whose suffixes end in “h” (e.g., `w0lo0105t.c1h`), consist entirely of ASCII text in fixed-length records of 80 bytes. These records contain header keywords that specify the properties of the image itself and the parameters used in executing the observation and processing the data. GEIS binary data files, whose suffixes end in “d” (e.g., `w0lo0105t.c1d`), contain one or more *groups* of binary data. Each group comprises a data array followed by an associated block of binary parameters called the Group Parameter Block (GPB). The sizes and datatypes of the data arrays and group parameters in

1. GEIS files are also commonly referred to as STSDAS images.

each group of a GEIS file are identical. Figure 2.2 depicts the structure of a GEIS data file graphically.

The binary content of GEIS files is machine dependent. Copying GEIS files directly from one platform to another (e.g., from a VAX to a Sun) may result in unreadable data.

Figure 2.2: GEIS File Structure



2.3.1 Converting FITS to GEIS

The STScI archive stores and distributes datasets from FOC, FOS, FGS, GHRS, HSP, WF/PC-1, and WFPC2 in a special archival FITS format. *We highly recommend that users convert these datasets back into their native GEIS format before working with them*. Your data must be in GEIS format for you to use many of the STSDAS software tools developed specifically for analysis of these data. It is important to use the **strfits** task found in **stsdas.fitsio** or in **tables.fitsio** to perform the conversion from archival FITS format to the GEIS format because the data-processing pipeline employs a special convention for mapping GEIS files to FITS format. While other FITS readers may be able to read portions of the data correctly, they are unlikely to reconstruct the entire data file properly.

To recreate the original multigroup GEIS file using strfits, you must first type:

```
cl> set imtype=hhh
```

This command tells IRAF to write output files in GEIS format. You then need to set the **strfits** parameters `xdimtogf` and `oldirafname` both to "yes". For example, after you have set `imtype = hhh`, you can convert the FITS file `*_hhf.fits` into the GEIS format files `*.hhh` and `*.hhd` by typing:

```
cl> strfits *_hhf.fits "" xdim=yes oldiraf=yes
```

2.3.2 GEIS Data Groups

One of the original advantages of GEIS format noted in Section 2.1 was that it could accommodate multiple images within a single file. This feature is useful because a single HST observation often produces multiple images or spectra. For example, a single WF/PC-1 or WFPC2 exposure generates four simultaneous images, one for each CCD chip. Likewise, the FOS and GHRS obtain data in a time-resolved fashion so that a single FOS or GHRS dataset comprises many spectra—one corresponding to each readout. The data corresponding to each sub-image (for the WF/PC-1 or WFPC2) or each sub-integration (for the FOS or GHRS) are stored sequentially in the groups of a single GEIS binary data file. The header file corresponding to this data file contains the information that applies to the observation as a whole (i.e., to all the groups in the image), and the group-specific keyword information is stored in the group parameter block of each data group in the binary data file.

The *number* of groups produced by a given observation depends upon the instrument configuration, the observing mode, and the observing parameters. Table 2.2 lists the *contents* and the number of groups in the final calibrated image for the most commonly-used modes of each instrument which uses the GEIS data format.

Table 2.2: Groups in Calibrated Images, by Instrument and Mode

Instrument	Mode	Number of Groups	Description
FGS	All	7	FGS data are not reduced with IRAF and STSDAS. Therefore, FGS groups have different meaning than for the other instruments.
FOC	All	1	All FOC images have only a single group.
FOS	ACCUM	*n*	Group *n* contains accumulated counts from groups (subintegrations) 1, 2, ... *n*. The last group is the full exposure.
	RAPID	*n*	Each group is an independent subintegration with exposure time given by group parameter EXPOSURE.

Instrument	Mode	Number of Groups	Description
HSP	All	1	HSP datasets always have only a single group that represents either digital star (.d0h, .c0h), digital sky (.d1h, .c1h), analog star (.d2h, .c2h), or analog sky (.d3h, .c3h).
GHRS	ACCUM	*n*	Each group is an independent subintegration with exposure time given by group parameter EXPOSURE. If FP-SPLIT mode was used, the groups will be shifted in wavelength space. The independent subintegrations should be coadded prior to analysis.
	RAPID	*n*	Each group is a separate subintegration with exposure time given by group parameter EXPOSURE.
WF/PC-1	WF	4	Group *n* represents CCD chip *n*, e.g., group 1 is chip 1 (unless not all chips were used). Group parameter DETECTOR always gives chip used.
	PC	4	Group *n* is chip *n* + 4, e.g., group 1 is chip 5. If not all chips were used, see the DETECTOR parameter which always gives the chip used.
WFPC2	All	4	Planetary chip is group 1, detector 1. Wide Field chips are groups 2–4 for detectors 2–4. If not all chips were used, see the DETECTOR keyword.

2.3.3 Working with GEIS Files

This section briefly explains how to work with information in GEIS header and data files.

GEIS Headers

Header keyword information relevant to each group of a GEIS file resides in two places, the header file itself and the parameter block associated with the group. Because GEIS header files are composed solely of ASCII text, they are easy to print using standard Unix or VMS text-handling facilities. However, the group parameters are stored in the binary data file. To access them you need to use a task such as **imheader**, as shown in section“Printing Header Information”.

You can use the IRAF **hedit** task to edit the keywords in GEIS headers. While it is possible to edit GEIS header files using standard Unix and VMS text editors, you must maintain their standard 80-character line length. The **hedit** task automatically preserves this line length. If you need to add or delete group parameters, you can use the STSDAS **groupmod** task in the **stsdas.hst_calib.ctools** package. The STSDAS **chcalpar** task, described in more detail in the Calibration chapters for each instrument’s data handbook, is useful for updating header keywords containing calibration switches and calibration reference files.

Always edit headers using tasks like hedit, eheader, and chcalpar. Editing headers with a standard text editor may corrupt the files by creating incorrect line lengths.

GEIS Data Files

Numerous IRAF/STSDAS tasks exist for working with GEIS images (see chapter 3 of the HST Introduction). Most of these tasks operate on only one image at a time, so you usually need to specify which group of a GEIS file is to be processed. If you do not specify a group, your task will choose the first group by default.

Specifying a Group

To specify a particular group in a GEIS file, append the desired group number in square brackets to the file name (e.g., `z2bd010ft.d0h[10]`). For example, to apply the **imarith** task to group 10 of a GEIS image, type the following (always refer to a GEIS file by its header file name, i.e. *.??h, even though mathematically you are operating on the data portion):

```
cl> imarith indata.hhh[10] + 77.0 outdata.hhh
```

This command will add 77.0 to the data in group 10 of the file `indata.hhh`, and will write the output to a new single-group file called `outdata.hhh`. Any operation performed on a single group of a multigroup GEIS file results in an output file containing a single group.

Specifying an Image Section

If you wish to process only a portion of an image, you can specify the image section after the group specification in the following manner:

```
cl> imarith indata.hhh[2][100:199,200:399] * 32.0 outdata.hhh
```

This command extracts a 100 by 200 pixel subsection of the image in the second group of the file `indata.hhh`, multiplies this data by a factor of 32.0, and stores the result in a new output file, `outdata.hhh`, which is a 100 by 200 pixel single group GEIS file.

Printing Header Information

As discussed in the previous section, the task **imheader** extracts and prints information about the GEIS image. This task reports the image name, dimensions (including the number of groups), pixel type, and title of the image when it is run in default mode. For example:

```
cl> imhead indata.hhh
    indata.hhh[1/64][500][real]: INDATA[1/64]
```

The output line indicates that `indata.hhh` is a multigroup GEIS file which contains 64 groups of images, each consisting of a spectral array 500 pixels in length. The data type of the values is real (floating point). Note that since no group designation was provided, the task defaulted to the first group. To reveal more information regarding group 10, you can type:

```
cl> imhead indata.hhh[10] long+ | page
```

which will generate a long listing of both the ASCII header parameters in the `*.hhh` file and the specific group parameters for group 10 from the `*.hhd` file.

Other Group-Related Tasks

Currently, IRAF or STSDAS tasks cannot process all the groups in an input image and write the results to corresponding groups in an output image. However, there are several STSDAS tasks, particularly in the **toolbox.imgtools** and **hst_calib.ctools** packages, that simplify working with group format data. Please refer to chapter 3 and the *STSDAS User's Guide* for more details about working with GEIS images.

2.3.4 The "waiver" FITS format

Although “waiver” is not quite the accurate or good word for the intended purpose, for historic reasons it has stuck and will be reluctantly adopted. However, in the past, a grammatically incorrect word “waivered” had been used.

The “waiver” FITS format was developed when the HST archive needed a format to store and distribute the data products in a machine-independent medium for the community, at a time before FITS image extension was standardized. As a result, the “waiver” FITS format was adopted as a compromise.

Since, at the time, FITS could only have a single image while the HST data (in GEIS format) may have several images as multiple groups in one file, the idea is to stack the images of different groups together as a new dimension in the FITS image. As for group parameters, they are put in an ASCII table and the table becomes the first (and only) extension of the FITS file.

For example, the WFPC2 pipeline generates the science data as a GEIS file of 4 groups, each is an 800x800 image corresponding to one of the 4 detectors. When this GEIS file is converted to the "waiver" FITS file, the FITS file has an image of 800x800x4 (a three-dimensional image!) at its primary HDU. Similarly, an FOS GEIS file may have 40 groups, each group is a 1-D image (spectrum) of the size 2064. The waiver FITS file then will have one 2-D image of the size 2064x40, at its primary HDU. In the case of WFPC2, the first extension of the waiver FITS file will be an ASCII table containing 4 rows; each row corresponds to a group. The value of each group parameter is under a column named after the group parameter, i. e. the value of the group parameter CRVAL1 of the 2nd group will be at the 2nd row, under the column named "CRVAL1". In other words, the ASCII table has as many rows as there are groups in the original GEIS file, and as many columns as group parameters.

Although, *in theory, certain* IRAF/STSDAS tasks can directly access the data in the "waiver" FITS file, e.g. to display the 2nd "group" of a WFPC2 image:

```
st.> display u67m0206r_c0f.fits[0][*,*,2]
```

will work, while *most tasks, especially those specific to HST instruments, can not*. It is therefore HIGHLY recommended that all waiver FITS files are converted back to the GEIS format, by using the task **strfits**, before further processing and analysis with IRAF/STSDAS tasks.

CHAPTER 3:

STSDAS Basics

In this chapter. . .

The Space Telescope Science Data Analysis System (STSDA) is the software system for calibrating and analyzing data from the Hubble Space Telescope. The package contains programs—called *tasks*—that perform a wide range of functions supporting the entire data analysis process, from reading tapes, through reduction and analysis, to producing final plots and images. This chapter introduces the basics of STSDAS, showing you how to display your data, leading you through some simple data manipulations, and pointing you towards more sophisticated tasks, some of which are described in the instrument data handbooks.

STSDAS is layered on top of the Image Reduction and Analysis Facility *(IRAF)* software developed at the National Optical Astronomy Observatory (NOAO). Any task in IRAF can be used in STSDAS, and the software is portable across a number of platforms and operating systems. To exploit the power of STSDAS effectively, you need to know the basics of IRAF. If you are not already familiar with IRAF, consult the IRAF Primer in Appendix A before reading further.

3.1 Navigating STSDAS

The tasks in STSDAS are far too numerous and complicated to describe comprehensively in this volume. Instead, we will show you where to find the STSDAS tasks appropriate for handling certain jobs. You can refer to online help or the *STSDAS User's Guide* for details on how to use these tasks. Some useful online help commands are:

- `help` *task* - provides detailed descriptions and examples of each task.
- `help` *package* - lists the tasks in a given package and their functions.
- `describe` *task* - provides a detailed description of each task.
- `example` *task* - provides examples of each task.
- `apropos` *word* - searches the online help database for tasks relating to the specified word (see figure A.4).

3.1.1 STSDAS Structure

STSDAS is structured so that related tasks are grouped together as packages. For example, tasks used in the calibration process can be found in the **hst_calib** package and tasks used for image display and plotting can be found in the **graphics** pack. Figure 3.1 shows the STSDAS package structure. Note that IRAF version 2.11 must be installed on your system in order for you to use STSDAS 2.0 and TABLES version 2.0 or higher

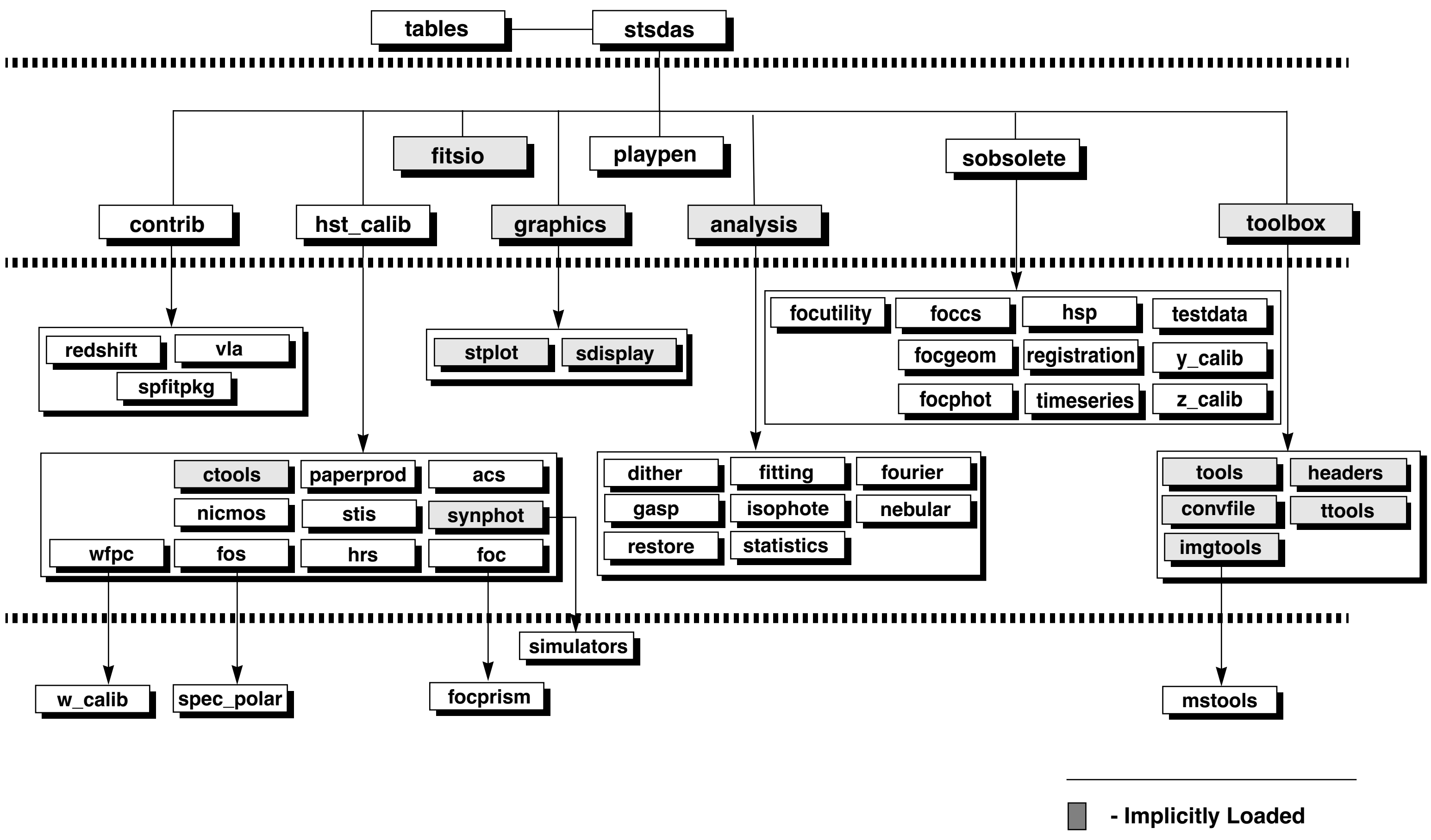
3.1.2 Packages of General Interest

Images

Both IRAF and STSDAS contain a large number of tasks that work with HST images. Some of the packages you should investigate are:

- **images**: This package includes general tasks for copying (**imcopy**), moving (**imrename**), and deleting (**imdelete**) image files. These tasks operate on both the header and data portions of the image. The package also contains a number of general purpose tasks for operations such as rotating and magnifying images.
- **stsdas.toolbox.imgtools**: This package contains general tools for working with multigroup GEIS images, including tasks for working with masks, and general purpose tasks for working with the pixel data, such as an interactive pixel editor (**pixedit**).

Figure 3.1: STSDAS Version 2.3 Package Structure



- **stsdas.toolbox.imgtools.mstools**: This package contains tools for working with FITS image extensions, in particular STIS and NICMOS image sets (imsets).
- **stsdas.analysis**: This package contains general tasks for image analysis, such as Fourier analysis and dither.

Tables

Several of the analysis packages in STSDAS, including calibration pipeline tasks, create output files in STSDAS table format, which is a binary row-column format, or in FITS binary table format. (ASCII-format tables are also supported, for input only.) The *STSDAS User's Guide* describes the STSDAS table format in detail. Tasks in the **ttools** package or in the external **tables** package can be used to read, edit, create, and manipulate tables. For example:

- **tread** displays a table, allowing you to move through it with the arrow keys.
- **tprint** displays a table.
- **tcopy** copies tables.
- **tedit** allows you to edit a table.

Many other tasks in **ttools** perform a variety of other functions. See the online help for details.

3.2 Displaying HST Images

This section will be of interest primarily to observers whose datasets contain two-dimensional images, as it explains:

- How to display images in IRAF using the **display** task.
- How to display subsections of images.

Observers viewing WF/PC-1 and WFPC2 data may wish to remove cosmic rays before displaying their data. The FOC photon-counting hardware does not detect cosmic rays at easily as CCDs, the NICMOS pipeline automatically removes cosmic rays from MULTIACCUM observations, and the STIS pipeline automatically removes cosmic rays from CR-SPLIT association products.

3.2.1 The display Task

The most general IRAF task for displaying image data is the **display** task, the best choice for a first look at HST imaging data. To display an image, you need to:

1. Start an image display server, such as SAOimage, in a separate window from your IRAF session, either from a different xterm window or as a background job before starting IRAF. To start SAOimage, type the following:

```
saoimage &
```

2. Load the **images.tv** package from the window where you're running IRAF:

```
cl> images
im> tv
```

Several different display servers, including SAOimage, ds9 (the next generation of SAOimage), and Ximtool, can be used with IRAF. ds9 may be retrieved from http://hea-www.harvard.ed u/RD/ds9/. Ximtool may be retrieved from ftp://iraf.noao.edu/iraf/x11iraf/.

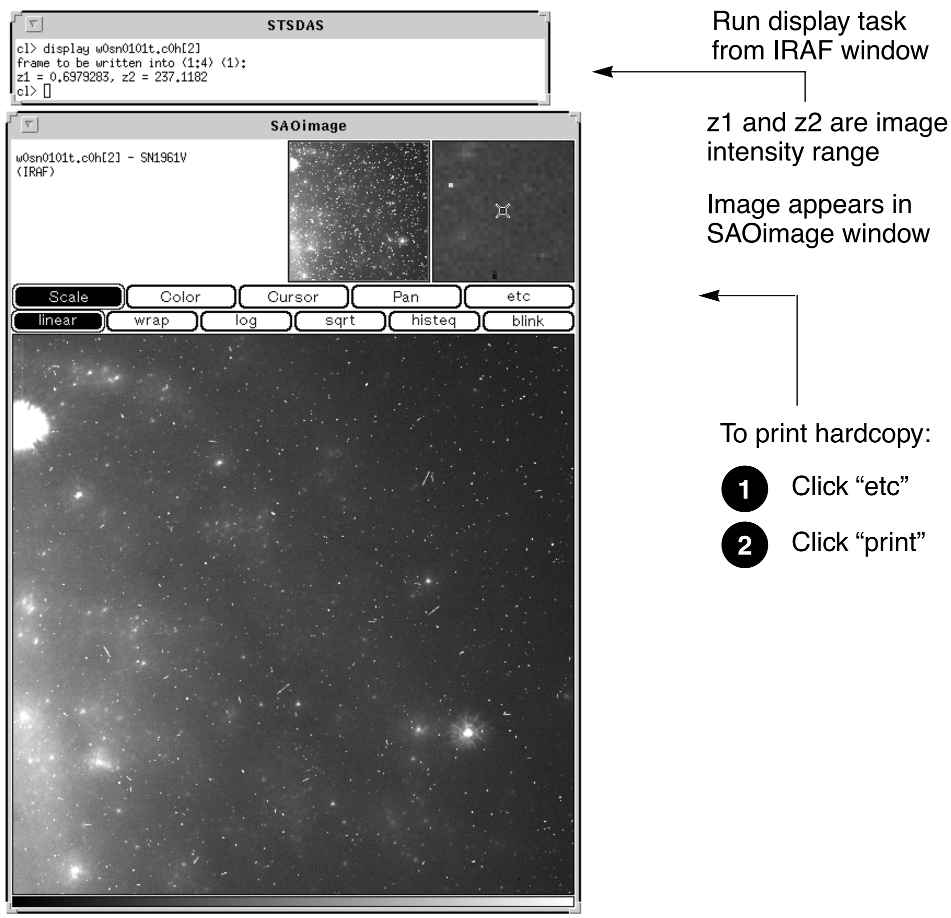
3. Display the image with the IRAF **display** task, using the syntax appropriate for the file format (Chapter 2 explains how to specify GEIS groups and FITS extensions):

```
tv> display fname.c0h[2] 1 (GEIS group 2)
tv> display fname.fits[11] 1 (FITS extension 11)
tv> display fname.fits[sci,3] 1 (FITS extension sci,3)
```

Note that when using **display** or any other task on GEIS images, you do not need to specify a group; the first group is the default. However, when working with FITS files you must specify an extension, unless the FITS file contains only a single image in the primary data unit and has no extensions. figure 3.2 shows how to display group two of a WF/PC-1 image.

If you want to display all four chips of a WF/PC-1 or WFPC2 image simultaneously, you can create a mosaic with the STSDAS wmosaic task in the hst_calib.wfpc package. Type help wmosaic for details.

Figure 3.2: Displaying an Image



Modifying the Display

There are two ways to adjust how your image is displayed:

- Use the SAOimage command buttons that control zooming, panning, etc.
- Reset the **display** task parameters.

Once an image appears in your SAOimage window, you can use the SAOimage commands displayed near the top of the image window to manipulate or print your image. The *SAOimage Users Guide* describes these commands, although most are fairly intuitive. Just click on the buttons to scale, pan, or print the image, or to perform other commonly-used functions. On-line help is also available at the system level: type `man saoimage` in Unix or `help saoimage` in VMS.

The example in figure 3.2 shows how you should display an image for a first look. By default, **display** automatically scales the image intensity using a sampling of pixels throughout the image. During your first look, you may want to experiment with the scaling using the `zscale`, `zrange`, `z1` and `z2` parameters. The `zscale` parameter toggles the autoscaling. Setting `zscale-` and `zrange+` tells the task to use minimum and maximum values from the image as the minimum and maximum intensity values. To customize your minimum and maximum intensity display values, set `zscale-`, `zrange-`, `z1` to the minimum value and `z2` to the maximum value that you want displayed. For example:

```
im> disp w0mw0507v.c0h 1 zrange- zscale- z1=2.78 z2=15.27
```

Notice in figure 3.2 that when you run **display**, the task shows you the `z1` and `z2` values that it calculates. You can use these starting points in estimating reasonable values for the minimum and maximum intensity display parameters.[1]

If you want to display an image with greater dynamic range, you may prefer to use logarithmic scaling. However, the log scaling function in SAOimage divides the selected intensity range into 200 linearly spaced levels before taking the log. The resulting intensity levels are rendered in a linear rather than logarithmic sense. You can often obtain better results if you create a separate logarithmic image to display. One way to create a logarithmic image is with the **imcalc** task:

```
im> imcalc x2ce0502t.c1h x2ce0502t.hhh "log10(im1+1.0)"
```

If the peak pixel in your original image contained 2000 counts, for example, you would then display the logarithmic image with `z1=0` and `z2=3.3`.

Otherwise, the user can simply do:

```
im> display  x2ce0502t.c1h ztrans=log
```

1. Type `help display` within IRAF to obtain more information about these parameters.

The image display buffer can also be adjusted in IRAF by setting the stdimage parameter. For example,

```
im> set stdimage = imt 2048
```

will allow a larger image to be displayed without losing the borders.

3.2.2 Working with Image Sections

Sometimes you may want to display only a portion of an image, using the syntax for specifying image sections discussed in chapter 2. Your specified pixel range should give the starting point and ending point, with a colon separating the two. List the horizontal (*x* axis) range first, followed by the vertical (*y* axis) range. For example, to specify a pixel range from 101 to 200 in the *x* direction and all pixels in the *y* direction from group three of a GEIS format image:

```
tv> display image.hhh[3][101:200,*] 1
```

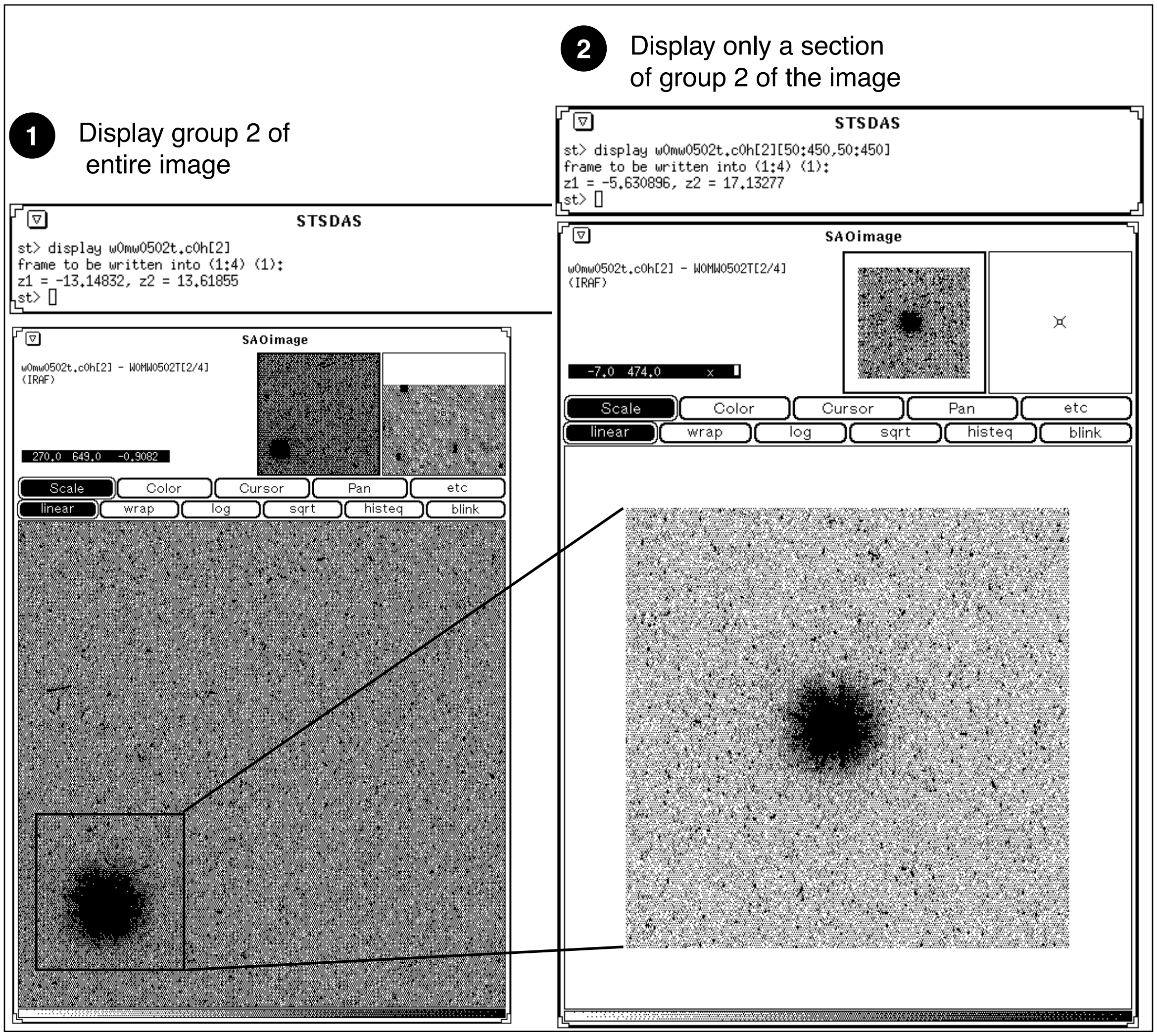
To specify the same pixel range in the second SCI extension of a NICMOS FITS image:

```
tv> display image.fits[sci,2][101:200,*] 1
```

If you specify both a group and an image section of a GEIS file, the group number must come first. When displaying sections of FITS image extensions, you must specify the extension, which also comes before the image section

Figure 3.3 shows examples of displaying an image and an image section.

Figure 3.3: Displaying Sections and Groups of an Image



3.3 Analyzing HST Images

This section describes methods for using STSDAS and IRAF to work with two-dimensional image data from HST. Subjects include:

- Relating your image to sky coordinates.
- Examining and manipulating your image.
- Working with STIS, ACS, and NICMOS imsets.
- Converting counts to fluxes.

3.3.1 Basic Astrometry

This section describes how to determine the orientation of an HST image and the RA and Dec of any pixel or source within it, including:

- Tasks that supply positional information about HST images.
- Methods for improving your absolute astrometric accuracy.

Positional Information

The header of every calibrated HST two-dimensional image contains a linear astrometric plate solution, written in terms of the standard FITS astrometry header keywords: CRPIX1, CRPIX2, CRVAL1, CRVAL2, and the CD matrix—CD1_1, CD1_2, CD2_1, and CD2_2. IRAF/STSDAS tasks can use this information to convert between pixel coordinates and RA and Dec. Two simple tasks that draw on these keywords to relate your image to sky coordinates are:

- **disconlab**: Displays your image with a superimposed RA and Dec grid. Simply open an SAOimage window and type, for example:

```
sd> disconlab n3tc01a5r_cal.fits[1]
```

- **xy2rd**: Translates *x* and *y* pixel coordinates to RA and Dec. (The task **rd2xy** inverts this operation.) SAOimage displays the current *x,y* pixel location of the cursor in the upper-left corner of the window. To find the RA and Dec of the current pixel, you supply these coordinates to **xy2rd** by typing

```
sd> xy2rd n3tc01a5r_cal.fits[1] x y
```

Table 3.1 lists some additional tasks that draw on the standard astrometry keywords.

Observers should be aware that these tasks do not correct for geometric distortion. Only FOC images currently undergo geometric correction during standard pipeline processing (the `.c0h/.c0d` and `.c1h/.c1d` FOC images have been geometrically corrected); STIS images will be geometrically corrected in the pipeline once suitable calibration files are in hand. If you need precise relative astrometry, you should use an instrument-specific task that accounts for image distortion, such as the **metric** task for WF/PC-1 and WFPC2 images.

Do not use tasks like rimcursor or xy2rd directly on WF/PC-1 or WFPC2 images if you require accurate relative positions. WF/PC-1 and WFPC2 pipelines do not correct for geometric distortions which will affect the accuracy of relative positions. Both wmosaic and metric, found in the stsdas.hst_calib.wfpc package, correct for this distortion.

Table 3.1: Additional IRAF and STSDAS Astrometry Tasks

Task	Purpose
compass	Plot north and east arrows on an image.
north	Display the orientation of an image based on keywords.
rimcursor	Determine RA and Dec of a pixel in an image.
wcscoords	Use WCS[1] to convert between IRAF coordinate systems.
wcslab	Produce sky projection grids for images.

1. World Coordinate System (WCS). Type "help specwcs" at the IRAF prompt for details.

Improving Astrometric Accuracy

Differential astrometry (measuring a position of one object relative to another in an image) is easy and relatively accurate for HST images, while absolute astrometry is more difficult, owing to uncertainties in the locations of the instrument apertures relative to the Optical Telescope Assembly (OTA or V1) axis and the inherent uncertainty in Guide Star positions. However, if you can determine an accurate position for any single star in your HST image, then your absolute astrometric accuracy will be limited only by the accuracy with which you know that star's location and the image orientation.

If there is a star on your image suitable for astrometry, you may wish to extract an image of the sky around this star from the Digitized Sky Survey and measure the position of that star using, for example, the GASP software (described in the *STSDAS User's Guide*). These tools provide an absolute positional accuracy of approximately 0″.7. Contact the Help Desk for assistance (send E-mail to `help@stsci.edu`).

3.3.2 Examining and Manipulating Image Data

This section describes **implot** and **imexamine**, two basic IRAF tools for studying the characteristics of an image, and table 3.3 lists some useful IRAF/STSDAS tasks for manipulating images.

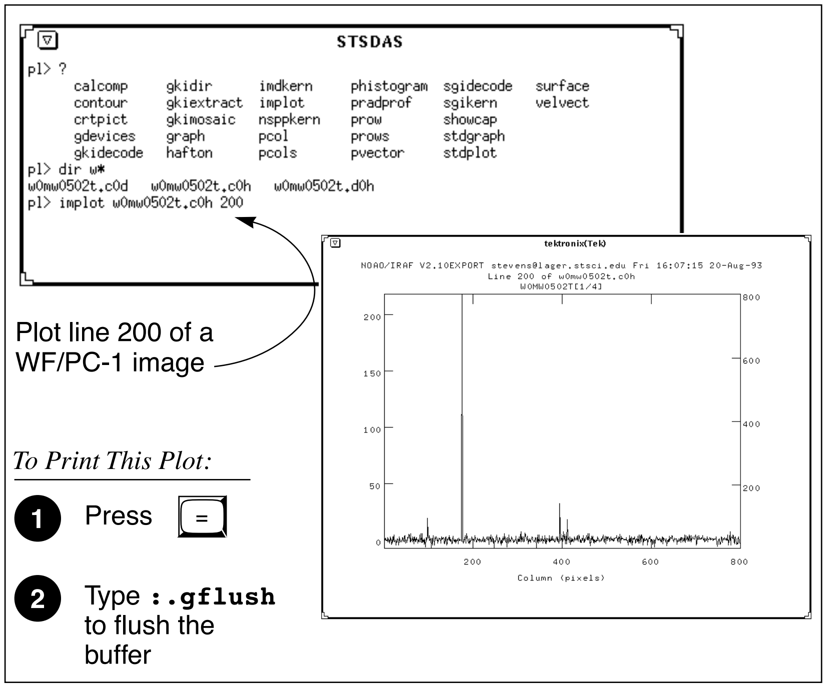
implot

The IRAF **implot** task (in the **plot** package) allows you to examine an image interactively by plotting data along a given *line* (*x* axis) or *column* (*y* axis). When you run the task, a large number of commands are available in addition to the usual cursor mode commands common to most IRAF plotting tasks. A complete listing of commands is found in the on-line help, but the most commonly used are listed in table 3.2. Figure 3.4 shows an example of how to use the **implot** task.

Table 3.2: Basic implot Commands

Keystroke	Command
?	Display on-line help.
L	Plot a line.
C	Plot a column.
Q	Quit implot.
J	Move down.
K	Move up.
Space	Display coordinates and pixel values.

Figure 3.4: Plotting Image Data with implot



imexamine

The IRAF **imexamine** task (in the **images.tv** package) is a powerful task that integrates image display with various types of plotting capabilities. Commands can be passed to the task using the image display cursor and the graphics cursor. A complete description of the task and its usage are provided in the online help, available from within the IRAF environment by typing `help imexamine`.

Table 3.3: Image Manipulation Tasks

Task	Package	Purpose
boxcar	images.imfilter	Boxcar smooth a list of images
gcombine	stsdas.toolbox.imgtools	Combine images using various algorithms and rejection schemes
gcopy	stsdas.toolbox.imgtools	Copy GEIS multigroup images
geomap	images.immatch	Compute a coordinate transformation
geotran	images.immatch	Resample an image based on geomap output
grlist	stsdas.graphics.stplot	List of file names of all groups of a GEIS image (to make @lists)
gstatistics	stsdas.toolbox.imgtools	Compute image statistics[1]
imcalc	stsdas.toolbox.imgtools	Perform general arithmetic on GEIS images[a]
imedit	images.tv	Fill in regions of an image by interpolation
imexamine	images.tv	Examine images using display, plots, and text (see “imexamine” on page 3-13)
implot	plot	Plot lines and columns of images (see “implot” on page 3-12)
magnify	images.imgeom	Magnify an image
msarith	stsdas.toolbox.mstools	Performs basic arithmetic on STIS and NICMOS imsets
mscombine	stsdas.toolbox.mstools	Extension of **gcombine** for STIS and NICMOS imsets
msstatistics	stsdas.toolbox.mstools	Extension of **gstatistics** for STIS and NICMOS imsets
newcont	stsdas.graphics.stplot	Draw contours of two-dimensional data
pixcoord	stsdas.hst_calib.wfpc	Compute pixel coordinates of stars in a GEIS image
plcreate	xray.ximages	Create a pixel list from a region file (e.g., from SAOimage)
rotate	images.imgeom	Rotate an image
saodump	stsdas.graphics.sdisplay	Make image and colormap files from SAOimage display
siaper	stsdas.graphics.stplot	Plot science instrument apertures of HST

1. Will process all groups of a multigroup GEIS file.

3.3.3 Working with STIS, ACS, and NICMOS Imsets

STIS, ACS, and NICMOS data files contain groups of images, called imsets, associated with each individual exposure. A STIS or ACS imset comprises SCI, ERR, and DQ images, which hold science, error, and data quality information. A NICMOS imset, in addition to its SCI, ERR, and DQ images, also contains TIME and SAMP images recording the integration time and number of samples corresponding to each pixel of the SCI image. See the STIS, ACS, and NICMOS Data Structures chapters for more details on imsets.

Here we describe several STSDAS tasks, located in the **stsdas.toolbox.imgtools.mstools** package, that have been designed to work with imsets as units and to deconstruct and rebuild them.

msarith

This tool is an extension of the IRAF task **imarith** to include error and data quality propagation. The **msarith** task supports the four basic arithmetic operations (+, -, *, /) and can operate on individual or multiple imsets. The input operands can be either files or numerical constants; the latter can appear with an associated error, which will propagate into the error array(s) of the output file. Table 3.4 below shows how this task operates on the SCI, ERR, and DQ images in a STIS, ACS, or NICMOS imset, as well as the additional TIME and SAMP images belonging to NICMOS imsets:

Table 3.4: Task msarith Operations

Operation	Operand2	SCI	ERR	DQ	TIME	SAMP
ADD	file	op1+op2	$\sqrt{\sigma 1^2 + \sigma 2^2}$	OR	T1+T2	S1+S2
SUB	file	op1-op2	$\sqrt{\sigma 1^2 + \sigma 2^2}$	OR	T1	S1
MULT	file	op1*op2	$(op1 \times op2)\sqrt{(\sigma 1/op1)^2 + (\sigma 2/op2)^2}$	OR	T1	S1
DIV	file	op1/op2	$(op1/op2)\sqrt{(\sigma 1/op1)^2 + (\sigma 2/op2)^2}$	OR	T1	S1
ADD	constant	op1+op2	$\sqrt{\sigma 1^2 + \sigma 2^2}$	...	...	...
SUB	constant	op1-op2	$\sqrt{\sigma 1^2 + \sigma 2^2}$	...	...	...
MULT	constant	op1*op2	$(op1 \times op2)\sqrt{(\sigma 1/op1)^2 + (\sigma 2/op2)^2}$	...	T1*op2	...
DIV	constant	op1/op2	$(op1/op2)\sqrt{(\sigma 1/op1)^2 + (\sigma 2/op2)^2}$	...	T1*op2	...

In table 3.4, the first operand (op1) is always a file, and the second operand (op2) can be either a constant or a file. The ERR arrays of the input files ($\sigma 1$ and $\sigma 2$) are added in quadrature. If the constant is given with an error ($\sigma 2$), the latter is added in quadrature to the input ERR array. Note that in table 3.4 the pixels in the SCI images are in counts, but **msarith** can also operate on count rates.

mscombine

This task allows you to run the STSDAS task **gcombine** on STIS, ACS, and NICMOS data files. It divides each imset into its basic components (SCI, ERR, and DQ, plus SAMP and TIME for NICMOS) to make them digestible for **gcombine**. The SCI extensions become the inputs proper to the underlying **gcombine** task, and the ERR extensions become the error maps. The DQ extensions are first combined with a user-specified Boolean mask allowing selective pixel masking and then fed into the data quality maps. If scaling by exposure time is requested, the exposure times of each imset are read from the header keyword PIXVALUE in the TIME extensions.

Once **gcombine** has finished, **mscombine** then reassembles the individual output images into imsets and outputs them as one STIS, ACS, or NICMOS data file. The output images and error maps from **gcombine** form the SCI and ERR extensions of the output imset. The DQ extension will be a combination of the masking operations and the rejection algorithms executed in **gcombine**. For NICMOS, the TIME extension will be the sum of the TIME values from the input files minus the rejected values, divided on a pixel-by-pixel basis by the number of valid pixels in the output image. The final TIME array will be consistent with the output SCI image (average or median of the science data). The SAMP extension for NICMOS is built from all the input SAMP values, minus the values discarded by masking or rejection.

msstatistics

This tool is an extension of **gstatistics** in the STSDAS package, which is in turn an extension of **imstatistics**. The main novelty is the inclusion of the error and data quality information included with STIS, ACS, and NICMOS images in computing statistical quantities. In addition to the standard statistical quantities (min, max, sum, mean, standard deviation, median, mode, skewness, kurtosis), two additional quantities have been added to take advantage of the error information: the weighted mean and the weighted variance of the pixel distribution. If x_i is the value at the i-th pixel, with associated error σ_i, the weighted mean and variance used in the task are:

$$\langle x \rangle_w = \frac{\sum_i \frac{x_i}{\sigma_i \times \sigma_i}}{\sum_i \frac{1}{\sigma_i \times \sigma_i}}$$

and:

$$\langle \sigma \rangle_w^2 = \frac{1}{\sum_i \frac{1}{\sigma_i \times \sigma_i}}$$

The data quality information carried by the STIS, ACS, or NICMOS file is used to reject pixels in the statistical computation. Users can supply additional masks to reject objects or regions from the science arrays.

mssplit and msjoin

The **mssplit** task extracts user-specified imsets from a STIS, ACS, or NICMOS data file and copies them into separate files. Each output file contains a single imset along with the primary header of the original file. You might find this task useful for reducing the size of a STIS, ACS, or

NICMOS file containing many imsets or for performing analysis on a specific imset. The **msjoin** task inverts the operation of **mssplit**: it assembles separate imsets into a single data file.

There are additional tasks in this package for deleting and sorting imsets, as well as tasks for addressing a specific image class within an imset.

3.3.4 Photometry

Included in this section are:

- A list of IRAF/STSDAS tasks useful for determining source counts.
- Instructions on how to use header keyword information to convert HST counts to fluxes or magnitudes.
- A brief description of **synphot**, the STSDAS synthetic photometry package.

IRAF and STSDAS Photometry Tasks

The following are some useful IRAF/STSDAS packages and tasks for performing photometry on HST images:

- **apphot**: aperture photometry package.
- **daophot**: stellar photometry package useful for crowded fields.
- **isophote**: package for fitting elliptical isophotes.
- **imexamine**: performs simple photometry measurements.
- **imstat**: computes image pixel statistics.
- **imcnts**: sums counts over a specified region, subtracting background.
- **plcreate**: creates pixel masks.

Consult the online help for more details on these tasks and packages. The document “Photometry using IRAF” by Lisa A. Wells, provides a general guide to performing photometry with IRAF; it is available through the IRAF web page:

`http://iraf.noao.edu/docs/photom.html`

The apphot package allows you to measure fluxes within a series of concentric apertures. This technique can be used to determine the flux in the wings of the PSF, which is useful if you wish to estimate the flux of a saturated star by scaling the flux in the wings of the PSF to an unsaturated PSF.

Converting Counts to Flux or Magnitude

All calibrated HST images record signal in units of counts or Data Numbers (DN)[2]—NICMOS data is DN s^{-1}. The pipeline calibration tasks do not alter the units of the pixels in the image. Instead they calculate and write the inverse sensitivity conversion factor (PHOTFLAM) and the ST magnitude scale zero point (PHOTZPT) into header keywords in the calibrated data. WF/PC-1 and WFPC2 observers should note that the four chips are calibrated individually, so these photometry keywords belong to the group parameters for each chip.

For all instruments other than NICMOS, PHOTFLAM is defined to be the *mean* flux density F_λ in units of erg cm^{-2} s^{-1} $Å^{-1}$ that produces 1 count per second in the HST observing mode (PHOTMODE) used for the observation. If the F_λ spectrum of your source is significantly sloped across the bandpass or contains prominent features, such as strong emission lines, you may wish to recalculate the inverse sensitivity using **synphot**, described below. WF/PC-1 observers should note that the PHOTFLAM value calculated during pipeline processing does not include a correction for temporal variations in throughput owing to contamination buildup. Likewise, FOC observers should note that PHOTFLAM values determined by the pipeline before May 18, 1994 do not account for sensitivity differences in formats other than 512 x 512.

To convert from counts or DN to flux in units of erg cm^{-2} s^{-1} $Å^{-1}$, multiply the total number of counts by the value of the PHOTFLAM header keyword and divide by the value of the EXPTIME keyword (exposure time). You can use the STSDAS task **imcalc** to convert an entire image from counts to flux units. For example, to create a flux-calibrated output image `outimg.fits` from an input image `inimg.fits[1]` with header keywords PHOTFLAM = 2.5E-18 and EXPTIME = 1000.0, you could type:

```
st> imcalc inimg.fits[1] outimg.fits "im1*2.5E-18/1000.0”
```

Calibrated NICMOS data are in units of DN s^{-1}, so the PHOTFLAM values in their headers are in units of erg cm^{-2} $Å^{-1}$. You can simply multiply these images by the value of PHOTFLAM to obtain fluxes in units of erg cm^{-2} s^{-1} $Å^{-1}$. NICMOS headers also contain the keyword PHOTFNU in units of Jy s. Multiplying your image by the PHOTFNU value will therefore yield fluxes in Janskys.

2. Except for 2-D rectified STIS images, which are in units of I_λ.

If your HST image contains a source whose flux you know from ground based measurements, you may choose to determine the final photometry of your HST image from the counts observed for this source.

To convert a measured flux *F*, in units of erg cm^{-2} s^{-1} $Å^{-1}$, to an ST magnitude, plug it into the following equation:

$m = -2.5 \times \log10 (F) + \text{PHOTZPT}$

where the value of the PHOTZPT keyword is the zero point of the ST magnitude scale. The zero point of the ST magnitude system has always been and probably always will be equal to –21.10, a value chosen so that Vega has an ST magnitude of zero for the Johnson *V* passband (see Koornneef et al., 1986; Horne, 1988; and the *Synphot Users Guide*).

synphot

The STSDAS synthetic photometry package, called **synphot**, can simulate HST observations of astronomical targets with known spectra. It contains throughput curves of all HST optical components, such as mirrors, filters, gratings, apertures, and detectors, and can generate passband shapes for any combination of these elements. It can also generate synthetic spectra of many different types, including stellar, blackbody, power-law and H II region spectra, and can convolve these spectra with the throughputs of HST's instruments. You can therefore use it to compare results in many different bands, to cross-calibrate one instrument with another, or to relate your observations to theoretical models.

One useful application of **synphot** is to recalculate the value of PHOTFLAM for a given observation using the latest calibration files. For example, to recalculate PHOTFLAM for an FOC observation, you could use the **calcphot** task in **synphot** as follows:

```
sy> calcphot foc,f/96,x96zlrg,f501n ‘unit(1,flam)’ counts
```

The first argument to **calcphot** gives the instrument and its configuration, in this case the FOC *f*/96 camera in full zoomed format with the F501 filter. (See the **obsmode** task in **synphot** and the *Synphot User's Guide* for help with these observation-mode keywords.) The second tells the task to model a flat F_λ spectrum having unit flux, and the third tells the task to produce output in units of counts per second. After you run **calcphot**, its `result` parameter will contain the count rate expected from the FOC, given this configuration and spectrum. The PHOTFLAM keyword, defined to be the flux required to produce one count per second, simply equals the reciprocal of this value, which you can print to the screen by typing `=1./calcphot.result` at the IRAF prompt.

Please see the *Synphot User's Guide* for more details on this package, and see appendix A for information on getting the **synphot** dataset, which is not included with STSDAS.

3.4 Displaying HST Spectra

This section shows how to plot your HST spectra for a quick first look and how to generate hardcopies of your plots. Because the STIS data format differs from that of FOS and GHRS, we will discuss STIS data separately.

3.4.1 FOS and GHRS Spectra

Before you work with FOS and GHRS data within STSDAS, you will want to convert the FITS files you received from the Archive into GEIS format (see section 2.3.1 for instructions). After conversion, the `.c1h` file will hold the calibrated flux values for each pixel, the `.c0h` file will hold the corresponding wavelengths, and the `.c2h` file will hold the propagated statistical errors.

Each group of an FOS or GHRS GEIS file contains the results of a separate subintegration. FOS readouts taken in ACCUM mode are cumulative, so the last group contains the results of the entire integration. In contrast, GHRS readouts and FOS readouts in RAPID mode are independent. If you want to see the results of an entire GHRS FP-SPLIT integration, you will need to align and coadd the spectra in the groups of the GHRS file. You can also combine all the groups in an FOS or GHRS data file, without wavelength alignment, using the **rcombine** task in the **hst_calib.ctools** package. See online help for details.

The STSDAS task **sgraph** (in the **graphics.stplot** package) can plot the contents of a single GEIS group. For example, if you want to see group 19 of the calibrated FOS spectrum with rootname `y3bl0104t` you can type

```
st> sgraph y3bl0104t.c1h[19]
```

Given an input flux image (`.c1h`), the task **fwplot** (in the **hst_calib.ctools** package) will look for the corresponding wavelength (`.c0h`) file and plot flux versus wavelength. If requested, it will also look for the error (.c2h) file and plot the error bars. To see a plot of the same spectrum as above, but with a wavelength scale and error bars, type

```
st> fwplot y3bl0104t.c1h[19] plterr+
```

If you ever need to plot the contents of multiple groups offset from one another on the same graph, you can use the **grspec** task in the **graphics.stplot** package. For example, to plot groups 1, 10, and 19 of a given flux file, you can type

```
st> grspec y3bl0104t.c1h 1,10,19
```

Note that **grspec** expects group numbers to be listed as a separate parameter, rather than enclosed in the standard square brackets.

3.4.2 STIS Spectra

STIS data files retrieved from the Archive can contain spectra in two different forms: as long-slit spectral images in FITS IMAGE extensions or as extracted echelle spectra in FITS BINTABLE extensions.

You can use **sgraph** to plot STIS long-slit spectra by specifying the image section that contains the spectrum. For example, to plot the entire *x* range of the calibrated two-dimensional spectrum in the first extension of the file o43ba1bnm_x2d.fits, averaging rows 100 through 1000, you would type

```
st> sgraph o43ba1bnm_x2d.fits[1][*,100:1000]
```

Displaying the long-slit spectral image using the **display** task (see section 3.2.1 in the HST Introduction) allows you to see the range of your spectrum in *x* and *y* pixel space, so you can choose a suitable image section for plotting.

To plot STIS spectra in BINTABLE extensions, you first need to understand how STIS spectra are stored as binary arrays in FITS table cells. Chapter 2 (section 2.2.2) discusses this format and describes the *selectors* syntax used to specify these data arrays. Each row of a STIS echelle table contains a separate spectral order, and each column contains data of a certain type, such as WAVELENGTH data or FLUX data. To specify a particular array, you must first type the file name, then the extension containing the BINTABLE, then the column selector, then the row selector. For example, to select the WAVELENGTH array corresponding to spectral order 80 of the echelle spectrum in extension 4 of `stis.fits`, you would specify the file as:

```
stis.fits[4][c:WAVELENGTH][r:sporder=80]
```

The **sgraph** task and the **igi** plotting package, to be discussed below, both understand the *selectors* syntax. In particular, if you wanted to plot the flux versus wavelength in STIS echelle order 80, you could type:

```
st> sgraph "stis.fits[4][r:sporder=80] WAVELENGTH FLUX"
```

Remember to include the quotation marks. Otherwise, **sgraph** will complain about too many positional arguments. Note also that **sgraph** understands only row selector syntax; columns are chosen by name.

The STIS-specific **echplot** task is particularly useful for browsing STIS echelle spectra. It can plot single spectral orders, overplot multiple orders on a single plot, or plot up to four orders in separate panels on the same page. For example, to overplot the orders contained in rows two through four and row six on a single page:

```
cl> echplot "stis_x1d.fits[1][r:row=(2:4,6)]" output.igi \
>>> plot_style=m
```

Note that the `plot_style` parameter governs how the spectral orders are plotted. The `plot_style` values `s`, `m`, and `p` plot one order per page, several orders on a single plot, and one order per panel, respectively. The default brightness unit is calibrated FLUX, although you can specify other quantities (e.g., NET counts) using the `flux_col` parameter. See the online help for details.

3.4.3 Producing Hardcopy

This section shows how to generate hardcopies of plots directly and describes **igi**, the Interactive Graphics Interpreter available in STSDAS.

Direct Hardcopies

To print a quick copy of the displayed plot:

1. Type `=gcur` in the command window (where your CL prompt is located).
2. Move the cursor to any location in the graphics window.
3. Press [=] to write the plot to the graphics buffer.
4. Type `q` to exit graphics mode.
5. At the cl prompt, type `gflush`.

Plots will be printed on the printer defined by the IRAF environment variable stdplot. Type show stdplot to see the current default printer; use set stdplot = printer_name to set the default printer.

The PostScript kernel **psikern** allows you to create PostScript files of your IRAF/STSDAS plots. For example, setting the `device` parameter in a plotting task equal to `psi_port` or `psi_land` invokes **psikern** and directs your plot to either a portrait-mode or a landscape mode PostScript file. For example:

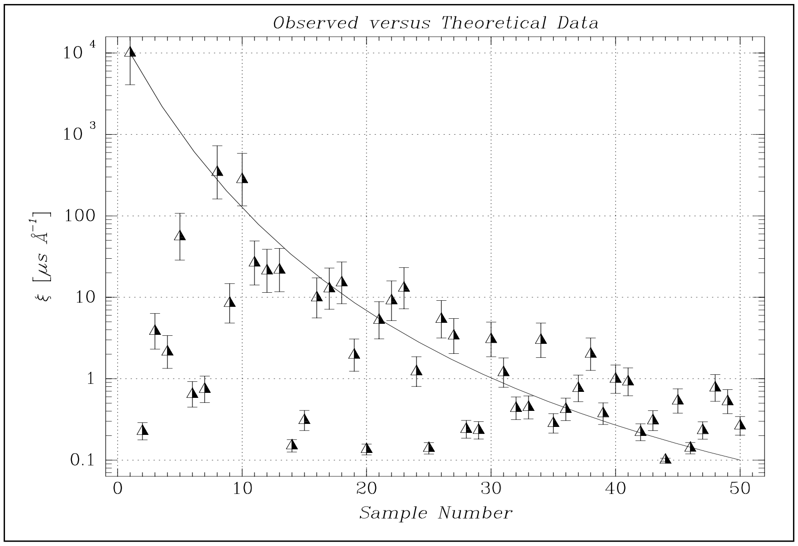
```
st> fwplot y3bl0104t.c1h[19] device=psi_land
st> gflush
/tmp/pskxxxx
```

The above commands would write a plot of flux vs. wavelength in landscape-mode into a temporary PostScript file, named `/tmp/psk`*xxxx* by a UNIX system. See the online help for more about **psikern**, including plotting in color and incorporating PostScript fonts into your plots.

igi

As your plotting needs grow more sophisticated—and especially as you try preparing presentations or publication-quality plots—you should investigate the Interactive Graphics Interpreter, or **igi**. This task, in the STSDAS **stplot** package, can be used with images as well as two- and three-dimensional tables and can draw axes, error bars, labels, and a variety of other features on plots. Different line weights, font styles, and feature shapes are available, enabling you to create complex plots. Figure 3.5 shows a sample plot created in **igi**, however, because **igi** is a complete graphics environment in itself, it is well beyond the scope of this document. You can learn more about **igi** in the *IGI Reference Manual*, available through the *STSDAS Web pages*.

Figure 3.5: Sample igi Plot.



3.5 Analyzing HST Spectra

This section describes some IRAF/STSDAS tasks that can be used for analyzing and manipulating spectral data. Some of these tasks operate directly on HST data files created by the pipeline. However, a number of the most useful IRAF tasks, such as **splot**, require special preparations of data other than STIS two-dimensional spectra. Before discussing these tasks we will first show how to recast your data into forms that are more generally accessible.

3.5.1 Preparing FOS and GHRS Data

The FOS and GHRS data reduction pipelines store fluxes and wavelengths in separate files. In GEIS format, the `.c1h` file contains the flux information and the `.c0h` file contains the wavelength information. Because IRAF tasks generally require both the flux and wavelength information to reside in the same file, you will probably want to create a new file that combines these quantities.

Several options for combining flux and wavelength information are available:

- **resample**: This simple task resamples your flux data onto a linear wavelength scale, creating a new flux file containing the starting wavelength of the new grid in the CRVAL1 keyword and the wavelength increment per pixel in the CD1_1 keyword. Encoding the wavelength information into these standard FITS header keywords makes this format quite portable, but the resampling process loses some of the original flux information. In addition, the error (`.c2h`) and data quality (`.cqh`) files cannot be similarly resampled, limiting the usefulness of this technique.

- **mkmultispec**: This task writes wavelength information into the header of a flux file while preserving all the original information. It is therefore a better choice than **resample** for most applications, and we describe it in more detail below.
- **imtab**: An alternative to writing wavelength information into the header is to use the **imtab** task to create a table recording the wavelength, flux, and if desired, the error data corresponding to each pixel. Many STSDAS tasks, such as those in the STSDAS **fitting** package, can access data in tabular form, so we describe this approach in more detail as well.

mkmultispec

The most convenient method of combining wavelength and flux information, and one that has no effect on the flux data at all, is to use the **mkmultispec** task. This task places wavelength information into the headers of your flux files according to the IRAF multispec-format World Coordinate System (WCS). The multispec coordinate system is intended to be used with spectra having nonlinear dispersions or with images containing multiple spectra, and the format is recognized by many tasks in IRAF V2.10 or later. For a detailed discussion of the multispec WCS, type `help specwcs` at the IRAF prompt.

The **mkmultispec** task can put wavelength information into the flux header files in two different ways. The first involves reading the wavelength data from the `.c0h` file, fitting the wavelength array with a polynomial function, and then storing the derived function coefficients in the flux header file (`.c1h`) in multispec format. Legendre, Chebyshev, or cubic spline (spline3) fitting functions of fourth order or larger produce essentially identical results, all having rms residuals less than 10^{-4} Å, much smaller than the uncertainty of the original wavelength information. Because these fits are so accurate, it is usually unnecessary to run the task in interactive mode to examine them.

If there are discontinuities in the wavelengths, which could arise due to the splicing of different gratings, you should run mkmultispec in interactive mode to verify the fits.

Because mkmultispec can fit only simple types of polynomial functions to wavelength data, this method will not work well with FOS prism data, because of the different functional form of the prism-mode dispersion solution. For prism spectra, use the header table mode of mkmultispec (see below) or create an STSDAS table using imtab.

The other method by which **mkmultispec** can incorporate wavelength information into a flux file is simply to read the wavelength data from the `.c0h` file and place the entire data array directly into the header of the flux (`.c1h`) file. This method simply dumps the wavelength value associated with each pixel in the spectrum into the flux header and is selected by setting the parameter `function=table`. To minimize header size, set the parameter `format` to a suitable value. For example, using `format=%8.7g` will retain the original seven digits of precision of the wavelength values, while not consuming too much space in the flux header file.

Be aware that there is a physical limit to the number of header lines that can be used to store the wavelength array (approximately 1000 lines). This limit cannot be overridden. Under ordinary circumstances this limitation is not an issue. However, if many spectral orders have been spliced together, it may not be possible to store the actual wavelength array in the header, and a fit must be done instead

imtab

Another way to combine wavelengths with fluxes is to create an STSDAS table from your spectrum. The **imtab** task in the STSDAS **ttools** package reads a GEIS format spectral image and writes the list of data values to a column of an STSDAS table, creating a new output table if necessary. The following example shows how to create a flux, wavelength, and error table from group eight of a GEIS-format FOS dataset:

```
cl> imtab y0cy0108t.c0h[8] y0cy0108t.tab wavelength
cl> imtab y0cy0108t.c1h[8] y0cy0108t.tab flux
cl> imtab y0cy0108t.c2h[8] y0cy0108t.tab error
```

The last word on each command line labels the three columns “wavelength”, “flux”, and “error”.

Constructing tables is necessary if you plan to use certain tasks—such as those in the STSDAS **fitting** package—that do not currently recognize the multispec format WCS header information. Tabulating your spectra is also the best option if you want to join two or more spectra taken with different gratings into a single spectrum covering the complete wavelength range. Because the data are stored as individual wavelength-flux pairs, you do not need to resample, and therefore degrade the individual spectra to a common, linear dispersion scale before joining them. Instead, you could create separate tables for spectra from different gratings, and then combine the two tables using, for example, the **tmerge** task:

```
cl> tmerge n5548_h13.tab,n5548_h19.tab n5548.tab append
```

Note that you will first have to edit out any regions of overlapping wavelength from one or the other of the input tables so that the output table will be monotonically increasing (or decreasing) in wavelength.

3.5.2 Preparing STIS Spectra for Analysis

Calibrated STIS spectra emerge from the pipeline either as two-dimensional images (`_x2d` files) or as one-dimensional spectra in tabular form (`_x1d` files.) You can analyze calibrated two-dimensional STIS spectra in IRAF as you would with any other long-slit spectral image, because their headers already contain the necessary wavelength information. Tabulated STIS spectra can be analyzed directly using STSDAS tasks that understand the *selectors* syntax described in section 2.2.2. However, to use IRAF tasks, such as **splot**, that rely on the multispec WCS or to use STSDAS tasks that do not understand three-dimensional tables, you will have to prepare your data appropriately. This section describes two useful tasks for putting your data in the proper form:

- **tomultispec**: This task is the STIS analog to **mkmultispec**, described above. It extracts STIS spectra from tables and writes them as IRAF spectral images with wavelength information in the header.
- **txtable**: This task extracts specified data arrays from STIS table cells and places them in conventional two-dimensional tables for easier access.
- **tximage**: Extracts specified data arrays from STIS table cells and places them into 1-D images. This task can write single group GEIS files.

tomultispec

The **tomultispec** task in the **stsdas.hst_calib.ctools** package extracts one or more spectral orders from a STIS table, fits a polynomial dispersion solution to each wavelength array, and stores the spectra in an output file in original IRAF format (OIF), using the multispec WCS. This task is layered upon the **mkmultispec** task, which performs a similar operation for FOS and GHRS calibrated spectra (see “mkmultispec” on page 3-25). Most of the parameters for **tomultispec** echo those for **mkmultispec**. As a helpful navigational aid, the STIS spectral order numbers are written to the corresponding *beam* numbers in the multispec image; the aperture numbers are indexed sequentially starting from one. You can choose to fit the dispersion solution interactively, but the default fourth-order Chebyshev polynomial will likely suffice for all STIS spectral orders, except for prism-dispersed spectra. However, you cannot use the interactive option if you are selecting more than one order from the input file.

For example, if you want to write all spectral orders from the STIS file `myfile_x1d.fits` to a multispec file:

```
cl> tomultispec myfile_x1d.fits new_ms.imh
```

Note that the `.imh` suffix on the output file specifies that the output file is to be an OIF file. This format is similar to GEIS format, in that it consists of two files: a header file (`.imh`) and a binary data file (`.pix`). The output format for **tomultispec** will always be OIF.

If you want to select particular spectral orders, rather than writing all the orders to the multispec file, you will need to use the **selectors** syntax. To select only the spectrum stored in row nine of the input table, the previous example would change to:

```
cl> tomultispec "myfile_x1d.fits[r:row=9]" new_ms.imh
```

Note that the double quote marks around the file name and row selector are necessary to avoid syntax errors. To select a range of rows, say rows nine through eleven:

```
cl> tomultispec "myfile_x1d.fits[r:row=(9:11)]" new_ms.imh
```

You can also select rows based upon values in some other column. For example, to select all rows whose spectral order lies in the range 270 to 272, type:

```
cl> tomultispec "myfile_x1d.fits[r:sporder=(270:272)]" \
>>> new_ms.imh
```

The calibrated flux is extracted by default. However, other intensity data can be specified by setting the `flux_col parameter`.

Be careful not to restrict the search for matching rows too heavily

Column selectors cannot be used with tomultispec

Choose the type of fitting function for the tomultispec dispersion solution with care. Using the table option, which writes the entire wavelength array to the image header for each order, will fail if more than about three orders are selected. This restriction results from a limit to the number of keywords that can be used to store the dispersion relation.

txtable

Tabulated STIS spectra are stored as data arrays within individual cells of FITS binary tables (see section 2.2.2). These tables are effectively three-dimensional, with each column holding a particular type of quantity (e.g., wavelengths, fluxes), each row holding a different spectral order, and each cell holding a one-dimensional array of values spanning the wavelength space of the order. The **txtable** in the **tables.ttools** package extracts these data arrays from the cells specified with the selectors syntax and stores them in the columns of conventional two-dimensional binary tables.

For example, suppose the first extension of the FITS file `data.fits` contains a STIS echelle spectrum and you want to extract only the wavelength and flux arrays corresponding to spectral order 68. You could then type:

```
tt> txtable “data.fits[1][c:WAVELENGTH,FLUX][r:sporder=68]” \
>>> out_table
```

This command would write the wavelength and flux arrays to the columns of the output table out_table. To specify multiple rows in a tabulated echelle spectrum, you would type:

```
tt> txtable “data.fits[1][c:WAVELENGTH,FLUX][r:row=(10:12)]” \
>>> echl
```

This command would generate three separate output files named echl_r0010.tab, echl_r0011.tab, and echl_r0012.tab.

See the online help for more details on **txtable** and the selectors syntax, and remember to include the double quotation marks.

The similar **tximage** task can be used to generate single-group GEIS files from STIS data, which can then be used as input to tasks such as **resample**.

```
tt> tximage "data.fits[1][c:WAVELENGTH][r:row=4]" wave.hhh
tt> tximage "data.fits[1][c:FLUX][r:row=4]" flux.hhh
```

3.5.3 General Tasks for Spectra

IRAF has many tasks for analyzing both one- and two-dimensional spectral data. Many observers will already be familiar with **noao.onedspec** and **noao.twodspec** packages, and those who are not should consult the online help. Table 3.5 lists some of the more commonly used IRAF/STSDAS spectral analysis tasks, and below we briefly describe **splot**, one of the most versatile and useful. Remember that many of these tasks expect to find WCS wavelength information in the header, so you should first run **mkmultispec** or **tomultispec** on your data, if necessary.

Table 3.5: Tasks for Working with Spectra

Task	Package	Input Format	Purpose
boxcar	images.imfilter	Image	Boxcar smooth a list of images
bplot	noao.onedspec	Multispec image	Plot spectra non-interactively
continuum	noao.onedspec	Image	Continuum normalize spectra
fitprofs	noao.onedspec	Image	Non-interactive Gaussian profile fitting to features in spectra and image lines
gcopy	stsdas.toolbox.imgtools	GEIS image	Copy multigroup images
grlist	stsdas.graphics.stplot	GEIS image	List file names for all groups in a GEIS image; used to make lists for tasks that do not use group syntax
grplot	stsdas.graphics.stplot	GEIS image	Plot arbitrary lines from 1-D image; overplots multiple GEIS groups; no error or wavelength information is used
grspec	stsdas.graphics.stplot	Multispec GEIS image	Plot arbitrary lines from 1-D image; stack GEIS groups
magnify	images.imgeom	Image	Interpolate spectrum on finer (or coarser) pixel scale
nfit1d	stsdas.analysis.fitting	Image, table	Interactive 1-D non-linear curve fitting (see section 3.5.4)
ngaussfit	stsdas.analysis.fitting	Image, table	Interactive 1-D multiple Gaussian fitting (see section 3.5.4)
poffsets	stsdas.hst_calib.ctools	GEIS image	Determine pixel offsets between shifted spectra
rapidlook	stsdas.hst_calib.ctools	GEIS image	Create and display a 2-D image of stacked 1-D images
rcombine	stsdas.hst_calib.ctools	GEIS image	Combine (sum or average) GEIS groups in a 1-D image with option of propagating errors and data quality values
resample	stsdas.hst_calib.ctools	GEIS image	Resample FOS and GHRS data to a linear wavelength scale (see section 3.5.1)
sarith	noao.onedspec	Multispec image	Spectrum arithmetic
scombine	noao.onedspec	Multispec image	Combine spectra
sfit	noao.onedspec	Multispec image	Fit spectra with polynomial function
sgraph	stsdas.graphics.stplot	Image, table	Plot spectra and image lines; allows overplotting of error bars and access to wavelength array (see section 3.4.1)
specalign	stsdas.hst_calib.ctools	GEIS image	Align and combine shifted spectra (see **poffsets**)
specplot	noao.onedspec	Multispec image	Stack and plot multiple spectra
splot	noao.onedspec	Multispec image	Plot and analyze spectra & image lines (see “splot” on page 3-31)

splot

The **splot** task in the IRAF **noao.onedspec** package is a good general analysis tool that can be used to examine, smooth, fit, and perform simple arithmetic operations on spectra. Because it looks in the header for WCS wavelength information, your file must be suitably prepared. Like all IRAF tasks, **splot** can work on only one group at a time from a multigroup GEIS file. You can specify which GEIS group you want to operate on by using the square bracket notation, for example:

```
cl> splot y0cy0108t.c1h[8]
```

If you don't specify a group in brackets, **splot** will assume you want the first group. In order to use **splot** to analyze your FOS or GHRS spectrum, you will first need to write the wavelength information from your `.c0h` file to the header of your `.c1h` files in WCS, using the **mkmultispec** task (see "mkmultispec" on page 3-25).

The **splot** task has *many* available options described in detail in the online help. Table 3.6 summarizes a few of the more useful cursor commands for quick reference. When you are using **splot**, a log file saves results produced by the equivalent width or de-blending functions. To specify a file name for this log file, you can set the `save_file` parameter by typing, for example:

```
cl> splot y0cy0108t.c1h[8] save_file=results.log
```

If you have used **tomultispec** to transform a STIS echelle spectrum into `.imh/.pix` OIF files with WCS wavelength information (see "tomultispec" on page 3-27), you can step through the spectral orders stored in image lines using the ")", "(", and "#" keys. To start with the first entry in your OIF file, type:

```
cl> splot new_ms.imh 1
```

You can then switch to any order for analysis using the ")" key to increment the line number, the "(" key to decrement, and the "#" key to switch to a specified image line. Note the beam label that gives the spectral order cannot be used for navigation. See the online help for details.

Table 3.6: Useful splot Cursor Commands

Command	Purpose
Manipulating spectra	
f	Arithmetic mode; add and subtract spectra
l	Convert spectrum from f_ν to f_λ (invert transformation with “n”)
n	Convert spectrum from f_λ to f_ν
s	Smooth with a boxcar
u	Define linear wavelength scale using two cursor markings
Fitting spectra	
d	Mark two continuum points & de-blend multiple Gaussian line profiles
e	Measure equivalent width by marking points around target line
h	Measure equivalent width assuming Gaussian profile
k	Mark two continuum points and fit a single Gaussian line profile
m	Compute the mean, RMS, and S/N over marked region
t	Enter interactive curve fit function (usually used for continuum fitting)
Displaying and redrawing spectra	
a	Expand and autoscale data range between cursor positions
b	Set plot base level to zero
c	Clear all windowing and redraw full current spectrum
r	Redraw spectrum with current windowing
w	Window the graph
x	Etch-a-sketch mode; connects two cursor positions
y	Overplot standard star values from calibration file
z	Zoom graph by a factor of two in X direction
$	Switch between physical pixel coordinates and world coordinates
General file manipulation commands	
?	Display help
g	Get another spectrum
i	Write current spectrum to new or existing image
q	Quit and go on to next input spectrum

3.5.4 STSDAS fitting Package

The STSDAS **fitting** package contains several tasks, as listed in table 3.7, for fitting and analyzing spectra and images. The **ngaussfit** and **nfit1d** tasks, in particular, are very good for interactively fitting multiple Gaussians and nonlinear functions, respectively, to spectral data. These tasks do not currently recognize the multispec WCS method of storing wavelength information. They recognize the simple sets of dispersion keywords such as W0, WPC and CRPIX, CRVAL, and CDELT, but these forms apply only to linear coordinate systems and therefore would require resampling of your data onto a linear wavelength scale first. However, these tasks do accept input from STSDAS tables, in which you can store the wavelength and flux data value pairs or wavelength, flux, error value triples (see "imtab" on page 3-26).

Table 3.7: Tasks in the STSDAS fitting Package

Task	Purpose
function	Generate functions as images, tables, or lists
gfit1d	Interactive 1-d linear curve fit to images, tables, or lists
i2gaussfit	Iterative 2-d Gaussian fit to noisy images (script)
nfit1d	Interactive 1-d non-linear curve fit to images, tables, or lists
ngaussfit	Interactive 1-d multiple Gaussian fit to images, tables, or lists
n2gaussfit	2-d Gaussian fit to images
prfit	Print contents of fit tables created by fitting task

When using tasks such as **ngaussfit** and **nfit1d**, you must provide initial guesses for the function coefficients as input to the fitting algorithms. You can either specify these initial guesses via parameter settings in the task's parameter sets (psets) or enter them interactively. For example, suppose you want to fit several features using the **ngaussfit** task. Using the default parameter settings, you can start the task by typing:

```
fi> ngaussfit n4449.hhh linefits.tab
```

This command reads spectral data from the image `n4449.hhh` and stores the results of the line fits in the STSDAS table `linefits.tab`. After you start the task, your spectrum should appear in a plot window and the task will be left in cursor input mode. You can use the standard IRAF cursor mode commands to rewindow the plot, resticting your display to the region around a particular feature or features that you want to fit. You may then want to:

- Define a sample region (using the cursor mode S command) over which the fit will be computed so that the task will not try to fit the entire spectrum.
- Define an initial guess for the baseline coefficients by placing the cursor at two baseline locations (one on either side of the feature to be fitted) using the B keystroke.
- Use the R keystroke to redraw the screen and see the baseline that you've just defined.
- Set the initial guesses for the Gaussian centers and heights by placing the cursor at the peak of each feature and typing P.
- Press F to compute the fit once you've marked all the features you want to fit.

The results will automatically be displayed. You can use the `:show` command to see the coefficient values.

Note that when the **ngaussfit** task is used in this way (i.e., starting with all default values), the initial guess for the FWHM of the features will be set to a value of one. Furthermore, this coefficient and the coefficients defining the baseline are held fixed by default during the computation of the fit, unless you explicitly tell the task through cursor *colon* commands[3] to allow these coefficients to vary. It is sometimes best to leave these coefficients fixed during an initial fit, and then to allow them to vary during a second iteration. This rule of thumb also applies to the setting of the `errors` parameter which controls whether or not the task will estimate error values for the derived coefficients. Because the process of error estimation is very CPU-intensive, it is most efficient to leave the error estimation turned off until you've got a good fit, and then turn the error estimation on for one last iteration.

Figure 3.6 and figure 3.7 shows the results of fitting the Hβ (4861Å) and [OIII] (4959 and 5007 Å) emission features in the spectrum of NGC 4449. The resulting coefficients and error estimates (in parentheses) are shown in figure 3.7.

3. To see the online help for details and a complete listing of cursor mode colon commands: type `help cursor`.

Figure 3.6: Fitting Hβ and [OIII] Emission Features in NGC 4449

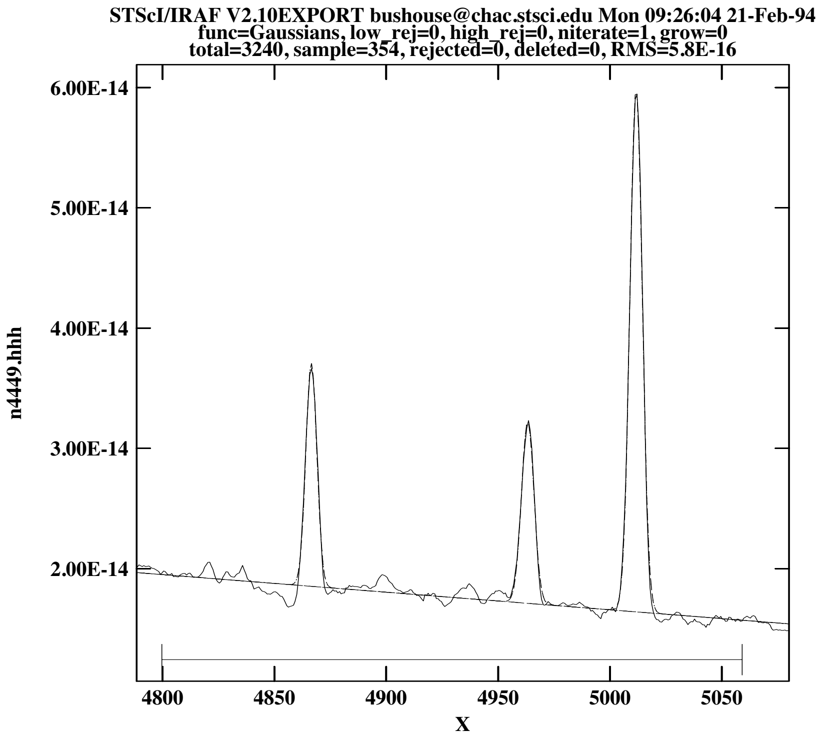


Figure 3.7: Coefficients and Error Estimates

```
function = Gaussians
coeff1 = 8.838438E-14    (0.)             - Baseline zeropoint (fix)
coeff2 = -1.435682E-17   (0.)             - Baseline slope (fix)
coeff3 = 1.854658E-14    (2.513048E-16)    - Feature 1: amplitude (var)
coeff4 = 4866.511        (0.03789007)     - Feature 1: center (var)
coeff5 = 5.725897        (0.0905327)      - Feature 1: FWHM (var)
coeff6 = 1.516265E-14    (2.740680E-16)    - Feature 2: amplitude (var)
coeff7 = 4963.262        (0.06048062)     - Feature 2: center (var)
coeff8 = 6.448922        (0.116878)       - Feature 2: FWHM (var)
coeff9 = 4.350271E-14    (2.903318E-16)     - Feature 3: amplitude (var)
coeff10 = 5011.731       (0.01856957)     - Feature 3: center (var)
coeff11 = 6.415922       (0.03769293)     - Feature 3: FWHM (var)
rms           = 5.837914E-16
grow          = 0.
naverage      = 1
low_reject    = 0.
high_reject   = 0.
niterate      = 1
sample        =  4800.132:5061.308
```

3.5.5 specfit

The **specfit** task, in the STSDAS **contrib** package, is another powerful interactive facility for fitting a wide variety of emission-line, absorption-line, and continuum models to a spectrum. This task was written by Gerard Kriss. Extensive online help is available to guide you through the task,[4] although because it is a contributed task, little to no support is provided by the STSDAS group.

The input spectrum to **specfit** can be either an IRAF image file or an ASCII file with a simple three-column (wavelength, flux, and error) format. If the input file is an IRAF image, the wavelength scale is set using values of W0 and WPC or CRVAL1 and CDELT1. Hence, for image input, the spectral data must be on a linear wavelength scale. In order to retain data on a non-linear wavelength scale, it is necessary to provide the input spectrum in an ASCII file, so that you can explicitly specify the wavelength values associated with each data value. The online help explains a few pieces of additional information that must be included as header lines in an input text file.

By selecting a combination of functional forms for various components, you can fit complex spectra with multiple continuum components, blended emission and absorption lines, absorption edges, and extinction. Available functional forms include linear, power-law, broken power-law, blackbody, and optically thin recombination continua, various forms of Gaussian emission and absorption lines, absorption-edge models, Lorentzian line profiles, damped absorption-line profiles, and mean galactic extinction.

3.6 References

3.6.1 Available from STScI

(http://stsdas.stsci.edu/STSDAS.html

- *STSDAS Users Guide* , version 1.3, September 1994.
- *STSDAS Installation and Site Managers Guide*, version 2.3, June 2001.
- *Synphot Users Guide*, December 1998.
- *IGI Reference Manual* , version 1.3, October 1992.

4. Additional information is available in the *Astronomical Data Analysis Software and Systems III*, ASP Conference Series, Vol. 61, page 437, 1994.

3.6.2 Available from NOAO

(http://iraf.noao.edu/docs/docmain.html)

- *A Beginners Guide to Using IRAF,* 1993, J. Barnes.
- *Photometry Using IRAF*, 1994, L. Wells.
- *A User's Guide to Stellar CCD Photometry with IRAF*, 1992, P. Massey and L. Davis.

3.6.3 Other References Cited in This Chapter

- Horne, K., 1988, in *New Directions in Spectrophotometry*, A.G.D. Philip, D.S. Hayes, and S.J. Adelman, eds., L. Davis Press, Schenectady NY, p. 145.
- Koorneef, J., R. Bohlin, R. Buser, K. Horne, and D. Turnshek, 1986, in *Highlights of Astronomy*, Vol. 7, J.-P. Swinds, ed., Reidel, Dordrecht, p. 833.
- Kriss, G., 1994, in *Astronomical Data Analysis Software and Systems III* , PASP Conference Series, Vol. 61, p. 437.

PART II:

WFPC2 Data Handbook

This handbook is designed to help you manipulate, process and analyze data from the Wide Field and Planetary Camera 2 (WFPC2) instrument on-board the Hubble Space Telescope (HST).

WFPC2 Introduction

How to Use this Handbook

This handbook is designed to help you manipulate, process and analyze data from the Wide Field and Planetary Camera 2 (WFPC2) instrument on-board the Hubble Space Telescope (HST). The book is presented as an independent and self-contained document, extensively based on the contents of an older edition (version 3.0) of the HST Data Handbook. The HST Data Handbook has now been subdivided into separate volumes for each instrument. Users who require more general information about details of acquiring HST data from archive, their file formats, and general purpose software for displaying and processing these data, are referred to a companion volume, the Introduction to Reducing the HST Data.

The current edition of the WFPC2 Data Handbook is being written in late 2001, as we approach Servicing Mission 3b (SM3b). The behavior of this instrument is not likely to change after the servicing mission. Therefore, the material presented in this handbook is expected to remain up-to-date during the next cycles. However, as each servicing mission is followed by a checkout period, to verify that no changes in the camera calibrations have occurred, any such changes are reported in Instrument Science Reports (e.g., see ISRs on WFPC2 observatory verifications after SM3a and SM2 (ISR 00-02 and 97-09)).

The present revision incorporates our detailed knowledge of the behavior and characteristics of the WFPC2 and the data obtained by this instrument. The main changes to the current WFPC2 data handbook over its previous version (revised in 1997) include: discussion of correction flatfields, which can be useful for highly-exposed science images in PC and lower exposure levels in UV filters on WF chips; advice on generating custom dark reference files, which could improve hot pixel corrections; summary of the WFPC2 pipeline processing history (OPUS, OTFC, OTFR) and the introduction of On The Fly Reprocessing (OTFR); and detailed information for converting the photometry from the WFPC2 filters to other systems widely used in literature.

While the present version of the Data Handbook contains the latest information for accurate reduction and analysis of the WFPC2 data, readers are advised to consult the Space Telescope Science Institute web site (http://hst.stsci.edu/hst/HST_overview/instruments) for the most recent up-dates regarding WFPC2 performance.

Bahram Mobasher, Chief Editor, HST Data Handbook
Sylvia Baggett and Matthew McMaster,
Editors, WFPC2 Data Handbook

CHAPTER 1:

WFPC2 Instrument Overview

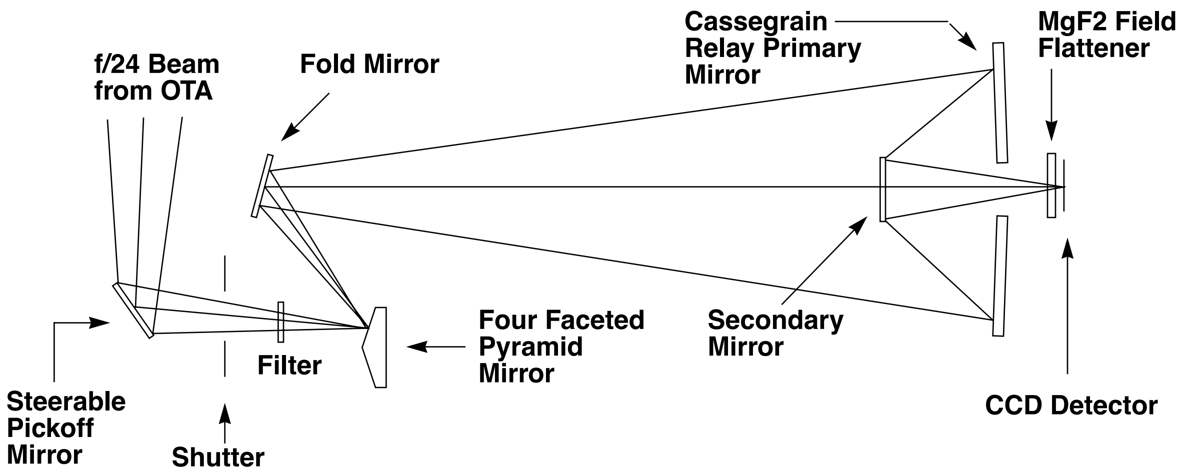
The Wide Field and Planetary Camera 2 (WFPC2) is a two-dimensional imaging device covering a wavelength range from Lyman-α to about 1 μm. Built at the Jet Propulsion Laboratory by an Investigation Definition Team (IDT) headed by John Trauger, WFPC2 was the replacement for the first Wide Field and Planetary Camera (WF/PC-1) and includes built-in corrections for the spherical aberration of the HST Optical Telescope Assembly (OTA). The WFPC2 was installed in HST during the First Servicing Mission in December 1993. An early IDT report of the WFPC2 on-orbit performance can be found in Trauger et al. (1994, *ApJ*, 435, L3), and a more detailed assessment of its capabilities can be found in Holtzman et al. (1995, *PASP*, 107, page 156 and page 1065).

The WFPC2 field of view is located at the center of the HST focal plane; figure 1.1 shows a schematic of its optical arrangement. The central portion of the *f*/24 beam coming from the OTA is intercepted by a steerable pick-off mirror attached to the WFPC2 and is diverted through an open port entry into the instrument. The beam then passes through a shutter and interposable filters. A total of 48 spectral elements and polarizers are contained in an assembly of 12 filter wheels. The light then falls onto a shallow-angle, four-faceted pyramid, located at the aberrated OTA focus. Each face of the pyramid is a concave spherical surface, dividing the OTA image of the sky into four parts. After leaving the pyramid, each quarter of the full field of view is relayed by an optically flat mirror to a Cassegrain relay that forms a second field image on a charge-coupled device (CCD) of 800 x 800 pixels. Each of these four detectors is housed in a cell sealed by a MgF_2 window, which is figured to serve as a field flattener.

The aberrated HST wavefront is corrected by introducing an equal but opposite error in each of the four Cassegrain relays. An image of the HST primary mirror is formed on the secondary mirrors in the Cassegrain relays.

The spherical aberration from the telescope's primary mirror is corrected on these secondary mirrors, which are extremely aspheric; the resulting point spread function is quite close to that originally expected for WF/PC-1.

Figure 1.1: WFPC2 Optical Configuration



The optics of three of the four cameras - the Wide Field Cameras (WF2, WF3, WF4) - are essentially identical and produce a final focal ratio of *f*/12.9. The fourth camera, known as the Planetary Camera (PC or PC1), has a focal ratio of *f*/28.3. figure 1.2 shows the field of view of WFPC2 projected on the sky; the U2,U3 axes are defined by the "nominal" Optical Telescope Assembly (OTA) axis, which is near the center of the WFPC2 FOV. The readout direction is marked with an arrow near the start of the first row in each CCD; note that it rotates 90 degrees between successive chips. The *x,y* arrows mark the coordinate axes for any POS TARG commands[1] that may have been specified in the proposal; the Proposal Instructions elaborate on the use of this requirement.

The position angle of V3 on the sky varies with pointing direction and observation epoch and is recorded in the calibrated science header keyword PA_V3. Note that for WFPC2, the PA_V3 is offset 180 degrees from any ORIENT that may have been requested in the HST proposal; as an optional parameter, ORIENT can be found in the proposals but is not recorded in the WFPC2 headers. The orientation of each camera on the sky, i.e., position angle of the y-axis of each detector, is provided by the ORIENTAT group keyword in the image headers. The geometry of the

1. POS TARG, an optional special requirement in HST observing proposals, places the target an offset of POS TARG (in arc sec) from the specified aperture.

cameras and the related group and image keywords are explained in greater detail in chapter 2.

Figure 1.2: WFPC2 Field of View Projected on the Sky

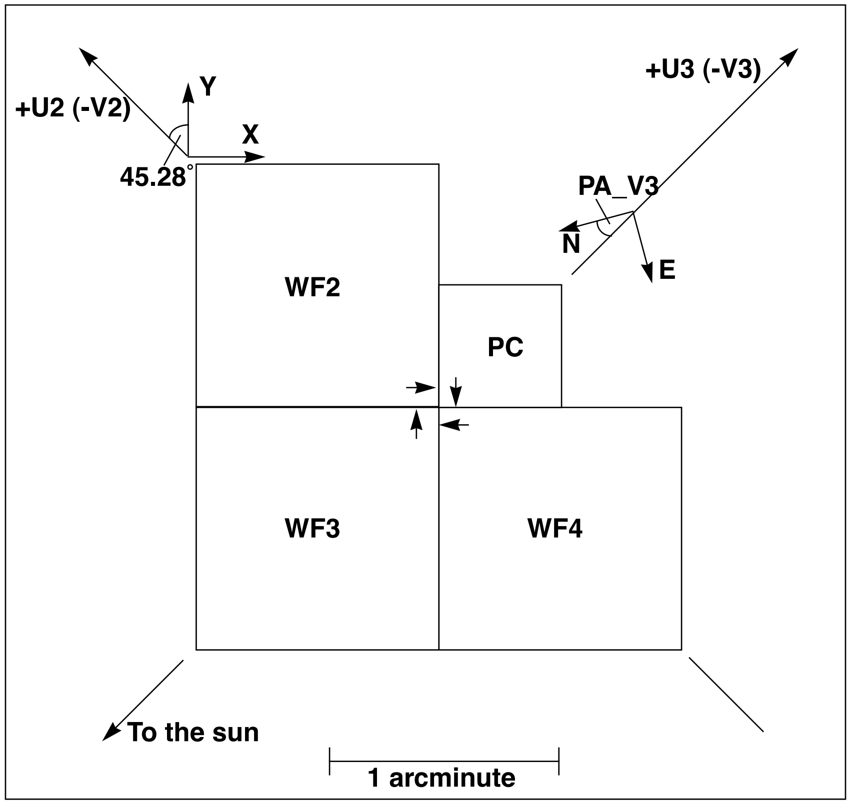


Table 1.1: Camera Configurations

Camera	Pixels	Field of View	Scale	f/ratio
PC	800 x 800	36" x 36"	0.0455" per pixel	28.3
WF2, 3, 4	800 x 800	80" x 80"	0.0996" per pixel	12.9

The Planetary Camera (PC) provides a field of view sufficient to obtain full disk images of all planets except for Jupiter, though the pixels undersample the point spread function of the telescope and camera optics by a factor of two at 5800 Å. The WF pixels are over a factor of two larger, and thus undersample the image by a factor of four at visual wavelengths. It is possible to recover some of the sampling lost to these large pixels by image dithering, i.e., taking observations at different sub-pixel offsets. A short discussion of dithering is provided in section 5.5; more detailed information is available in the HST Dither Handbook.

The readout direction of the four CCDs is defined such that in IRAF pixel numbering (origin at lower left corner), the origin of the CCD lies at the corner of the chip pointing towards the apex of the WFPC2 pyramid (see figure 1.2). As a result of the aberration of the primary beam, the light from sources near the pyramid edges is divided between adjacent chips. Consequently, the lower columns and rows of the PC and WF chips are strongly vignetted, as shown in table 1.2. The CCD *x*,*y* (column, row) numbers given in this table vary at the 1–2 pixel level because of bending and tilting of the field edge in detector coordinates due to geometric distortion in the camera.

Table 1.2: Inner Field Edges of Field Projected Onto CCDs

Camera	Start Vignetted Field	Contiguous Field	Start Unvignetted Field
PC1	x>0 and y>8	x> 44 and y>52	x>88 and y>96
WF2	x>26 and y>6	x>46 and y>26	x>66 and y>46
WF3	x>10 and y>27	x>30 and y>47	x>50 and y>67
WF4	x>23 and y>24	x>43 and y>44	x>63 and y>64

The STSDAS task **wmosaic** provides a convenient way to piece the four groups into a single image comprising the full WFPC2 field of view. This task, in its default mode, will combine the four chips into a large, 1600 x 1600 pixel image at the resolution of the Wide Field cameras, resampling the pixels and correcting for the chip overlap, rotations, and geometric distortion. Consequently, resolution will be lost in the PC, whose pixels are rebinned to the resolution of the Wide Field Cameras (a factor 2.3 coarser).

While the images produced by* wmosaic *are usually adequate for presentations and the identification of interesting features, they are not recommended for science uses because of the loss of resolution and photometric accuracy associated with data resampling, especially in the PC.

Finally, a comment about readout modes. There are two observation modes available on WFPC2, full and area; the mode used for a given observation is recorded in the image header keyword MODE. In full mode, each pixel is read out individually, while in area mode pixels are summed in 2 x 2 boxes before they are read out. The advantage of area mode is that readout noise for the larger pixels is nearly the same as for the unsummed pixels: $6e^-$ vs. $5e^-$ per pixel. Thus, area mode can be useful in observations of extended sources when the primary source of noise is readout noise, as is often the case in the far UV.

In practice, observers have made very limited use of the area mode capability; less than 0.1% of all WFPC2 images in the archive are area mode. As a result, area mode calibration is not supported at the same level as full mode. Although reference files such as biases, darks, and flatfields are available for area mode images, they may not provide the best calibration as they are not updated and improved as frequently as the full mode reference files. Researchers using area mode images are advised to consult the list of best available reference files, and consider generating their own area mode calibration files in order to manually recalibrate their data. See section 3.4 for more information on how to manually recalibrate WFPC2 data. For assistance, questions, or problems, e-mail the HST helpdesk at help@stsci.edu.

CHAPTER 2:

WFPC2 Data Structures

In this chapter. . .

This chapter describes how WFPC2 data are configured and delivered and how these data products relate to the original specifications in the Phase II proposal. We describe the data format used by STScI to distribute WFPC2 observations and the meanings of the header keywords that the user is likely to find most important. Finally, we describe the paper products made available to the Principal Investigator (PI) with the initial data delivery into the Archive and how users can reproduce them.

2.1 Data Files and Suffixes

HST data files are distributed by the Archive in FITS format, either via tape or electronically (see chapter 1 of the HST Introduction). For historical reasons, *WFPC2 files are provided in "waivered FITS" format, which is not the same as the extension FITS format of the more recent STIS and NICMOS instruments*. (See chapter 2 of the HST Introduction) The waivered FITS format WFPC2 files can be converted into the so-called GEIS format using the STSDAS task **strfits**. Users unfamiliar with GEIS format or the **strfits** task should consult chapter 2 of the HST Introduction;

in addition, the WFPC2 Data Analysis Tutorial provides cookbook examples of converting and working with WFPC2 images.

A Note about HST File Formats

Data for WFPC2 and other older instruments (FOC, FOS, FGS, GHRS, HSP, WF/PC1) are generated in the so-called ***GEIS***, or Generic Edited Information Set, format. An HST-specific format, a GEIS image consists of a header file and a binary data file; one of the primary reasons it was used for the early generations of HST instruments was that it easily accommodated multiple images, each assigned to its own group, within a single GEIS file. A WFPC2 exposure, consisting of four images, one from each camera, could be stored in a single GEIS file.

However, GEIS format is also machine-dependent and is therefore not ideal for archival storage and distribution. For this reason, a specialized FITS format was developed, referred to as "***waivered***" ***FITS***. Since waivered FITS format can only be a single file, multiple group data, such as in WFPC2 exposures, must be stored as a 3-dimensional image. For example, a typical WFPC2 observation file contains four 800x800 pixel images (one for each chip); each of the four images is stored in its own group in one GEIS format file, while the waivered FITS format consists of the four images in an 800x800x4 (3-d) cube.

Observers who intend to use IRAF and STSDAS tasks for their WFPC2 data analysis should first convert from FITS format images to GEIS format. Many IRAF and STSDAS tasks do not work properly on the waivered FITS format WFPC2 files, particularly for groups 2 through 4.

Several years after the implementation of the waivered FITS format, new enhancements were developed for FITS format data, providing significant flexibility. In particular, FITS files can now contain multiple image extensions, each with its own header, size, and datatype. This type of FITS has been dubbed "***extension***" ***FITS*** and has now been adopted as the standard for current and future HST data (e.g., STIS, NICMOS, ACS).

The example below illustrates the use of the STSDAS **catfits** task, which can be used to ascertain the FITS format of a file; the WFPC2 image u5kl0101r is in waivered FITS format (note the dimensions) while the NICMOS image is in the new extension FITS format. Please refer to chapter 2 of the HST Introduction for a more extensive comparison of the various formats.

```
cl> catfits u5kl0101r_c0f.fits

EXT#  FITSNAME     FILENAME            EXTVE DIMENS
BITPI OBJECT

0    u5kl0101r_c0f u5kl0101r_cvt.c0h         800x800x4
-32F

1    TABLE    u5kl0101r_cvt.c0h.tab    49Fx4R


cl> catfits n3zd0wetq_ima.fits

EXT#  FITSNAME     FILENAME            EXTVE DIMENS
BITPI OBJECT

0    n3zd0wetq_ima n3zd0wetq_ima.fits                   16

1      IMAGE      SCI                1    256x256     -32

2      IMAGE      ERR                1    256x256     -32

3      IMAGE      DQ                 1    256x256      16

4      IMAGE      SAMP               1                 16

5      IMAGE      TIME               1                -32

6      IMAGE      SCI                2    256x256     -32

7      IMAGE      ERR                2    256x256     -32

8      IMAGE      DQ                 2    256x256      16

... [lines removed to improve readability]

55    IMAGE     TIME            11           -32
```

To avoid confusion for experienced WFPC2 observers, WFPC2 data continues to be delivered from the Archive in waivered FITS format. Note, however, that since observers are becoming more familiar with extension FITS format in the new instruments, adding an extension FITS option to WFPC2 Archive retrieval formats is being considered. Work is underway to upgrade IRAF and STSDAS tasks to handle WFPC2 data in both GEIS and extension FITS format (this is needed before the Archive can begin to deliver WFPC2 data in extension FITS format), though the changes will not guarantee that the tasks will work properly on waivered FITS data. This work will require the release of some new conversion tasks (fits2geis and geis2fits) and changes to the Archive to make extension FITS format an option for retrieving WFPC2 data. In any event, the waivered FITS format will not disappear, extension FITS format merely would become a new option for data retrieval and analysis. Any such future enhancements will be clearly advertised via the Newsletters and WWW pages.

GEIS Files

After conversion to GEIS format, a directory listing (type `dir` within IRAF) will show that the files have a nine-character rootname and a three-character suffix (also called the “extension”). By definition, all files for a single exposure will have the same rootname. The image rootnames (e.g., `u2850303p`) are constructed from several pieces: the first character represents the instrument used (always U for WFPC2), followed by a three character program ID (unique to each proposal), a two character observation set ID (often identical to the visit number), a two character observation number, and a single character for the data transfer path. For each instrument, the suffix uniquely identifies the file contents. The WFPC2 suffixes are listed in table 2.1.

Files whose suffix ends with the letter “h” (e.g., `u2850303p.c1h`) are the ASCII *header files*. The header files contain keywords that describe the parameters used to take the observation, the processing of the data, the properties of the image, and a description of the group keywords. Files whose suffix ends in the letter “d” (e.g., `u2850303p.c1d`) are binary *data files*; these files contain the data as well as values of the group keywords. A single GEIS image is composed of a header and data *pair* (e.g., the files `u2850303p.c1h` and `u2850303p.c1d` together represent a single image). Note that in FITS format, useful for network transfers, header and data are combined into a single file; the name of the FITS file becomes: *rootname_suffix*`.fits`, with the letter “f” replacing “h” or “d” in the suffix (e.g., `u2850303p_c1f.fits`). GEIS files may be converted back to waivered FITS format by using the STSDAS task **stwfits**, see chapter 3 of the HST Introduction. As noted in chapter 3 of the HST Introduction, you should set your ’tmp’ directory to "./", imtype to ".hhh", and imdir to "HDR$" as shown below:

```
cl> set tmp = "./"
cl> set imtype = "hhh"
cl> set imdir = "HDR$"
```

You can also make these settings in your login.cl or loginuser.cl files. (Note that most STSDAS tasks will not work properly if you have imtype set to "imh".)

Table 2.1: WFPC2 Dataset Suffixes and File Sizes

GEIS Format Suffix	Waivered Fits[1] Format Suffix	File Contents	Approximate Size
Raw Data Files			
.d0h/.d0d	_d0f.fits	Raw science data	5 MB
.q0h/.q0d	_q0f.fits	Data quality for raw science data	5 MB
.x0h/.x0d	_x0f.fits	Extracted engineering data	100 kB
.q1h/.q1d	_q1f.fits	Data quality for extracted engineering data	100 kB
.shh/.shd	_shf.fits	Standard header packet containing observation parameters	30 kB
.pdq[2]	_pdq.fits	Text file containing jitter statistics and other data quality information	20 kB
.dgr	_dgr.fits	Text file listing the values of the group header keywords in the raw image.	5-10 kB
Calibrated Data Files			
.c0h/.c0d	_c0f.fits	Calibrated science data	10 MB
.c1h/.c1d	_c1f.fits	Data quality for calibrated science data	5 MB
.c2h/.c2d	_c2f.fits	Histogram of science data pixel values	220 kB
.c3t	_c3t.fits	The output throughput table generated based upon the PHOTMODE group header keyword.	10-30 kB
.cgr	_cgr.fits	Text file listing the values of the group header keywords in the calibrated image.	5-10 kb
.trl	_trl.fits	Trailer file	10-30 kB

1. Observers using IRAF tasks for their WFPC2 data analysis should first convert their images to GEIS format as many tasks do not work properly on the waivered FITS format files from the Archive.
2. PDQ files and Observation Logs (jitter) files, see appendix C, are not automatically distributed as part of the OTFR products but must be specifically requested, see chapter 1 of the HST Introduction. The jitter files are discussed in appendix C.

A single WFPC2 exposure is obtained as four images, one image for each CCD chip. GEIS files use group format to keep all of the data from a given HST exposure together in a single image file, see chapter 2 of the HST Introduction. The data corresponding to each sub-image for the WFPC2 are stored sequentially in the groups of a single GEIS image. The header file for an image contains the information that applies to the observation as a whole (i.e., to all the groups in the image); this information is viewable by simply paging the header. The group-specific (that is, chip-specific) keyword information is stored in two places. The descriptions for each keyword can be found in the main header, while the keyword values are stored with the group data itself in the binary data file; group keyword values are only accessible via specialized software, such as the STSDAS tasks **hedit**, **hselect,** or **imhead**.

WFPC2 images are normally four-group images. The first group is used for the planetary camera and groups 2, 3, and 4 are used for the wide field cameras. If only a subset of chips are read out, only a subset of groups will be present. The keyword, DETECTOR, gives the chip used for a specific group (1 through 4 for PC1, WF2, WF3, and WF4, respectively). For example, if you have a single-group image (not uncommon before the installation of the solid state recorder) and would like to know which chip was used for the observation, check the `DETECTOR` keyword. The total number of groups within the image is stored in the keyword, `GCOUNT`.

2.2 Header Keywords

Table 2.3 and table 2.4 list some of the more commonly used keywords found in a calibrated WFPC2 image (`.c0h`). A complete list of header keywords, with brief explanations, can be found in the WWW Keyword Dictionary.

The values of any of the header and group keywords can be determined using STSDAS tasks such as **hedit**, **hselect**, and **imhead.** The examples below illustrate the use of these tasks on a general image keyword (EXPSTART) and a group keyword (DETECTOR); the "[3]" string specifies the group desired.

Table 2.2: **hedit**, **hselect** and **imhead** examples

```
cl>hedit u5kl0101r.c0h[3] expstart,detector .
u5kl0101r.c0h[3],EXPSTART = 5.159859322738E+04
u5kl0101r.c0h[3],DETECTOR = 3

cl> hsel u5kl0101r.c0h[3] expstart,detector yes
5.159859322738E+04      3

cl> imhead u5kl0101r.c0h[3] long+ | match EXPSTART
EXPSTART=   5.159859322738E+04 / exposure start time
(Modified Julian Date)

cl> imhead u5kl0101r.c0h[3] long+ | match DETECTOR
DETECTOR=                    3
```

Most of the tasks provide only the keyword value; **imhead** shows both the value and the description for primary header keywords, but only the value for group keywords. Descriptions for group keywords can be viewed with a standard editor; each group keyword has three entries in the header file (e.g., `c0h`): one line defining the name and description of the group keyword, one specifying the space required for the keyword in the binary data file, and one providing the data type. As mentioned earlier, the group keyword *value* is stored in the binary data file and is only accessible via one of the STSDAS tasks. As an example, the entries for the group keyword DETECTOR are given below.

```
cl>page u5kl0101r.c0h
...
PTYPE19 = 'DETECTOR'     /CCD detector: PC 1, WFC 2-4
PDTYPE19= 'INTEGER*4'       /
PSIZE19 =             32 /
...
```

WFPC2 header keywords include items such as observing mode, integration time, filters and reference files used, calibration steps performed, and the properties of the data itself (e.g., number of groups, dimensions in pixels of each group); some additional calibration information is given at the end of the header file in the header HISTORY keywords. Group keywords include the reference pixels, coordinates, scale, flux units, and image statistics for each chip.

Observers new to WFPC2 data should peruse the header keyword comments in their images, as some keywords can occasionally be misleading. For example, DATE refers to the date the file was written while DATE-OBS refers to the date of the observation and `PROCTIME` refers to the date and time an image was processed through the On-The-Fly system, see section 3.1. The `FILTER1` and `FILTER2` keywords record the numerical designations of the filter(s) used while the filter names are stored in `FILTNAM1` and `FILTNAM2`. Also, `PHOTZPT` is *not* the photometric zeropoint (in the ST magnitude system) as normally understood, but rather the zeropoint in the ST magnitude system to be used after conversion to FLAM units (see table 5.1).

Astrometry keywords can also be confusing. The orientation of the image is specified by a global keyword, `PA_V3`, and a group keyword, `ORIENTAT`. The keyword, `PA_V3`, gives the position angle (in degrees) of the telescope's V3 axis on the sky, measured from North through East (see figure 1.2). The V3 axis is roughly 225 degrees from the *x* axis of the PC. The V3 axis differs by exactly 180 degrees from the ORIENT[1] value, if any, specified in the Phase II submission. The group keyword, `ORIENTAT`, records, for each detector, the position angle of the y axis in the plane of the sky, measured from North through East. This angle differs from PA_V3 by roughly –135, –45, +45, and +135 degrees, for PC1, WF2, WF3, and WF4, respectively. See figure 1.2 for a graphic representation of the geometric relationship between the four detectors. Accurate values of the positions and rotations between chips can be obtained from the Science Instrument Aperture File (SIAF), which is available on the WWW. In addition, each group has eight coordinate-related keywords (listed under coordinate-related keywords below) that specify the transformation from pixels to world coordinates (right ascension and declination) in the tangent plane approximation at the center of the chip.

Table 2.3: Frequently-used WFPC2 Group Header Keywords

Keyword	Description
	Image keywords
DETECTOR	CCD detector contained in group (PC1, WF2, WF3, WF4)
	Coordinate-related keywords
CRVAL1	RA of reference pixel (deg)
CRVAL2	Dec of reference pixel (deg)
CRPIX1	*X* coordinate of reference pixel

1. ORIENT is an optional parameter used in HST proposals to request a particular orientation of the field of view on the sky and refers to the position angle of the U3 axis.

Keyword	Description
CRPIX2	*Y* coordinate of reference pixel
CD1_1	Partial derivative of RA with respect to *x*
CD1_2	Partial derivative of RA with respect to *y*
CD2_1	Partial derivative of Dec with respect to *x*
CD2_2	Partial derivative of Dec with respect to *y*
Orientation	
MIR_REVR	Is image mirror reversed?
ORIENTAT	Orientation of *y* axis (deg)—different for each group
Bias level information (based on pixels in columns 9-14, rows 10-790 in .x0h/.x0d file)	
DEZERO	Bias level from engineering data
BIASEVEN	Bias level based on average of odd columns in `.x0h/.x0d` file (used for even columns in science image)
BIASODD	Bias level based on average of even columns in `.x0h/.x0d` file (used for odd columns in science image)
Pixel statistics	
GOODMIN	Minimum value of “good” pixels (not flagged in DQF)
GOODMAX	Maximum value of “good” pixels
DATAMEAN	Mean value of “good” pixels
GPIXELS	Number of good pixels (out of 640,000 possible)
ATODSAT	Number of saturated pixels
Photometry keywords (populated if DOPHOTOM=yes)	
PHOTMODE	Photometry mode
PHOTFLAM	Inverse sensitivity (units of erg/sec/cm^2/Å for 1 DN/sec)
PHOTZPT	Zeropoint (currently -21.10)
PHOTPLAM	Pivot wavelength (in angstroms)
PHOTBW	rms bandwidth of filter (in angstroms)
Image statistics keywords	
MEDIAN	Middle data value when good quality pixels sorted
HISTWIDE	Width of the histogram
SKEWNESS	Skewness of the histogram
MEANC10	Mean of a 10 x 10 region at the center of the chip

Keyword	Description
MEANC100	Mean of a 100 x 100 region at the center of the chip
MEANC300	Mean of a 300 x 300 region at the center of the chip
BACKGRND	Estimated background level

Table 2.4: Frequently-used WFPC2 General Header Keywords

Keyword	Description
	Information about the groups
GROUPS	Multi-group image? Indicates whether data has groups.
GCOUNT	Number of groups per observation (1 to 4)
	Image keywords
INSTRUME	Instrument used; always WFPC2
ROOTNAME	Rootname of the observation set
FILETYPE	SHP - standard header packet EXT - extracted engineering file EDQ - EED data quality file SDQ - science data quality file SCI - science data file
MODE	Mode: FULL (full resolution) or AREA (2 x 2 pixel summation)
SERIALS	Serial clocks: ON, OFF
	Data type keywords
IMAGETYP	DARK/BIAS/IFLAT/UFLAT/VFLAT/KSPOT/EXT/ECAL
CDBSFILE	GENERIC/BIAS/DARK/FLAT/MASK/NO Is the image a reference file and if so, type is specified
	Reference file selection keywords
DATE	File creation date
FILTNAM1	First filter name
FILTNAM2	Second filter name; blank if none
FILTER1	First filter number (0–48) (Used in SOGS - Science Operations Ground System)
FILTER2	Second filter number (0–48)
FILTROT	Partial filter rotation angle (degrees)
	More reference file selection keywords
ATODGAIN	Analog to digital gain (electrons/DN)

Keyword	Description
	Calibration switches
MASKCORR	Do mask correction: PERFORM, OMIT, COMPLETE
ATODCORR	Do A-to-D correction: PERFORM, OMIT, COMPLETE
BLEVCORR	Do bias level correction: PERFORM, OMIT, COMPLETE
BIASCORR	Do bias correction: PERFORM, OMIT, COMPLETE
DARKCORR	Do dark correction: PERFORM, OMIT, COMPLETE
FLATCORR	Do flatfield correction: PERFORM, OMIT, COMPLETE
SHADCORR	Do shaded shutter correction: PERFORM, OMIT, COMPLETE
DOSATMAP	Output saturated pixel map: PERFORM, OMIT, COMPLETE
DOPHOTOM	Fill photometry keywords: PERFORM, OMIT, COMPLETE
DOHISTOS	Make histograms: PERFORM, OMIT, COMPLETE
OUTDTYPE	Output image datatype: REAL, LONG, SHORT
	Calibration reference files used[1]
MASKFILE	Name of the input static mask containing known bad pixels and charge traps
ATODFILE	Name of the A-to-D conversion file
BLEVFILE	Name of engineering file with extended register data
BLEVDFIL	Name of data quality file (DQF) for the engineering file
BIASFILE	Name of the superbias reference file
BIASDFIL	Name of the superbias reference DQF
DARKFILE	Name of the dark reference file
DARKDFIL	Name of the dark reference DQF
FLATFILE	Name of the flatfield reference file
FLATDFIL	Name of the flatfield reference DQF
SHADFILE	Name of the reference file for shutter shading
PHOTTAB	Name of the photometry calibration table
SATURATE	Data value at which saturation occurs (always 4095 for WFPC2, which includes the bias)
	Ephemeris data
PA_V3	Position angle of V3 axis of HST
RA_SUN	Right ascension of the sun (deg)

Keyword	Description
DEC_SUN	Declination of the sun (deg)
EQNX_SUN	Equinox of the sun
	Fill values
PODPSFF	0 (no fill), 1 (fill present)
RSDPFILL	Bad data fill value set in pipeline for calibrated image
	Exposure Information
DARKTIME	Estimate of darktime (in sec)
EQUINOX	Equinox of the celestial coordinate system
SUNANGLE	Angle between sun and V1 axis (deg)
MOONANGL	Angle between moon and V1 axis (deg)
SUN_ALT	Altitude of the sun above Earth's limb (deg)
FGSLOCK	Commanded FGS lock (FINE, COARSE, GYROS, UNKNOWN)
	Timing information
DATE-OBS	UT date of start of observation
TIME-OBS	UT time of start of observation (hh:mm:ss)
EXPSTART	Exposure start time (Modified Julian Date)
PROCTIME	Date and time of OTFR pipeline processing (Modified Julian Date)
EXPEND	Exposure end time (Modified Julian Date)
EXPTIME	Exposure duration (seconds)
EXPFLAG	How exposure time was calculated. (NORMAL, INTERRUPTED, INCOMPLETE, EXTENDED, UNCERTAIN, INDETERMINATE, or PREDICTED)
	Proposal information
TARGNAME	Proposer's target name
RA_TARG	Right ascension of the target (deg) (J2000)
DEC_TARG	Declination of the target (deg) (J2000)
PROPOSID	RPS2 proposal identifier

1. Calibration reference file keywords are populated even if unused.

2.3 Correlating Phase II Exposures with Data Files

Because of the need to schedule observations as efficiently as possible, the order in which exposures are executed may be different from the order in which they appear in the observer's Phase II submission, unless an explicit special requirement dictates otherwise. As a result, the data may be received in an order that differs from that originally proposed by the observer. In this section, we discuss how to correlate the data received with the exposures specified in the Phase II submission, which can often facilitate the process of interpreting the observations and their interconnection. The Phase II proposal specifications submitted by the investigator can be found by entering the proposal ID on the HST Program Information page or in the Program Status box on the top HST page.

The first step is often identifying the program to which a data file belongs, and can be accomplished via the header keyword PROPOSID. Data files can then be associated with the corresponding exposure line in the Phase II proposal by comparing exposure information in the Phase II proposal with data file header keywords. For WFPC2 data, the most useful comparisons are shown in the table below.

Table 2.5: Comparing Phase II Proposal Keywords to Data Header Keywords

Phase II	Data Header
Proposal ID	PROPOSID
Target_Name	TARGNAME
Position	RA_TARG, DEC_TARG
Spectral Element	FILTNAM1, FILTNAM2
Time_Per_Exposure	EXPTIME

A convenient tool for viewing some of the more important data header keywords in an easy-to-read formatted output is the STSDAS task, **iminfo**. An example of the output of this task in shown in figure 2.1. Note that the data header keywords are expanded to standard English words in this output. The header file (`.c0h`) can also be examined with IRAF tasks **hedit** or **imhead**, with any standard text editor, or simply by listing the contents of the file. Again, please note that a standard text editor will show only the comments for the group keywords, not the values which are stored in the image file.

Figure 2.1: Displaying WFPC2 Header Keywords with iminfo

```
Rootname          Instrument              Target Name
U2P60204T            WFPC2                CAL-GANY-W

Program         = 2P6                 Obs Date        = 19/08/95
Observation set = 02                  Proposal ID     = 05837
Observation     = 04                  Exposure ID     = 02-023
Source          = Tape Recorded       Right ascension =  16:16:34.4
File Type       = SCI                 Declination     = -20:45:14
                                      Equinox         = J2000

First filtername  = F410M                       Number of groups = 4
Second filtername =                             Data type        = real

Image type        = EXT               Exposure time (sec)     = 5.
Mode              = FULL              Dark time (sec)         = 5.
Serials           = OFF
Shutter           = B                 Calibration steps done:
Kelsall spot lamp = OFF                 MASK ATOD BLEV BIAS FLAT SHAD
im>
```

In the specific example shown in figure 2.1 the Proposal ID is given as 05837. Entering the proposal ID into the space provided on either the HST Program Information web page or Program Status box on the HST web page (without the leading 0) and clicking on **[Get Program Information]**, will bring up the Program Information page for that proposal. Under Program Contents on that page you can choose either the file typed in during Phase II or a formatted output. The latter may be easier to read; we reproduce a portion of that file in table 2.6.

The Exposure ID listed by **iminfo** is 02-023. This corresponds to visit 02, exposure 23. A different format was used in Cycles 0 through 4; exposures in these proposals have a single, unique numeric identifier. To reach this exposure line, page down through the proposal until visit 02 is reached. Now search for exposure 23 in visit 02. As shown in table 2.6, this exposure requested a single 5 second exposure of target CAL-GANY-W through filter F410M. A quick comparison with the keywords listed by **iminfo** shows that, indeed, this data file contains the observation specified in this exposure line.

Table 2.6: Exposure Log Sheet for WFPC2

```
Visit: 02
     Visit Requirements:  BEFORE 16-OCT-95
     On Hold Comments:    <none>
     Additional Comments: This visit has limited scheduling opportunities, we prefer as close to
                          Jupiter opposition as possible exp-time calculated from observed Callisto WF
                          images from SL9 campaign
```

Exposures

Exposure Number	Target Name	Instr Config	Oper. Mode	Aper or FOV	Spectral Element	Central Waveln.	Optional Parameters	Num Exp	Time	Special Requirements
21	Cal-Gany-W	WFPC2	IMAGE	PC1	F218W		ATD-GAIN=7	2	500S	NO SPLIT
22	Cal-Gany-W	WFPC2	IMAGE	PC1	F255W		ATD-GAIN=7	1	40S	
23	Cal-Gany-W	WFPC2	IMAGE	PC1	F410M		ATD-GAIN=15	1	5S	
24	Cal-Gany-W	WFPC2	IMAGE	PC1	F953N		ATD-GAIN=15	1	30S	
25	Cal-Gany-W	WFPC2	IMAGE	PC1	F675W		ATD-GAIN=15	1	0.2S	
26	Cal-Gany-W	WFPC2	IMAGE	PC1	F300W		ATD-GAIN=15	1	10S	

A comparison of these keywords should quickly reveal the data file corresponding to a given exposure line. There are, however, two cases in which such a comparison is somewhat more complicated.

It is recommended that WFPC2 exposures longer than 600 seconds be split into two shorter exposures to facilitate the removal of cosmic rays. If the optional parameters CR-SPLIT and CR-TOLERANCE are omitted in the Phase II submission, and the exposure is *longer* than 600 seconds, it will be split into two exposures for more efficient scheduling. The default CR-TOLERANCE of 0.2 can be used, meaning that the split exposure times could each range from 30–70% of the total exposure, with their sum equal to the original total exposure time.

Exposure times may occasionally be shortened or lengthened by up to 20% without the approval of the PI, provided that the resulting S/N is 90% of that with the original exposure time. Such changes may be required to fit observations into specific orbital time slots. If, after examining your exposure headers, you still have questions regarding the execution of your observing plan, we recommend you speak with your program coordinator or email help@stsci.edu.

The output generated by **iminfo** contains information on the target, exposure time, and filters used, but nothing on guide star status. Any of the STSDAS tasks (**hselect**, **hedit**, or **imhead**), see table 2.2, can provide access to that information by printing the FGSLOCK header keyword to the screen.

The FGSLOCK keyword can have the values FINE, COARSE, GYROS, or UNKNOWN. Coarse tracking is no longer allowed, so this FGSLOCK in recent data will most likely read either FINE or GYROS. Gyro tracking allows a drift rate of approximately 1 mas/sec. It would only be used if requested by the proposer. FINE tracking typically holds pointing with an rms error of less than 7 mas. Normally, two guide stars are used in HST observations, but on occasion only one appropriate guide star can be found. Such observations will suffer from small drift rates (a few mas in a 1000 second exposure). To determine the quality of tracking obtained during your observations, please review appendix C of the HST Introduction which describes how to determine the number and quality of guide stars actually used, as well as how to use the OMS jitter files.

2.4 WFPC2 Paper Products

In the past, observers received a package of so-called *paper products* as part of the initial data delivery; mailed in paper form, these products provided a quick-look summary of the data. In August 1999, the Archive discontinued printing and mailing of these products; instead, the summaries are now made available in PDF format to observers via the Archive's Paper Products WWW page. Note, however, that the PDF files on the WWW are available only for the most recent 6 months of data; for older data, observers can generate their own paper products using the STSDAS task **pp_dads**.

2.4.1 Visit-level Output

The **pp_dads** output consists of two parts, a visit-level overview of the datasets and an exposure-level summary. The visit-level summary is meant to be similar to the observing log in ground-based observations. The information is presented in three separate tables: Target List, Observation List, and Observation Statistics. The Target List gives the targets, including their positions, observed in the visit. The Observation List includes essential information on each dataset, such as rootname, target name, operating mode, aperture, filter, exposure time, and a number of flags intended to alert the user to any procedural problem with the data. The flags are represented graphically by circles, open when the data are okay, filled if any (potential) problem is encountered; see figure 2.2 for a Target List and Observation List example. The Observation Statistics is a table with basic image statistics for each dataset, such as mean counts, background level, and a rough estimate of the limiting magnitude that can be reached with respect to the background level in the image (see figure 2.3). Note that this limiting magnitude is computed with a rather simple, all-purpose algorithm, and is meant only as an approximate indication; it should not be used for any detailed calculations. Image statistics are given separately for each CCD.

2.4.2 Exposure-level Output

The second part of the **pp_dads** output presents the data exposure by exposure. Usually, there are three pages for each exposure: the first two pages are grayscale representations of the image, one containing all four chips together, the other featuring the PC only (see figure 2.4); the third summarizes various exposure characteristics as well as any flags and error conditions that might have arisen (see figure 2.5). The grayscale presentation on the first page of the four chips together is a crude mosaic; each chip is rotated and placed in the correct position with respect to the others, but the overlap and the small differential rotations between chips (see chapter 1) are not corrected. The next page presents the PC by itself, at a larger scale, which enhances smaller details not evident in the mosaic. The third page, containing the dataset information, is divided into several zones, each summarizing information on a specific topic: the HST Spacecraft Performance Summary, with information on pointing and jitter; the Pipeline Processing Summary, with information on whether the file was processed properly by the pipeline (see chapter 3); the Calibration Data Quality Summary, where any inconsistencies in the choices of calibration files are highlighted; the Exposure Summary, which details when and how the exposure was taken; and the Calibration Status Summary, which reports all reference files used in the calibration and their pedigree, if available. Some basic consistency checks are carried out and the user is alerted to any potential problems.

2.4.3 A note about grayscales

A few comments are in order regarding the grayscale representation of the data. The images are presented as they appear after the standard pipeline processing (see chapter 3). Bias, standard dark, and flatfield corrections have been applied, but hot pixels and cosmic rays are not removed; hence, many images will appear mottled, especially those with exposure times longer than a few hundred seconds. In order to limit the size of the printouts, images are block-averaged (2 x 2), causing some details to be lost. In general, because of the limited resolution of even good black-and-white printers, finer image details are lost (see figure 2.4); the grayscale images cannot in any way replace even a quick look on the screen.

Paper products shipped before August 1997 differ from the current **pp_dads** output in two main respects. First, they did not have the visit-level summary of observations; some of the information was available via the tape log, but without any data quality flags or image statistics. Second, the exposure-level information was presented in a different way; the dataset information page consisted simply of a printout of the PDQ file (see “PDQ Files” in appendix B). The grayscale images were produced by a different task, which gave them a different appearance, but the overall information content in them was very similar to the current output. Sample paper products in the current format are shown in figure 2.2 - 2.5. Users who have received paper products in the old format can regenerate them in the new format using **pp_dads**.

2.4.4 Obtaining paper products

Observers with data taken within the last 6 months may obtain PDF format versions of the paper products from the Archive's Paper Products WWW page. The query form provides a wide variety of search options such as dataset name, proposal number, observation date, and so on. Any questions or requests for assistance with the search may be directed to archive@stsci.edu.

For data older than 6 months, observers can generate the data products using the STSDAS task **pp_dads**. At a minimum, the task requires the calibrated science image (`c0h/c0d`) and the standard header information (`shh/shd`) as input files. The jitter files (see section C.3 in appendix C) are optional; if they are missing, the summary of the spacecraft performance information (see figure 2.5), including number of recenterings and jitter measurements in V2 and V3, are left blank by the task.

To generate the paper products, load the **stsdas**, **hst_calib**, and **paperprod** packages, then execute the task in the directory containing the input files. The *device* parameter specifies the output device. In the example below, psi_land directs the summaries to a postscript file, which is written to the /tmp directory. The *output_select* parameter provides control over the information summarized: cover page, visit page, exposure pages, or all output. Please refer to the online STSDAS help for **pp_dads** for more details on the available parameters and options.

```
cl> stsdas
cl> hst_calib
cl> paperprod
cl>pp_dads u*c0h device=psi_land output_select=all
   === Space Telescope Paper Product, Version 2.33 (April 24, 2001) ===
/tmp/psk6741a
```

Figure 2.2: Paper Products: List of Targets and Observations

Visit: 35 **Proposal: 05370** *WFPC2*

Target List

Target Name	R.A. (J2000)	Dec. (J2000)	Description
HI-LAT	13:27:11.62	-47:29:54.8	STARS; GALAXIES;

Observation List

Logsheet Line#	Rootname	Target Name	Operating Mode	Serials/ Gain	Aperture or FOV	Filters	Wavelength	Exposure (sec)	Quality Flags Obs	Proc	Cal
35.000	U27R8502T	HI-LAT	FULL	OFF/7.00	WFALL	F814W	8006.80	600.0	○		○
35.000	U27R8501T	HI-LAT	FULL	OFF/7.00	WFALL	F814W	8006.80	600.0	○		○
39.000	U27R9U01T	HI-LAT	FULL	OFF/7.00	WFALL	F814W	8006.80	700.0	○		○
39.000	U27R9U02T	HI-LAT	FULL	OFF/7.00	WFALL	F814W	8006.80	700.0	○		○

Quality flags: ○ = OK ● = Not OK Blank = Unknown or file missing

Figure 2.3: Paper Products: Observation Statistics (separately for each CCD)

Visit: 35 **Proposal: 05370** *WFPC2*

Observation Statistics

Logsheet Line#	Rootname	Target Name	Filter	Exposure Time	POSTARG		Detector	Modal Sky	Sky Sigma	Min DN	Max DN	Limiting Mag.
35.000	U27R8502T	HI-LAT	F814W	600.00	N/A	N/A	1	6.14	2.51	-359.14	18101.54	28.82
35.000	U27R8502T	HI-LAT	F814W	600.00	N/A	N/A	2	27.68	20.75	-1126.21	52096.83	26.74
35.000	U27R8502T	HI-LAT	F814W	600.00	N/A	N/A	3	40.38	72.99	-410.52	92238.00	25.47
35.000	U27R8502T	HI-LAT	F814W	600.00	N/A	N/A	4	56.39	90.57	-1382.49	125202.3	25.14
35.000	U27R8501T	HI-LAT	F814W	600.00	N/A	N/A	1	9.37	2.60	-300.12	35567.71	28.78
35.000	U27R8501T	HI-LAT	F814W	600.00	N/A	N/A	2	66.88	20.56	-1131.11	287711.6	26.75
35.000	U27R8501T	HI-LAT	F814W	600.00	N/A	N/A	3	43.30	68.34	-576.75	108361.5	25.54
35.000	U27R8501T	HI-LAT	F814W	600.00	N/A	N/A	4	55.46	89.38	-1570.77	124874.8	25.15
39.000	U27R9U01T	HI-LAT	F814W	700.00	N/A	N/A	1	20.07	4.14	-302.07	103304.2	28.45
39.000	U27R9U01T	HI-LAT	F814W	700.00	N/A	N/A	2	38.79	30.39	-1315.45	110014.1	26.49
39.000	U27R9U01T	HI-LAT	F814W	700.00	N/A	N/A	3	43.25	90.29	-649.44	76723.60	25.41
39.000	U27R9U01T	HI-LAT	F814W	700.00	N/A	N/A	4	60.14	103.00	-1845.88	123228.6	25.16
39.000	U27R9U02T	HI-LAT	F814W	700.00	N/A	N/A	1	6.01	2.70	-354.96	12388.22	28.91
39.000	U27R9U02T	HI-LAT	F814W	700.00	N/A	N/A	2	42.91	25.78	-1234.59	121265.8	26.67
39.000	U27R9U02T	HI-LAT	F814W	700.00	N/A	N/A	3	71.66	88.56	-815.84	266563.8	25.43
39.000	U27R9U02T	HI-LAT	F814W	700.00	N/A	N/A	4	66.55	104.06	-1770.08	157240.0	25.15

Figure 2.4: Paper Products: Combined Grayscale Display

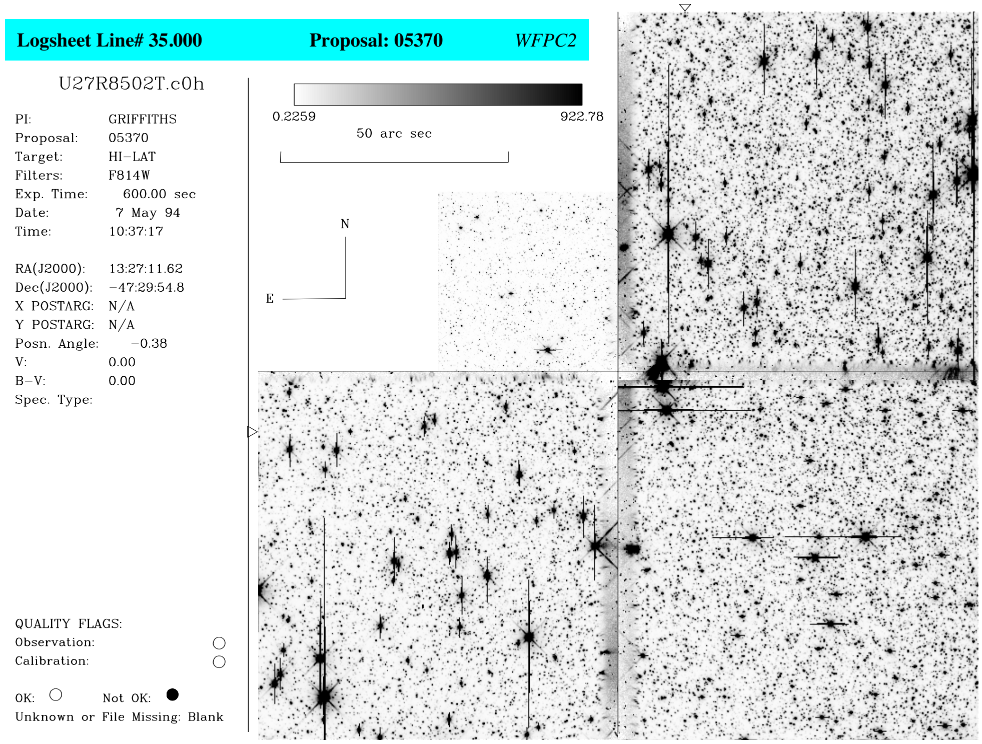


Figure 2.5: Paper Products: Observation Summary

Logsheet Line# 35.000 **Observation: U27R8502T** **Proposal: 05370** *WFPC2*

HST Spacecraft Performance Summary

Recenterings:
V2 Jitter (RMS):
V3 Jitter (RMS):

Losses of Locks:
V2 Jitter (PP):
V3 Jitter (PP):

Could not find JITTER file.
Very highly packed star field.
Brighter stars saturated and blooming. Filter F814W, exposure 600s

Pipeline Processing Summary

No Error Checks Made.

Calibration Data Quality Summary

No Anomalies.

No Calibration File Pedigree Information available.

Exposure Summary

Target Name:	HI-LAT
RA (J2000):	13:27:11.62
Dec (J2000):	-47:29:54.8
X POSTARG:	N/A
Y POSTARG:	N/A
Aperture:	WFALL
Exp Time (sec):	600.0
Rootname:	U27R8502T
Date:	7 May 94
Time:	10:37:17
Proposal:	05370
PI:	GRIFFITHS

Chip 3 Statistics

Sky:	40.38
Sky Sigma:	72.99
Minimum:	-410.52
Maximum:	92238.00
Limiting Mag:	25.47

Calibration Status Summary

Switches and Flags / Reference Files and Tables

Keyword	Value	Calibration Step	Keyword	filename	Pedigree
MASKCORR	COMPLETE	Mask Correction	MASKFILE	uref$e2112084u.r0h	
ATODCORR	COMPLETE	A-to-D Correction	ATODFILE	uref$dbu1405iu.r1h	
BLEVCORR	COMPLETE	Bias Level Correction	BLEVFILE	ucal$u27r8502t.x0h	
BIASCORR	COMPLETE	Bias Correction	BIASFILE	uref$e4p1629bu.r2h	
DARKCORR	COMPLETE	Dark Correction	DARKFILE	uref$e1q1433du.r3h	
FLATCORR	COMPLETE	Flat Field Correction	FLATFILE	uref$e391434fu.r4h	
SHADCORR	OMIT	Shaded Shutter Correction	SHADFILE	uref$e371355eu.r5h	
DOPHOTOM	COMPLETE	Populate Photometry Keywords	PHOTTAB	ucal:u27r8502t.c3t	

CHAPTER 3:

WFPC2 Calibration

In this chapter. . .

This chapter discusses the processing and calibration of WFPC2 data, the routine processing that must be performed before detailed data analysis can commence. We begin by describing the pipeline calibration that occurs before the data are delivered to the observer, then detail possible reasons to refine and enhance the routine calibration and the various options available to do so.

3.1 Data Processing Pipelines

Up until 1999, HST observers received their data via tape and/or via Archive retrieval requests; the raw and calibrated data were copies of files that had been stored on the archive media and were the result of pipeline processing *at the time the image was taken*. In December 1999, the On-The-Fly Calibration (OTFC) system was released to the public. In response to a user request for data, OTFC retrieved raw files (`.d0*,.q0*,.x0*,.q1*`) from the archive, then calibrated and shipped the data to the requestor. The primary advantages of OTFC included the

- automatic application of improved calibration files and switches,
- use of most recent calibration software (allowing for rapid access to improved algorithms, new capabilities, and software fixes), and
- correction of header keywords, if needed.

An additional major benefit to OTFC was that only the uncalibrated data needed to be stored in the archive[1].

The On-The-Fly Reprocessing (OTFR) system replaced OTFC on May 16, 2001, a change transparent to the majority of HST archive users. Requests for data are submitted either via StarView or the WWW (see chapter 1 of the HST Introduction); freshly-processed raw and calibrated data are delivered[2]. There is no need to explicitly ask for OTFR, *all requests for WFPC2 data are now handled by the OTFR system*.

The primary difference between the two on-the-fly systems is that OTFR begins earlier in the data path. OTFR starts with the original telemetry files ("POD" files) received from Goddard Space Flight Center and performs all pipeline processing steps, including data partitioning, fixing data dropouts, converting the partitioned data packets into raw science files, and calibrating the newly-created raw files. OTFC performed only the last pipeline processing step, calibration, on raw files stored in, and retrieved from, the archive.

An overview of the data flow for both systems is summarized in the table below. The benefits of the new OTFR system encompass the benefits of the OTFC system, plus OTFR data need fewer header corrections since most problems are fixed as part of the pre-calibration pipeline processing. Also, the OTFR system as a whole requires significantly less maintenance effort than OTFC. As of late 2001, both the POD files and raw pre-calibration WFPC2 data are still being archived; the raw files are not used for distribution but kept merely as a backup to the POD files. Future

1. As of June 2000, calibrated WFPC2 data are no longer archived.

2. By default, OTFR currently delivers both raw and calibrated data. A future enhancement to the retrieval process will allow requests for subsets of files (e.g., only calibrated).

plans call for the eventual cessation of raw data archiving, after which only the POD files will be archived.

Table 3.1: Comparison of Dataflow in the On-The-Fly Systems

OTFC (December 1999 - May 2001)	OTFR (May 2001 - present)
Request for data is submitted to the archive via StarView or WWW interface. Archive responds with acknowledgement email.	Same as OTFC.
Raw files are retrieved from the HST archive and passed to the OTFC system. For WFPC2, the raw files are the `d0`, `q0`, `q1`, `x0`, and `trl` files.	POD file[1] (original telemetry file) is retrieved from HST archive and passed to OTFR system. Pre-calibration OPUS processing is performed: data partitioning, fixing dropouts, generating raw files (`d0`, `q0`, `q1`, `x0`, and `trl` files).
Any problems in the header keywords are fixed by special lookup table.	Same as OTFC although the OPUS pre-calibration processing fixes the majority of keyword problems automatically (i.e., significantly fewer header corrections required in OTFR).
The best calibration files & switches are determined by a separate standalone task, and header keywords updated accordingly.	Not needed. The best calibration files & switches are set by the pre-calibration OPUS code (generic conversion).
Images are calibrated by STSDAS calwp2 and sent back to the archive system.	Same as OTFC.
Archive delivers raw + calibrated data and emails completion notification to the requestor.	Same as OTFC. Files contain a new keyword, PROCTIME, to record when the OTFR system processed the data.

1. For WFPC2, there is 1 image per POD file.

3.2 Data Processing Steps

After WFPC2 observations have executed, the data pass through the *OPUS pipeline*, where they are processed and calibrated. A substantial fraction of header keyword values are extracted and used to populate the Archive databases; observers access these databases each time they browse the Archive contents and perform searches via the HST Archive Search WWW form or the Archive's database browser, StarView. The resulting raw and calibrated data files from this first pipeline processing are not seen by the observer. Instead, when an archive data request is submitted, the images are completely reprocessed by the *On-The-Fly Reprocessing (*OTFR*)* system before they are delivered. The OTFR system processing is identical to the OPUS pipeline processing, except that, as discussed in the previous section, the most up-to-date reference files and software at the time of processing are used. So, for example, if an observer waits several weeks after an observation before requesting the data products, it is very likely that OTFR will have access to an updated dark reference file with which to process the science data - a reference file that was not in place at the time the observation was taken (see Reference File Memo).

All of the steps performed by OTFR are the same as those performed in the OPUS pipeline; these steps are recorded in the trailer file for each dataset. Figure 3.1 shows an example of a trailer file and identifies the major pipeline steps:

1. The data are partitioned: the POD file is separated into individual files, e.g., the engineering and science data sections.
2. The data are edited to insert dummy values (an arbitrary assigned value given in the header keyword STDCFFP) in place of missing pixel values.
3. The data are evaluated to determine discrepancies between the subset of the planned and executed observational parameters.
4. The data are converted to a generic format and the header keywords populated.
5. The data are calibrated using a standard WFPC2-specific calibration algorithm and the best available reference files.

Figure 3.1: Sample Trailer File

```
2001296190432-I-INFO -------------- Data Partitioning Starts ---------- (1)
2001296190432-I-INFO POD file name   : /info/opscl/pipe/clark/dat/dct/lz_a2db_161_0000226918_u5kl0101.pod_proc (1)
2001296190432-I-INFO Observation name: u5kl0101r (1)
2001296190438-I-INFO Finished partitioning obs u5kl0101r (1)
2001296190438-I-INFO Expected 3201 packets, Recieved 3201 packets  (1)
2001296190438-I-INFO (1 SHP, 0 UDL, 0 BAD, 3200 SCI).  (1)
2001296190438-I-INFO -------------- Data Partitioning ends ---------- (1)
2001296190449-I-INFO ------------- Data Quality Editing Started: u5kl0101r ---------- (1)
2001296190450-I-INFO ------------- Data Quality Editing Completed: u5kl0101r -------- (1)
2001296190502-I-INFO -------------- Data Validation Started: u5kl0101r ------------ (1)
2001296190502-I-INFO Mismatched weight (0) was lower than threshold (9) (1)
2001296190503-I-INFO -------------- Data Validation Completed: u5kl0101r ------------ (1)
2001296200730-I-INFO ------ World Coordinate System Beginning: u5kl0101r -------
2001296200734-I-INFO ----------- World Coordinate System Started --------- (1)
2001296200736-I-INFO ----------- World Coordinate System Ended   --------- (1)
2001296200736-I-INFO ------- World Coordinate System Completed: u5kl0101r -------
2001296200747-I-INFO -------------- Generic Conversion Started: u5kl0101r ----------- (1)
2001296200807-I-INFO -------------- Generic Conversion Completed: u5kl0101r --------- (1)
CALBEG ------------ Tue Oct 23 20:08:18 GMT 2001------------------
---  xWFPC2 Calibration Starting: CALWP2 Version 2.1 (Oct. 13, 2000)
---  Starting CALWP2: Input = u5kl0101r   Output = u5kl0101r
MASKFILE=uref$f8213081u.r0h  MASKCORR=COMPLETED
PEDIGREE=INFLIGHT 01/01/1994 - 15/05/1995
DESCRIP=STATIC MASK - INCLUDES CHARGE TRANSFER TRAPS
  uref$dbu1405iu.r1h has no PEDIGREE keyword
BIASFILE=uref$kcd1557lu.r2h  BIASCORR=COMPLETED
PEDIGREE=INFLIGHT 26/08/99 - 29/08/00
DESCRIP=not significantly different from j9a1612mu.
DARKFILE=uref$k311100ju.r3h  DARKCORR=COMPLETED
PEDIGREE=INFLIGHT 24/02/2000 - 24/02/2000
DESCRIP=Pipeline dark: 120 frame superdark with hotpixels from 24/02/2000
FLATFILE=uref$g640925ru.r4h  FLATCORR=COMPLETED
PEDIGREE=INFLIGHT 01/05/1994 - 01/10/1994
DESCRIP=Improved Cyc4 flat, fixed errors at CCD edges - now < 0.5% RMS
---  Starting processing of element 1
PC1: bias jump level ~0.149 DN.
photmode = WFPC2,1,A2D7,F606W,,CAL
---  Starting processing of element 2
WF2: bias jump level ~0.139 DN.
photmode = WFPC2,2,A2D7,F606W,,CAL
---  Starting processing of element 3
WF3: bias jump level ~0.130 DN.
photmode = WFPC2,3,A2D7,F606W,,CAL
---  Starting processing of element 4
photmode = WFPC2,4,A2D7,F606W,,CAL
---  Computing image statistics of element 1
---  Computing image statistics of element 2
---  Computing image statistics of element 3
---  Computing image statistics of element 4
---  WF/PC-2 Calibration Ending for observation
CALEND ------------ Tue Oct 23 20:08:29 GMT 2001------------------
```

1 Partitioning

2 Editing

3 Evaluation

4 Conversion

5 Calibration

3.2.1 Calibration of WFPC2 Images

The calibration software used by both the OPUS pipeline and OTFR is the same as that provided within STSDAS (**calwp2** in the **hst_calib** package). The calibration files and tables used are taken from the Calibration Data Base (CDBS) at STScI and are the most up-to-date calibration files available at the time of processing. All CDBS files are available through the HST Data Archive. (See chapter 1 of the HST Introduction).

The flow of the data through **calwp2** is presented in schematic form in figure 3.2. The software takes as input the raw WFPC2 data file pairs (see table 2.1) and any necessary calibration reference images or tables. The calibration steps performed are determined by the values of the calibration switches (e.g., MASKCORR, BIASCORR, etc.) in the header of the raw data (`.d0h`) file. Likewise, the reference files to be used in the calibration of the data are set by the values in the reference file keywords (e.g., MASKFILE, BIASFILE, BIASDFILE, etc.). The appropriate settings of the calibration switches and reference file keywords depend on the instrumental configuration used (such as A-to-D gain, `MODE`, `SERIALS`, filters), the date of the observation, and any special pre-specified constraints. They are initially set in the headers of the raw data file during the generic conversion step, see figure 3.1; if reprocessing is necessary, they can be redefined by editing the raw header file (`.d0h`) using the STSDAS tasks **hedit** or **chcalpar** and then running **calwp2** on the raw files.

The values of the calibration switches in the headers of the raw and calibrated data indicate which processing steps the pipeline applied to the data and the reference files used. Calibration switches will have one of the following values:

PERFORM - calibration step to be applied by **calwp2**

OMIT - correction is not performed during processing

COMPLETE - calibration step has been completed

SKIPPED - step was skipped because the reference file was a dummy or placeholder file (i.e., has no effect on the data, such as a flatfield filled with values of 1).

For convenience, these keywords are reported in several locations:

- In the dataset information page of the paper products, see section 2.4.
- In the trailer files, see figure 3.1.
- In the HISTORY keywords at the end of the calibrated science data image (`.c0h`) file.

As with other header keywords, the calibration keywords can be viewed using the STSDAS tasks **imhead**, **hselect**, or **hedit**. Alternatively, the **chcalpar** task in the STSDAS **tools** package can be used to view and change the calibration keywords directly.

The flow chart below summarizes the sequence of calibration steps performed by **calwp2**, including the input calibration reference files and tables, and the output data files from each step. The purpose of each calibration step is briefly described in the accompanying table; a more detailed explanation is provided in the following section.

Figure 3.2: Pipeline Processing by calwp2

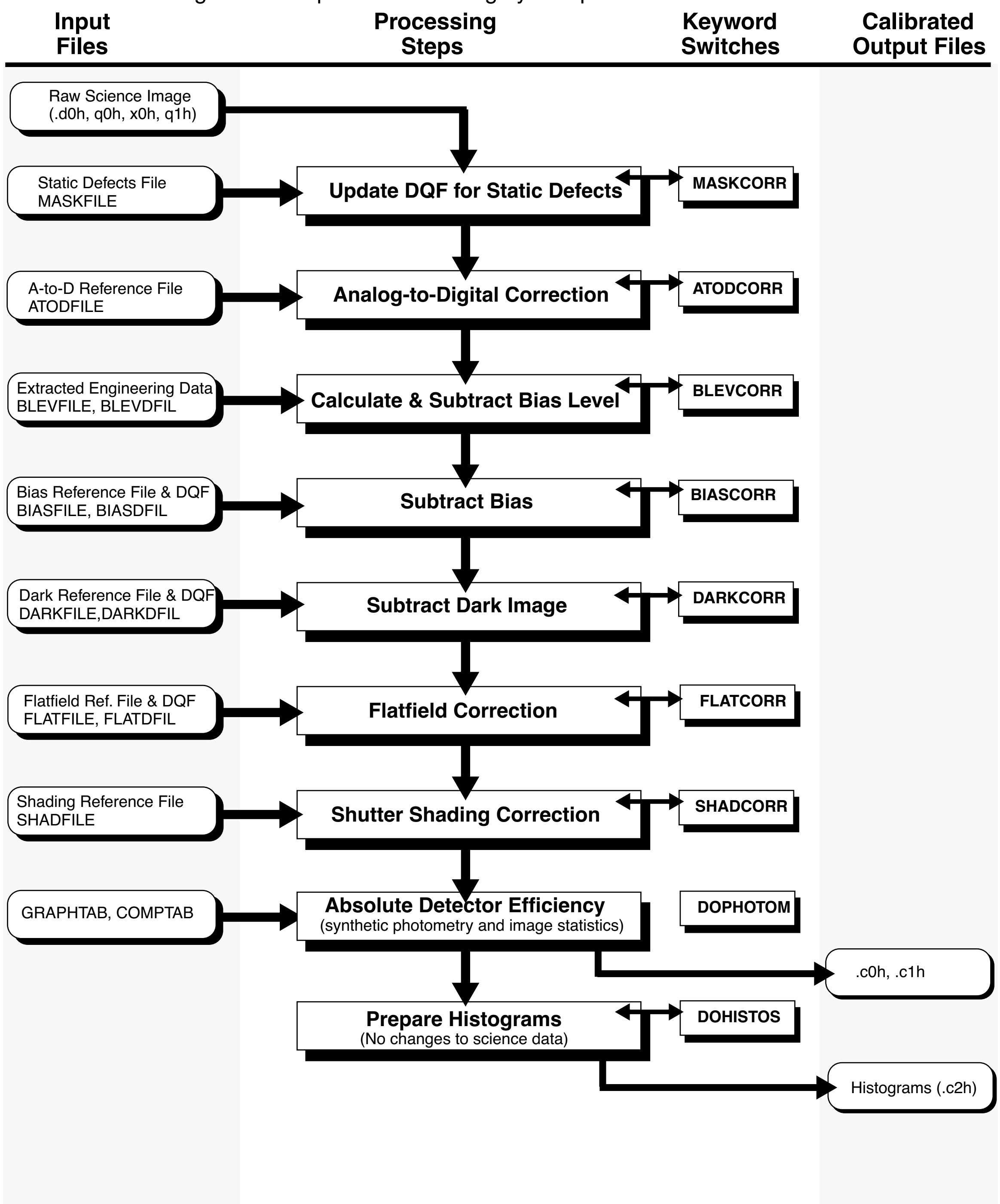


Table 3.2: Calibration Steps and Reference Files Used for WFPC2 Pipeline Processing

Switch	Processing Step	Reference File
MASKCORR	Update the data quality file using the static bad pixel mask reference file (MASKFILE), which flags defects in the CCD that degrade pixel performance and that are stable over time.	maskfile (`r0h`)
ATODCORR	Correct the value of each pixel for the analog-to-digital conversion error using information in the A/D lookup reference file (ATODFILE).	atodfile (`r1h`)
BLEVCORR	Subtract the mean bias level from each pixel in the science data. Mean values are determined separately for even column pixels (group parameter BIASEVEN) and odd column pixels (BIASODD) because the bias level exhibits a column-wise pattern that changes over time.	blevfile, blevdfil (`x0h`/ `q1h`)
BIASCORR	Subtract bias image reference file (BIASFILE) from the input science image and update output data quality file with bias image data quality (BIASDFIL).	biasfile, biasdfil (`r2h`/`b2h`)
DARKCORR	Correct for dark current by scaling the normalized dark image reference file to the exposure time and subtracting it from science data. Dark image is multiplied by total dark accumulation time keyword (DARKTIME).	darkfile, darkdfil (`r3h`/`b3h`)
FLATCORR	Correct for pixel-to-pixel gain variation by multiplying by flat-field image.	flatfile, flatdfil (`r4h`/`b4h`)
SHADCORR	Remove shading due to finite shutter velocity (exposures less than 10 seconds)	shadfile (`r5h`)
DOPHOTOM	Determine absolute sensitivity using throughputs in **synphot** tables identified in GRAPHTAB and COMPTAB. This step does not change science data values.	
DOHISTOS	Create 3-row image (`.c2h`) for each group. Row 1 is a histogram of raw science values, row 2 the A/D correction, row 3 the calibrated image. (Optional, default is not to produce them.)	

3.3 Standard Pipeline Calibration

Each calibration step, and the keyword switches used to turn the step on or off, is described in detail in the following sections. These steps are performed in the following order:

1. Flag static bad pixels.
2. Perform analog-to-digital (A/D) correction.
3. Subtract bias level.

4. Subtract bias image.
5. Scale and subtract dark image for exposures longer than 10 seconds.
6. Multiply by flatfield image.
7. Apply shutter shading correction to exposures of less than 10 seconds.
8. Calculate photometry keywords and update calibrated science image header accordingly (*does not affect pixel values*).
9. Calculate histograms.
10. Generate final science data quality file.

3.3.1 Calibration Files

Table 3.3 lists the types and related suffixes of the WFPC2 reference files used in **calwp2**. Most suffixes have the form `rNh/rNd`, where *N* is a number that identifies the step in which the file is used. The associated data quality file, if it exists, has the suffix `bNh/bNd`. The rootname of a reference file is based on the year, date, and time that the file was delivered to the Calibration Data Base System (CDBS).

Table 3.3: WFPC2 Calibration Reference Files

Suffix	Reference File
`r0h, r0d`	Static mask
`r1h, r1d`	Analog-to-digital look-up table
`r2h, r2d, b2h, b2d`	Bias
`r3h, r3d, b3h, b3d`	Dark frame
`r4h, r4d, b4h, b4d`	Flatfield
`r5h, r5d`	Shutter shading
`c3t`	Photometry table (generated, not required)

The file names and history of all WFPC2 reference files in CDBS (and retrievable from the HST Archive) are summarized in the WWW Reference File Memo, updated with each new delivery. Any CDBS file is available for retrieval through the HST Data Archive (see chapter 1 of the HST Introduction). Some older, alternative reference files generated by the WFPC2 IDT are listed in the IDT Reference File Memo, also available on the web. All of the installed reference files contain HISTORY keywords at the end of the header that can be viewed using the **imhead** task or a standard editor. These HISTORY keywords provide detailed information about how the reference file was generated and when it was installed into the database.

There are history records at the bottom of the header file of the calibrated data as well as each of the calibration reference file headers. These history comments sometimes contain important information regarding the reference files used to calibrate the data in the pipeline.

3.3.2 Calibration Steps

Static Mask Application

Header Switch: MASKCORR
Header Keywords Updated: MASKCORR
Reference File: MASKFILE

The static mask reference file (`.r0h/.r0d`) contains a map of the known bad pixels and columns; the mask reference filename is recorded in the MASKFILE header keyword in the science header images (`.d0h` and `.c0h`). If this correction is requested, (MASKCORR=PERFORM), the mask is included in the calibration output data quality files; the science data themselves are *not* changed in any way. The STSDAS task **wfixup** can be used on the final calibrated science image (`.c0h/.c0d`) to interpolate across pixels flagged as bad in the final data quality file (.`c1h`).

A/D Correction

Header Switch: ATODCORR
Header Keywords Updated: ATODCORR
Reference File: ATODFILE

The analog-to-digital (A/D) converter takes the observed charge in each pixel in the CCD and converts it to a digital number. Two settings, or gains, of the A/D are used on WFPC2. The first converts a charge of approximately seven electrons to a single count (called a *Data Number* or *DN*), and the second converts a charge of approximately 14 electrons to a DN, also referred to as "*gain 15*" for historical reasons. The precise gain conversion values for each chip are listed in the WFPC2 Instrument Handbook.

A/D converters work by comparing the observed charge with a reference and act mathematically as a “floor” function. However, these devices are not perfect and some values are reported more (or less) frequently than they would be by a perfect device; although the "true" DN values can never be recovered, one can statistically adjust for this systematic bias. Fortunately, the WFPC2 A/D converters are relatively well-behaved and the correction is small (the largest correction is about 1.8 to 2.0 DN for bit 12, i.e., 2048)

The A/D fix up is applied when the ATODCORR keyword is set to PERFORM; the calibration file (lookup table) used to correct for the A/D errors has the suffix `.r1h`. The file has four groups, one for each detector; each group has 4096 columns (i.e., all possible DN values for a 12 bit detector) and two rows. The first row contains a -1 in the first pixel, followed by the Bay 3 temperature values in the subsequent pixels; the next row (each row corresponds to one temperature) contains the A-to-D conversion corrections for each DN value[3]. The example below illustrates determining the A-to-D fix up for a DN value of 450, in WF2, for gain 7, assuming the ATODFILE has already been retrieved from the Archive. Note that the correction for a given DN value is found in the DN+1'th pixel (i.e., [DN+1,2]).

```
cl> listpix dbu1405iu.r1h[2][451,2]
1.  450.1722
```

Bias Level Removal

Header Switch: BLEVCORR
Header Keywords Updated: BLEVCORR
Group Header Keywords Updated: DEZERO, BIASEVEN, BIASODD
Reference File: BLEVFILE, BLEVDFIL

The charges that are in each pixel sit on top of an electronic pedestal, or "bias", designed to keep the A/D levels consistently above zero. The mean level of the bias must be determined empirically using the extended register (overscan) pixels which do not view the sky. The values of these pixels are placed in the extracted engineering files (`.x0h`/`.x0d`). The overscan area used to calculate the mean bias levels is [9:14,10:790], with BIASODD being determined from columns 10, 12, and 14 and a BIASEVEN being determined from columns 9, 11, and 13 (this counter-intuitive nomenclature is due to an offset in the `.x0h` file; even and odd are correctly oriented with respect to the data file columns). In observations taken before March 8, 1994, the pipeline used a larger part of the overscan region, resulting in occasional oversubtraction of the bias level and possibly large negative pixel values. Separate even and odd bias levels were extracted in data taken and/or processed after May 4, 1994. Note that any data retrieved through the OTFR system will have the correct bias levels determined and removed. The keyword BLEVCORR controls the subtraction of the bias in **calwp2**.

3. On-orbit tests have shown that for WFPC2, the conversion values have remained constant; therefore, the A-to-D reference file contains only one temperature and one set (row) of conversion values.

Bias Image Subtraction

Header Switch: BIASCORR
Header Keywords Updated: BIASCORR
Reference File: BIASFILE, BIASDFIL

The value of the bias pedestal can vary with position across the chip. Therefore, once the mean bias level correction has been completed, the pipeline looks at the keyword BIASCORR. If it is set to PERFORM, then a bias image (`.r2h/.r2d`) is subtracted from the data to remove any position-dependent bias pattern. The bias reference file is generated by stacking a large set of A/D and bias-level corrected zero-length exposures. The correction consists of subtracting the bias reference file from the observation; any bad pixels flagged in the data quality file for the bias (`.b2h/.b2h`) are also flagged in the science image data quality file (`.c1h/.c1d`).

Dark Image Subtraction

Header Switch: DARKCORR
Header Keywords Updated: DARKCORR
Reference File: DARKFILE, DARKDFIL

A dark correction is required to account for the thermally-induced dark current as well as a *glow* (see section 4.3.2) from the field flattening lens. The dark reference file (`.r3h/.r3d`) is generated from a combination of a superdark image (a stack of typically 120 dark frames[4]) and warm pixels identified from a smaller stack of individual dark frames (five, as of ~1996). Prior to stacking, each dark frame is examined and regions affected by image anomalies, such as CTE residual images (see figure 4.2), are masked out. If a dark correction is requested (DARKCORR=PERFORM), the dark reference file, which was normalized to one second, is scaled by the DARKTIME keyword value and subtracted from the observation. By default, DARKCORR is set to "PERFORM" for all exposures longer than 10 seconds, and set to "OMIT" for shorter exposures.

Flatfield Multiplication

Header Switch: FLATCORR
Header Keywords Updated: FLATCORR
Reference File: `FLATFILE, FLATDFIL`

The number of electrons generated in a given pixel by a star of a given magnitude depends upon the quantum efficiency of that individual pixel as

4. A dark frame is a long exposure taken with the shutter closed; each individual dark has the standard calibration corrections applied (ATODCORR, BLEVCORR, and BIASCORR).

well as on any large scale vignetting of the field-of-view caused by the telescope and camera optics. To correct for these variations, the science image is multiplied by an inverse flatfield file. WFPC2 flatfields are currently generated from a combination of on-orbit data (so-called Earthflats, images of the bright Earth) and pre-launch ground data. The on-orbit data allow a determination of the large-scale illumination pattern while the pre-launch data are used to determine the pixel-to-pixel response function. The application of the flatfield file (extension `.r4h`) is controlled by the keyword `FLATCORR`.

Shutter Shading Correction

Header Switch: `SHADCORR`
Header Keywords Updated: `SHADCORR`
Reference File: `SHADFILE`

The finite velocity of the shutter produces uneven illumination across the field of view (thus the term "shutter shading"), resulting in a position-dependent exposure time. *The effect is only significant, however, for exposures of a few seconds or less*. The shutter shading calibration is applied by default to all exposures less than ten seconds. It has the form of an additive correction, scaled to the appropriate exposure time, that varies spatially across the detectors. The keyword switch is `SHADCORR`, and the shutter shading file name is stored in the keyword, `SHADFILE`.

Creation of Photometry Keywords

Header Switch: `DOPHOTOM`
Header Keywords Updated: `DOPHOTOM, PHOTTAB`
Group Header Keywords Updated: `PHOTMODE`, `PHOTFLAM`, `PHOTZPT`, `PHOTPLAM`, `PHOTBW`
Reference File: `GRAPHTAB`, `COMPTAB`

Photometry keywords, which provide the conversion from calibrated counts (DN) to astronomical magnitude, are computed by **calwp2** using the STSDAS package **synphot**. (More information on **synphot** can be found in this document, and in the *Synphot User's Guide*, which is available via the web.) The keyword switch for this step is `DOPHOTOM`, and the reference file keywords are `GRAPHTAB` and `COMPTAB`. *Note that the science data (*`.c0h/.c0d`*) pixel values are not changed as a result of performing DOPHOTOM, the data remain in units of DN (data number);* **calwp2** *merely computes the photometric parameters and populates the appropriate header keywords*.

The photometric keywords that are computed are listed in figure 3.3 below; the first two are in the ASCII header (both `.d0h` and `.c0h`), while the last five keywords are group parameters (use the IRAF tasks **imheader**, **hselect**, or **hedit** to examine the group keywords—see chapter 2 and chapter 3 of the HST Introduction for more details).

Figure 3.3: Photometry Keyword Descriptions

Header parameters

```
DOPHOTOM= 'YES ' / Fill photometry keywords: YES, NO, DONE
PHOTTAB = 'ucal$u27s0301n.c3t' / name of the photometry calibration table
```

Group parameters

```
'PHOTMODE' / Photometry mode     (for example, WFPC2,1, A2D7, F675W,CAL)
'PHOTFLAM' / Inverse Sensitivity (erg/sec/cm2/Å for 1 DN/sec)
'PHOTPLAM' / Pivot wavelength (angstroms)
'PHOTBW ' / RMS bandwidth of the filter (angstroms)
'PHOTZPT' / Photometric zeropoint (magnitude)
```

The calwp2 task constructs the PHOTMODE based on the specific image characteristics, which are given in the header keywords (i.e., INSTRUMENT, DETECTOR, ATODGAIN, FILTNAM1, FILTNAM2 and LRFWAVE); the throughput table for that PHOTMODE is then generated based upon the paths and files defined in the GRAPH and COMP tables stored in the HST Calibration Data Base System (CDBS). That path, i.e., the input files used to generate the final throughput table for the image, is recorded in the HISTORY comments of the calibrated science image (.c0h), and may also be viewed by running the STSDAS task **showfiles**.

The example below steps through both options; please refer to the *Synphot Handbook* for more details concerning the synphot tasks and the "Photometric Tables" section for suggestions on how to download the most recent **synphot** tables. Note that in the example below, the individual throughput files that are used to create the final image throughput table are: HST OTA, WFPC2 optics, filter (F606W), detector quantum efficiency table, a-to-d gain, and flatfield. Observers may notice that currently, the flatfield tables wfpc2_flat* (invoked by the "cal" in the photmode) are set to 1 though this could of course change with future WFPC2 flatfield and **synphot** table updates.

The final throughput table created for the image is saved in a STSDAS table with extension of "`.c3t`"; **calwp2** computes the photometric parameters from the `.c3t` table and updates the group keyword values accordingly.

```
wf> hsel u5kl0101r.c0h[2] $I,instrume,detector,atodgain,filtnam1,filtnam2 yes
u5kl0101r.c0h[2]        WFPC2   2       7.0     F606W
wf> hsel u5kl0101r.c0h[2] photmode,photflam,photplam,photbw,photzpt yes
 WFPC2,2,A2D7,F606W,,CAL 1.842431E-18    6004.956        637.824 -21.1
cl> imhead u5kl0101r.c0h long+ | match HISTORY
...[some HISTORY lines removed to save space]
HISTORY   The following throughput tables were used:
HISTORY   crotacomp$hst_ota_007_syn.fits, crwfpc2comp$wfpc2_optics_006_syn.fits,
HISTORY   crwfpc2comp$wfpc2_f606w_006_syn.fits,
HISTORY   crwfpc2comp$wfpc2_dqewfc2_005_syn.fits,
HISTORY   crwfpc2comp$wfpc2_a2d7wf2_004_syn.fits,
HISTORY   crwfpc2comp$wfpc2_flatwf2_003_syn.fits
wf> showfiles "WFPC2,2,A2D7,F606W,,CAL"
#Throughput table names:
crotacomp$hst_ota_007_syn.fits
crwfpc2comp$wfpc2_optics_006_syn.fits
crwfpc2comp$wfpc2_f606w_006_syn.fits
crwfpc2comp$wfpc2_dqewfc2_005_syn.fits
crwfpc2comp$wfpc2_a2d7wf2_004_syn.fits
crwfpc2comp$wfpc2_flatwf2_003_syn.fits
wfl> bandpar "WFPC2,2,A2D7,F606W,,CAL" photlist=all
               # OBSMODE          URESP          PIVWV          BANDW
 WFPC2,2,A2D7,F606W,,CAL     1.8424E-18         6004.9         637.82
               # OBSMODE           FWHM          WPEAK          TPEAK
 WFPC2,2,A2D7,F606W,,CAL          1502.         6188.8       0.020972
               # OBSMODE          AVGWV          QTLAM          EQUVW
 WFPC2,2,A2D7,F606W,,CAL         6038.9      0.0066095         39.467
               # OBSMODE          RECTW          EMFLX        REFWAVE
 WFPC2,2,A2D7,F606W,,CAL         1881.8     3.6564E-15         6038.9
               # OBSMODE        TLAMBDA
 WFPC2,2,A2D7,F606W,,CAL       0.019887
```

It is not necessary to rerun *calwp2* and/or re-retrieve data via OTFR to merely recompute the photometric parameters; these may be obtained by running the STSDAS Synphot task *bandpar* directly, as shown in the example above.

Histogram Creation

Header Switch: DOHISTOS
Header Keywords Updated: DOHISTOS
Reference File: none

This step will create a multigroup image (`.c2h/.c2d`) with one group for each group in the calibrated data file. Each group contains a three-line image where the first row is a histogram of the raw data values, the second row is a histogram of the A/D corrected data, and the third row is a histogram of the final calibrated science data. This operation is controlled by the keyword DOHISTOS; the default is to skip this step.

Data Quality File Creation

By performing a bitwise logical OR, the **calwp2** software combines the raw data quality file (.`q0h`, .`q1h`) with the static pixel mask (.`r0h`) and the data quality files for bias, dark, and flatfield reference files (.`b2h`, .`b3h`, .`b4h`) in order to generate the calibrated science data quality file (.`c1h`). This step is always performed; even if no *CORR keyword is set (i.e., if MASKCORR, BLEVCORR, BIASCORR, etc. were all set to OMIT), a `.c1h` file would still be generated, though it would not contain much useful information. The flag values used are defined below; by convention, DQF pixel values of zero (0) designate *good* pixels. The final calibrated data quality file (.`c1h`) may be examined, for example, using SAOimage, ximtool, or **imexamine**, to identify which pixels may be bad in the science image.

Table 3.4: WFPC2 Data Quality Flag Values

Flag Value	Description
0	Good pixel
1	Reed-Solomon decoding error. This pixel is part of a packet of data in which one or more pixels may have been corrupted during transmission.
2	Calibration file defect—set if pixel flagged in any calibration file. Includes charge transfer traps identified in static pixel mask file (`.r0h`).
4	Permanent camera defect. Static defects are maintained in the CDBS database and flag problems such as blocked columns and dead pixels. (Not currently used.)
8	A/D converter saturation. The actual signal is unrecoverable but known to exceed the A/D full-scale signal (4095).[1]
16	Missing data. The pixel was lost during readout or transmission. (Not currently used.)
32	Bad pixel that does not fall into above categories.
128	Permanent charge trap. (Not currently used.)
256	Questionable pixel. A pixel lying above a charge trap which may be affected by the trap.
512	Unrepaired warm pixel.
1024	Repaired warm pixel.

1. Calibrated saturated pixels may have values significantly lower than 4095 due to bias subtraction and flatfielding. In general, data values above 3500 DN are likely saturated.

3.4 Recalibration

With the advent of the On-The-Fly Reprocessing (OTFR) system in May 2001, all WFPC2 data requested from the Archive are automatically and completely reprocessed from the original telemetry file, using the most up-to-date software and calibration files. As such, the need for observers to manually recalibrate WFPC2 images has been greatly reduced. If recalibration is desired (e.g., due to an improvement in a reference file), the data can be re-retrieved from the Archive.

3.4.1 Why and When to Re-retrieve data through OTFR

The primary reason to re-request or reprocess WFPC2 data is the availability of improved or more up-to-date reference files and tables, especially darks, flatfields, **synphot** component tables, and improvements to the pipeline software, such as the calibration task **calwp2**. In this section, we provide a brief summary of some relevant changes to the pipeline task and related elements as of today (November, 2001). Details on changes to the pipeline software are maintained in the WFPC2 History Memo (section 5). A quantitative account of the differences between various generations of reference files is given in chapter 4.

Reference Files

Improved reference files will necessarily lag the science images in time. For example, the best dark reference file for a given WFPC2 observation will generally not be available until a few weeks after the science observation is taken. The time is required to retrieve the dark frames from the Archive, generate a new reference file, deliver the file to CDBS, and install the file for use in OTFR. Generally, there is one dark reference file per week, a combination of the dark frames taken that week and the current super dark.

Other reference files, such as the bias and flatfield, are more stable and thus are updated at less frequent intervals than the weekly darks. Bias reference files are generated roughly on an annual basis from a large set of frames taken over the course of one year. These new bias reference files become retroactive, applicable to any science data taken during the year covered by the individual bias frames used to generate the reference file. Superdarks are also generated about once per year; the input dark frames are processed with the superbias covering that year. The flatfields are typically updated less frequently than biases and darks, usually only once every few years. The mask file, A-to-D lookup table, and shutter shading files were created early in the mission of WFPC2 and have not changed since then. To check the quality of the reference files applied to your science observations, check the PEDIGREE and DESCRIP keywords in the HISTORY comments at the end of the header of the calibrated image (`.c0h`). For more details, refer to the reference file header itself, particularly the HISTORY records.

Darks

Prior to the public release of OTFC in 2000, the calibrated data originally delivered to the principle investigator and to the Archive had been processed through the pipeline within a few days of the observation. At that time, the available dark reference file normally did not contain the most up-to-date information about warm pixels, which change on a weekly timescale (see section 3.5.1). Thus, pre-OTFC calibrated data were *always* processed with an out-of-date dark, and the correction of warm pixels could be improved by manually recalibrating with a more appropriate dark file or by using the STSDAS task **warmpix**. In this era of OTFR (see section 3.1) however, reprocessing with updated reference files can be accomplished by simply requesting the data from the Archive at least a few weeks after the science observations were taken.

Since August 1, 1996, the dark reference files used in the pipeline have been generated by combining an appropriate superdark (stack of 120 individual dark frames, taken over the course of about one year) with the information on warm pixels from one week's worth of darks (stack of 5 darks taken over less than two days). Thus, a new pipeline dark reference file exists for every week in which a set of five long dark frames were taken; the primary difference from week to week is the warm pixel population, since the superdark contribution remains the same over a year.

Prior to August 1996, pipeline dark reference files had been generated from a stack of only ten dark frames taken during a two week interval. Thus, very deep observations taken before August 1996 could benefit from recalibration with an improved dark reference file. For observations longer than about 20,000 seconds (10,000 seconds in the UV and in narrow-band filters), the noise in the dark frame is a significant contributor to the total noise in the final calibrated image. For this reason, if the science results are limited by the noise, observers are advised to manually recalibrate their images with a superdark, since this will significantly reduce the noise associated with dark subtraction. Note that it is also advisable to use an appropriate superbias as well as correct for warm pxiels independently (e.g., by a post-pipeline processing task such as **warmpix**, discussed in section 3.5.1). Some early superdarks are listed in the WWW Reference File Memo and are available from the Archive; others are listed in the IDT Reference File Memo. Also, the individual dark frames are always available from the Archive, should observers wish to generate their own custom superdark.

Flatfields

Very early observations, those processed before March 9, 1994, used interim flatfields based on pre-launch data. These flatfields did not have good large-scale properties (peak errors were about 10%) and thus WFPC2 observations processed before that date should be re-retrieved through OTFR (the processing date can be determined from the trailer file). After March 1994, in-flight flatfields were used. Their quality has steadily improved, and those currently in the pipeline are believed to be good to about 0.3% on small scales, and 1% or less on large scales. See section 4.2 for a detailed discussion of the differences between various generations of flatfields.

If you are in doubt about the quality of the flatfielding in your observations, check the PEDIGREE and DESCRIP keywords of the flatfield file, also reported (after December 1994) in the HISTORY comments at the end of the header of the calibrated image. If PEDIGREE is GROUND, the data will need to be recalibrated. If the PEDIGREE is INFLIGHT, the flatfield was obtained from on-orbit data, and the DESCRIP keyword gives some information on its quality. INFLIGHT flatfields are of sufficient quality for most scientific goals, but for especially demanding applications and data with very high signal-to-noise ratio, it may be advisable to recalibrate with the most recent flatfields.

Photometric Tables

The photometric component tables are used by **synphot** to determine the photometric calibration header parameters, namely PHOTFLAM and PHOTPLAM (see chapter 5). These component tables have been updated several times, most recently on May 16, 1997, in order to contain the most up-to-date information on the throughput of WFPC2. If the photometric tables have changed, users can either re-retrieve their observations from the Archive or run **synphot** directly to determine the header parameters (see section 3.3.2). Note that to run **synphot** directly, observers must have the most up-to-date **synphot** tables installed at their local site; as a group, these tables are part of the standard STSDAS installation which is described in appendix A. Individual tables may be retrieved via the STScI ftp sites:

ftp://ftp.stsci.edu/cdbs/cdbs2/mtab/

ftp://ftp.stsci.edu/cdbs/cdbs2/comp/ota/

ftp://ftp.stsci.edu/cdbs/cdbs2/comp/wfpc2/

Users can also use the alternate methods given in section 5.1 to photometrically calibrate their observations.

Pipeline Calibration Task calwp2

Another possible reason for recalibration is to use a more recent version of the calibration pipeline task **calwp2**. This task has seen several minor revisions, usually to add information to processed data; the current version, as of this writing, is 1.3.5.2. Only three of the **calwp2** revisions since WFPC2 operations began actually affect the calibrated data. The first two were changes in how the bias level is computed. Starting in March 8, 1994 (version 1.3.0.5), columns 3 through 8 of the overscan data were no longer used because they could be affected by the image background; beginning on May 4, 1994 (version 1.3.0.6), separate bias levels were computed for even and odd columns, resulting in a slightly better image flatness for about 1% of all WFPC2 images (see WFPC2 ISR 97-04).

The third update (version 1.3.5.2, January 3, 1997) corrects a bug introduced in December 1994 (1.3.0.7) in the calibration of WFPC2 single-chip, two-chip, or three-chip observations that do not include the PC (about 1% of all archived observations). We recommend that observers in possession of observations taken and processed between December 1994 and January 1997, re-request their data from the Archive.

3.4.2 Running calwp2 manually

As of May 2001, all WFPC2 data requested from the archive are processed through the On-The-Fly Reprocessing (OTFR) system, using the most up-to-date reference files and software. As such, recalibrating WFPC2 images can be done by simply re-retrieving the data via OTFR. However, occasionally, users may wish to recalibrate manually, for example, to make use of a non-standard dark or flatfield. In these cases, **calwp2** will need to be run from the IRAF/STSDAS command line. To recalibrate, the raw data and all reference files must be retrieved, the headers must be updated with the desired corrections to be performed, and the reference file names must be changed as needed. This section outlines in detail the necessary steps required to manually recalibrate WFPC2 data.

Retrieve necessary files

In order to recalibrate a WFPC2 observation, you need to retrieve the dataset as well as *all* of the reference files and tables needed for calibration. Since standard pipeline processing uses those files listed by StarView as the best reference files, see chapter 1 of the HST Introduction for a description of how to obtain the appropriate reference files from the STScI Archive. We suggest copying the raw data files and the required reference files and tables to a subdirectory used for recalibration as this will preserve all original files. Before beginning, any calibrated files (e.g., `.c0h/.c0d, .c1h/.c1d, .c3t, .cgr`) must be removed from the recalibration directory, since **calwp2** will not overwrite pre-existing calibrated products.

Edit calibration switches and reference files

The next step in recalibrating WFPC2 data is to set the calibration switches and reference keywords in the header of your raw data file (`.d0h`). These switches determine which calibration steps will be performed and which reference files will be used at each step in the process. The calibration header keywords in a dataset can be changed using the **hedit** or **chcalpar** task in the STSDAS **hst_calib.ctools** package. The **hedit** task provides more detailed control over individual keywords and is preferred by some users experienced with calibration of WFPC2; though simpler to use, each switch and file must be changed individually.

The **chcalpar** task takes a single input parameter—the name(s) of the image files to be edited. When **chcalpar** starts, it automatically determines the instrument used to produce that image and opens one of several parameter sets (*pset*) which it loads with the current values of the header keywords. The WFPC2 pset is named `ckwwfp2`. Typing **ckwwfp2**, as a task name, at the `cl>` prompt will also edit this pset.

A detailed description of the steps involved in changing header keywords follows:

1. Start the **chcalpar** task, specifying the image(s) for which you want to change keyword values. If you specify more than one image, say

by using wildcards, the task will take initial keyword values only from the first image. For example, you could change keywords for all WFPC2 raw science images in the current directory (with initial values from the first image), using the following command:

```
wf> chcalpar u*.d0h
```

2. When **chcalpar** starts, you will be placed in **epar**—the IRAF parameter editor, and will be able to edit the parameter set of calibration keywords. Change the values of any calibration switches, reference files or tables to the values you wish to use for recalibrating your data. Remember that **no** processing has been done on the raw datasets. Therefore, even if you wish to correct, for instance, only the flatfielding, you will need to redo the bias and dark current subtraction as well; hence, the switches for all these steps must be set to PERFORM. Note that only the keywords you actually type in will be substituted.
3. Exit the editor by typing `:q` two times (the first `:q` to exit the pset editor, the second to exit the task). The task will ask if you wish to accept the current settings. If you type "`y`", the settings are saved and you will return to the IRAF prompt. If you type "`n`", you will be placed back in the editor to re-define the settings. If you type "`a`", you will return to the IRAF prompt and any changes will be discarded. For additional examples of updating the calibration keywords, check the on-line help by typing `help chcalpar`.

Set directory pointers

The calibration reference file names in the header of the raw data (i.e., the `.d0h` file) are typically preceded by five characters (e.g., `uref$` for calibration images and `utab$` for calibration tables). These are pointers to the subdirectory where the reference and `.x0h/.q1h` raw data files are located. Before calibrating your data, you will need to set these pointers. For WFPC2 data, you would use something like the following:

```
to> set uref = "/your/hstdata/caldir/"
to> set mtab = "/your/hstdata/caldir/"
to> set ucal = "/your/hstdata/rawdir/"
```

where `caldir` is the subdirectory for the reference files and `rawdir` is the subdirectory for the uncalibrated images.

To set the `uref in VMS`, one would use:

```
to> set uref = "DISK$SHARE:[HSTDATA.CALDIR]"
```

where HSTDATA.CALDIR is the directory where you have stored the calibration reference files and tables.

Execute calwp2

Once you have correctly changed the values of the calibration keywords in the header of the raw data file, you are ready to recalibrate your data. The WFPC2 calibration software, **calwp2**, is run by typing the name of the task followed by the *rootname* of the observation dataset. For example, to recalibrate the dataset u0w10e02t and write the log of the results to the file calwp2.log (rather than to the screen), type:

```
wf> calwp2 u0w10e02t "" > calwp2.log
```

Note that* calwp2 *will not overwrite an existing calibrated file. If you run the task in the directory where you already have calibrated data, you will need to specify a different output file name, for example:
wf> calwp2 u00ug201t wfpc_out > wfpc.log

For more information about how these routines work, use the on-line help by typing help calwp2.

A note about calculating the absolute sensitivity for WFPC2

If you set DOPHOTOM=OMIT before running **calwp2**, then the values of inverse sensitivity (PHOTFLAM), pivot wavelength (PHOTPLAM), RMS bandwidth (PHOTBW), zeropoint (PHOTZPT), and observation mode (PHOTMODE) will not be written to the header of the recalibrated data file. Remember that the DOPHOTOM calibration step does not alter the values of the data (which are always counts or data numbers in the calibrated file), but only writes the information necessary to convert counts to flux in the header of the file. Therefore, unless you wish to recalculate the absolute sensitivity for your observation (e.g., because a more recent estimate of the throughput exists for your observing mode), there is no need to recompute these values and you can simply use the keyword values from your original calibrated file and apply them to your recalibrated data. However, new estimates of WFPC2 transmission and absolute sensitivity were obtained in September 1995, May 1996, and May 1997. If your data were processed in the pipeline before May 1997, you may wish to re-create the absolute sensitivity parameters using the latest version of **synphot**, which contains tables based on the most recent photometric calibration of

WFPC2; see "Creation of Photometry Keywords", for an example of this computation.

If you wish to recalculate the absolute sensitivity, set DOPHOTOM=YES in the `.d0h` file before running **calwp2**, or alternately, use the tasks in the **synphot** package of STSDAS. The **"synphot"** section in section 3.3.4 of the the HST Introduction has more information about how to use this package. To calculate the absolute sensitivity, **calwp2** and the **synphot** tasks use a series of component lookup and throughput tables. These tables are not part of STSDAS itself, but are part of the **synphot** dataset, which can easily be installed at your home site (see appendix section A.3.2 for information about how to do this). A more detailed discussion of photometric calibration can be found in section 5.2.

The most recent **synphot** ***tables must be in place in order to recalculate absolute sensitivity for WFPC2 data using*** **calwp2** ***or*** **synphot** ***(see chapter 3 of the HST Introduction).***

3.5 Improving the Pipeline Calibration

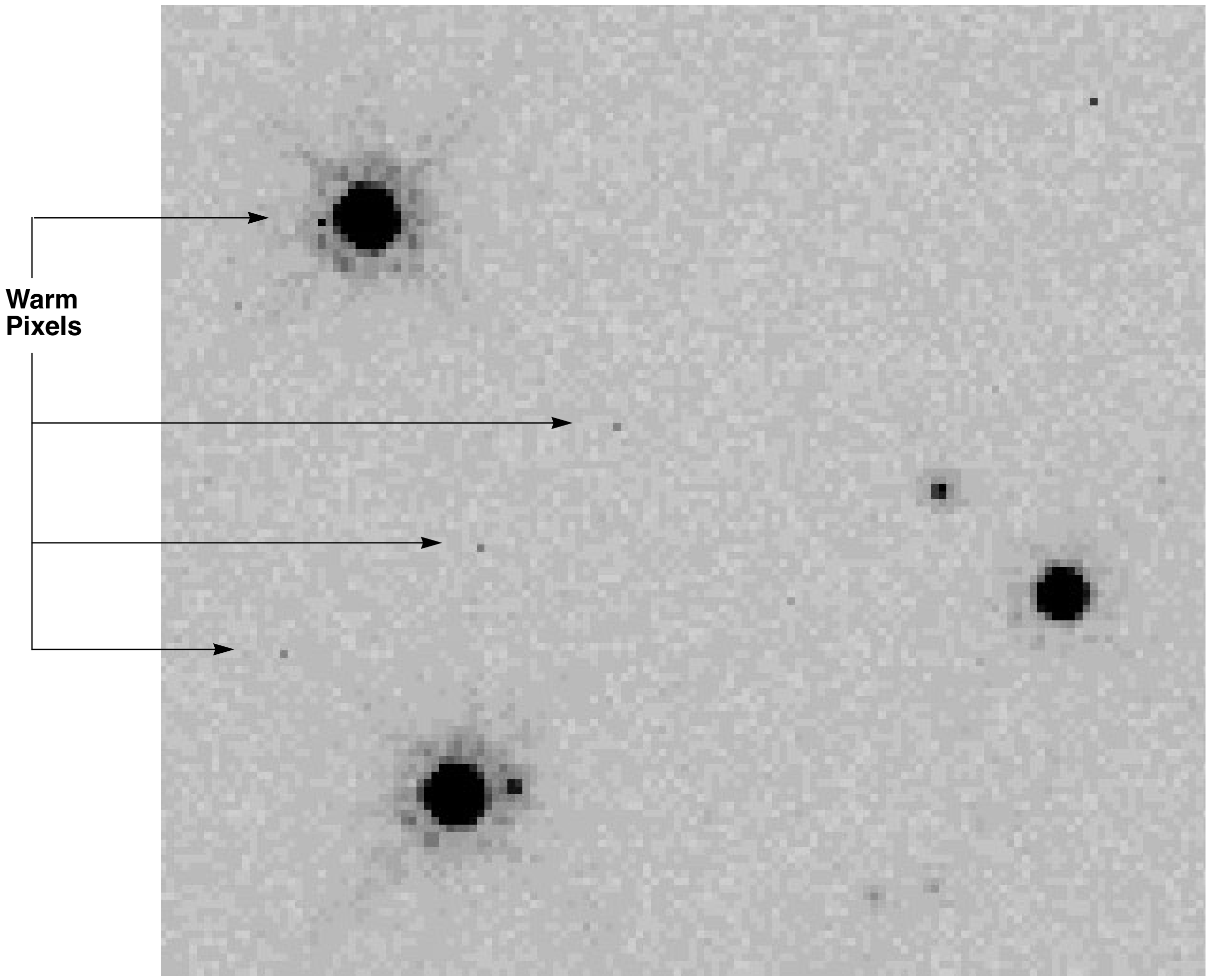
The individual calibrated images produced by the standard pipeline processing are, in most respects, as good as our knowledge of the instrument can make them. The usefulness of post-pipeline calibration is, in general, limited to three areas: improving the correction of pixels with elevated dark current (warm pixels), which are known to vary with time; employing a correction flatfield or alternate flatfield; and removing cosmic rays by comparing multiple images of the same field.

The treatment of warm pixels and cosmic rays can be quite different in the case of dithered data. This case is discussed in section 5.5; the present discussion refers to co-aligned data only.

3.5.1 Warm Pixels

Figure 3.4 shows a section of a PC image of a stellar field where cosmic rays have been removed through comparison of successive images. Nonetheless, individual bright pixels are clearly visible throughout the field.

Figure 3.4: PC Image of Stellar Field Showing Warm Pixels

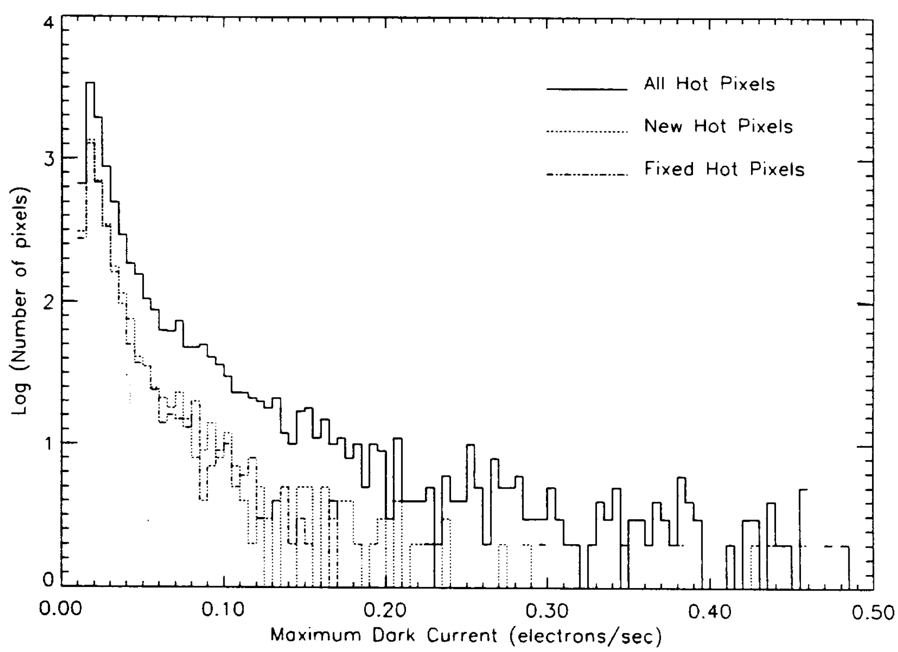


These bright pixels are *warm (or hot)* pixels, i.e., pixels with an elevated dark current. The vast majority of WFPC2 pixels have a total dark current of about 0.005 e^{-}/s^{-1} (including the *dark glow*, discussed in section 4.3.2). However, at any given time there are a few thousand pixels in each CCD, called warm pixels, with a dark current greater than 0.02 e^{-}/s^{-1}, up to several e^{-}/s^{-1} in a few cases (see figure 3.5). Some of these pixels are permanently warm, but most become warm during the course of the month, probably as a consequence of on-orbit bombardment by heavy nuclei. STIS, another instrument currently aboard HST that uses CCDs, exhibits a similar behavior. Most warm pixels return to normal after the CCDs are brought to room temperature for a few hours.

Will Warm Pixels Hurt my Science?

The impact of warm pixels on the scientific results obtained from WFPC2 images depends on a number of factors: the exposure length, the number of objects, and the science goals. If the principal goal of the program is to acquire morphological information on well-resolved targets, warm pixels are usually not a serious concern since they are easily recognizable. If the goal is accurate photometry of point sources, the probability that uncorrected warm pixels will influence the measurement at a given level can be computed on the basis of the distribution of warm pixels (see figure 3.5). In general, warm pixels are a concern in two cases: accurate photometry of faint sources in crowded fields, where warm pixels can easily be confused with cores of faint sources; and aperture photometry with very large apertures and/or of extended objects. In the latter case, warm pixels cause a positive tail in the count distribution that is not included in the background determination, but—depending on the software used—could be included in the integrated source flux, which then will be positively biased.

Figure 3.5: Distribution of Dark Current for Warm Pixels



Repairing warm pixels

Decontaminations, during which the instrument is warmed up to about 22° C for a period of six hours, are performed about once per month. These procedures are required in order to remove the UV-blocking contaminants which gradually build-up on the CCD windows (thereby restoring the UV throughput) as well as fix warm pixels. These pixels, with dark current levels of 0.02 electrons per sec or higher, generally appear at a rate of about 30 pixels per detector per day. A decontamination procedure typically anneals about 80% of the new warm pixels that arise during the month. Of those pixels that are not fixed, about half are fixed after two or three additional decontamination procedures. After that, the rate of correction decreases; longer decontaminations do not appear to improve the fraction of pixels fixed. For more detailed information, see the *WFPC2 Instrument Handbook*.

Because of the time variability of warm pixels, the standard pipeline dark correction (generally, one dark reference file per week) may not deal with them adequately. Even dark frames taken within a day of the observation will contain some warm pixels that vary significantly from those in the science observation. There are several ways to improve the correction for pixels which are known to be warm or which have varied near the time of the observations: flag the pixels in some way; use the STSDAS task, **warmpix**; or generate a custom dark reference file and recalibrate manually. These methods will be outlined in the following sections.

Identifying and flagging warm pixels

The first method to treat warm pixels is to identify and flag them. Depending on the software used, the flagged pixels can either be ignored (PSF fitting software generally allows this) or be interpolated from nearby pixels (for software that requires a valid value for all pixels, such as most aperture photometry tasks). The identification of warm pixels can be accomplished by taking advantage of the fact that they are the only WFPC2 feature to extend across only one pixel; both cosmic rays and photons, in the form of point sources, involve more than one pixel. The IRAF task **cosmicrays**, written originally to remove single-pixel cosmic rays in ground-based data, has been used with some success to identify warm pixels in WFPC2 data. Identification of warm pixels is also possible using information from dark frames taken before and after the observations were executed, as described below.

Subtracting warm pixels via warmpix

The second option is to attempt subtraction of the warm pixel dark current that existed at the time of the observations. This has the advantage that the information that exists in the measured signal in the pixel is retained, but it does require independent timely information on the dark current. WFPC2 takes about five long dark frames every week, thus information on warm pixels is available with a time resolution of about one week. The STSDAS task **warmpix,** will flag and/or correct warm pixels using an input table, available on the WWW, containing the locations and dark count rates for warm pixels that existed around the time of the science observation. Each table typically spans the time interval between decontamination procedures, with information derived from dark files taken at several epochs (roughly once per week) within that period. This procedure will generally fix 90% to 95% of the warm pixels found in typical user data, though there are some uncertainties in the results due to the intrinsic variability of warm pixels and the time span between darks. The steps necessary to run **warmpix** are summarized below.

1. Obtain the relevant warm pixel tables from the WWW. Each table name reflects its applicability dates; for example, the table named *decon_951214_960111.tab.Z* applies to all observations between December 14, 1995 and January 11, 1996.

These tables are in Unix-compressed format. On some systems, the retrieved table will not have the .Z extension, but they still need to be renamed to add the .Z extension and uncompressed by the Unix task **uncompress.** ***Please contact the Help Desk at help@stsci.edu if you have a non-Unix system or if you encounter difficulties in retrieving the tables.***

2. Retrieve the calibration reference files used for dark subtraction and flatfielding from the Archive, see section 1.1 of the HST Introduction. The filenames are recorded in the science header keywords DARKFILE and FLATFILE, respectively.
3. Redefine the IRAF variable `uref$` to point to the directory where the dark and flatfield files are stored. This step is required for **warmpix** to undo the dark current subtraction performed in the pipeline and substitute its own. *If* **warmpix** *cannot find these reference files, it will not be able to correct the dark current subtraction and will flag all pixels as being uncorrectable.*
4. Run **warmpix** to correct and/or flag warm pixels. There are a number of user-adjustable parameters to decide which pixels should be fixed and which should be flagged as uncorrectable. Please see the online **warmpix** STSDAS help file for more details (type "help warmpix" at the iraf prompt).

At the end of this process, pixels that exceed the user-defined thresholds either will be corrected for the dark current measured in the darks, linearly interpolated to the date of the observation, or flagged as uncorrectable. Specifically, if the pixel has a high or extremely variable dark count rate, **warmpix** will not change the pixel value in the science image but the data quality file will have its 10th least significant bit set to indicate that it is a "bad" or irrepairable pixel (i.e. value of 512, logically OR'ed with the other calibration reference data quality file flags for that pixel). If the pixel has a moderate dark count rate, **warmpix** will fix the pixel in the image and insert a value determined from an extrapolation of the warm pixel's value between two epochs that cover the time of observation for the image. In addition, the data quality file will have the value 1024 logically OR'ed with the other data quality files. Pixels with low dark count rates are not modified by **warmpix**.

Non-STSDAS tasks generally ignore the data quality files, and thus may not properly use the information indicating which pixels need to be rejected. Users should propagate this information by the appropriate method, which will depend on the specifics of the task.

Generating a custom dark reference file using "daily darks"

In July 1997, a calibration program was begun to obtain up to three dark frames every day, to allow for better warm pixel corrections. These darks, also referred to as "daily darks", are relatively short (1000 seconds) so that the observations can fit into almost any occultation period, making automatic scheduling feasible. In addition, the priority of the daily darks is low; they are taken only when there is no other requirement for that specific occultation period, so daily coverage is not guaranteed. Observers should be aware that only the standard (1800 second) darks, taken at the rate of five per week, are used in generating the pipeline darks, superdarks, and warm pixel tables. The daily darks are available without a proprietary period to the GO community via the Archive.

These daily darks should be used if very accurate identification of warm pixels is needed. Many observers develop their own software to make use of daily darks to improve the warm pixel correction. An alternative, however, is to use canned IRAF scripts available from STScI to generate a custom dark reference file for use in manually recalibrating their science images (see ISR 01-01 and Addendum 01-08). These reports provide detailed instructions on how to use the scripts to generate a custom dark; section 3.4.2 provides details on how to manually rerun **calwp2**.

3.5.2 Alternate Flatfields

Correction Flatfields

As of December 2001, the noise characteristics of the WF chips in the standard WFPC2 pipeline flatfield reference files are such that the signal-to-noise achievable in the final calibrated science images is *not* limited by the flatfield. However, all PC1 flatfields (and some WF flatfields in the UV) have less than ideal noise properties; improving these flatfields can improve the resulting signal-to-noise in the calibrated images.

A set of "correction" flatfields, designed to be applied after normal pipeline processing (i.e., OTFR), have been developed in order to help reduce the flatfield noise. In particular, highly-exposed science images (>20,000 e^-/pixel, or 2860 and 1335 DN/pixel for gains 7 and 15, respectively) will show significant noise reduction, especially in the PC, if the new correction flatfields are used. Science images in some of the UV filters will show significant improvement as well, even at lower exposure levels. The correction flats are available from the Archive and have been generated so that they merely need to be multiplied into the calibrated (including flatfielded) science images. Please see ISR 01-07 for the details and names of these correction flats, as well as some caveats regarding their application to science images. *Note that these correction flatfields are not, as of November 2001, in the OTFR pipeline*, though they may be incorporated for selected filters in the future.

Flatfielding Linear Ramp Filter Images

Images observed with the linear ramp filters (LRFs) are, by design, currently *not* flatfielded in the OTFR pipeline. The calibrated science headers and trailers will indicate that the flatfield used was a "dummy" (i.e., 1 everywhere) and that the correction was effectively skipped. This is the case in the LRF image example below. The raw file (`.d0h`) has the `FLATCORR` set to `PERFORM`; however, based upon the flatfield reference file `PEDIGREE`, **calwp2** flags the correction step as `SKIPPED` in the calibrated image (`.c0h`).

```
cl> hedit u*d0h flat* .
u5ly020cr.d0h,FLATCORR = PERFORM
u5ly020cr.d0h,FLATFILE = uref$f4i1559cu.r4h
u5ly020cr.d0h,FLATDFIL = uref$f4i1559cu.b4h

cl> hedit uref$f4i1559cu.r4h pedigree,descrip .
uref$f4i1559cu.r4h,PEDIGREE = "DUMMY  18/04/1995"
uref$f4i1559cu.r4h,DESCRIP = "All pixels set to value of 1."

cl> hedit u*c0h flat* .
u5ly020cr.c0h,FLATCORR = SKIPPED
u5ly020cr.c0h,FLATFILE = uref$f4i1559cu.r4h
u5ly020cr.c0h,FLATDFIL = uref$f4i1559cu.b4h

cl> page *trl | grep FLAT
FLATFILE=uref$f4i1559cu.r4h  FLATCORR=SKIPPED
```

A single pipeline flatfield is difficult to generate for the LRFs, primarily due to the lack of an accurate spectrum for the external and internal flatfield light sources (i.e., observations of the bright Earth or images taken with the internal WFPC2 VISFLAT lamp). The color of the Earth can vary considerably, depending upon the feature observed (land, sea, or clouds). The color of the internal VISFLAT lamp is known to vary as a function of the position in the field of view, the total lamp “on” time, and the total number of times the lamp has been cycled on and off. Furthermore, since the linear ramp filters are far from the focal plane (the OTA beam has a diameter of approximately 33 arcseconds at the filter), any dust spots and other small imperfections in the filter have essentially no effect on the data. Any large-scale variations in the filter are contained in the filter transmission curves and are corrected during photometric calibration. Moreover, some of the ramps have pinholes and if LRF flats were to be made, they would unnecessarily degrade the science data.

Observers with LRF data are advised to check what flatfield has been applied to their data and if necessary, select an existing narrow band flatfield reference file close in wavelength to their LRF science observation (the header parameter `LRFWAVE` records the wavelength of the image) and manually recalibrate using **calwp2**. Since there are no narrow band filters near 8000 Å, the best alternative at these wavelengths is to use the F791W flatfield reference file. The WWW Reference File memo or the Archive’s StarView can be used to peruse the flatfields available in neighboring wavelength regimes.

3.5.3 Removing Cosmic Rays from Co-aligned Images

WFPC2 images typically contain a large number of *cosmic ray* events, which are caused by the interaction of galactic cosmic rays and protons from the Earth’s radiation belt with the CCD. Hits occur at an average rate of about 1.8 events s^{-1} per CCD (1.2 s^{-1} cm^{-2}), with an overall variation in rate of 60% (peak-to-peak) depending upon geomagnetic latitude and position with respect to the South Atlantic Anomaly (also see the *WFPC2 Instrument Handbook*, v. 6.0, pages 51-52).

Unlike events seen on the ground, most WFPC2 cosmic ray events deposit a significant amount of charge in several pixels; the average number of pixels affected is 6, with a peak signal of 1500 e^- per pixel and a few tens of electrons per pixel at the edges. About 3% of the pixels, or 20,000 pixels per CCD, will be affected by cosmic rays in a long exposure (1800 seconds). Figure 3.6, shows the impact of cosmic rays in an 800 second exposure with WFPC2. The area shown is about 1/16th of one chip (a 200 x 200 region); pixels affected by cosmic rays are shown in black and unaffected pixels are shown in white. A typical long WFPC2 exposure (2000 seconds) would have about 2.5 times as many pixels corrupted by cosmic rays.

Cosmic rays are noticeable even for very short exposures. The WFPC2 electronics allow activities to be started only at one-minute intervals; thus, a minimum-length exposure will collect at least one minute’s (the interval between camera reset and readout) worth of cosmic rays, and will be affected by about a hundred of them per CCD.

As a result of the undersampling of the WFPC2 PSF by the WF and PC pixels, it is very difficult to differentiate stars from cosmic rays using a single exposure. If multiple co-aligned images are available, cosmic rays can be removed simply and reliably by comparing the flux in the same pixel in different images, assuming that any differences well above the noise are positive deviations due to cosmic rays. STSDAS tasks such as **crrej** and **gcombine** can identify and correct pixels affected by cosmic rays in such images. (The task **crrej** has been significantly improved since the previous edition of the *HST Data Handbook* and is now the recommended choice.) If the images are shifted by an integral number of pixels, they can be realigned using a task such as **imshift**. Because each CCD is oriented differently on the sky, this operation will need to be done on one group at a time, using the pixel shift appropriate for each CCD in turn.

Another consequence of the undersampling of WFPC2 pixels is that small pointing shifts will cause measurable differences between images at the same nominal pointing. These differences are especially noticeable in PC data, where offsets of only 10 mas can cause a difference between successive images of 10% or more near the edges of stellar PSFs. We recommend that users allow for such differences by using the multiplicative noise term included in the noise model of the cosmic ray rejection task (`scalenoise` for **crrej** and `snoise` for **gcombine**). For typical pointing uncertainties, a multiplicative noise of 10% is adequate (note, this is specified as 10 for `scalenoise` and 0.1 for `snoise`). It is also strongly recommended that an image mask be generated for each image, in order to determine if an undue concentration of cosmic rays are identified near point sources—usually an indication that the cores of point sources are mistaken for cosmic rays. Detailed explanations of **crrej** and **gcombine** can be found in the on-line help.

Figure 3.6: WF Exposure Showing Pixels Affected by Cosmic Rays

Because sub-pixel dithering strategies are now very common, the image combination tasks in the **drizzle** package (see section 5.5) include a script that can remove cosmic rays from images taken at multiple pointings.

How many Images for Proper CR Rejection?

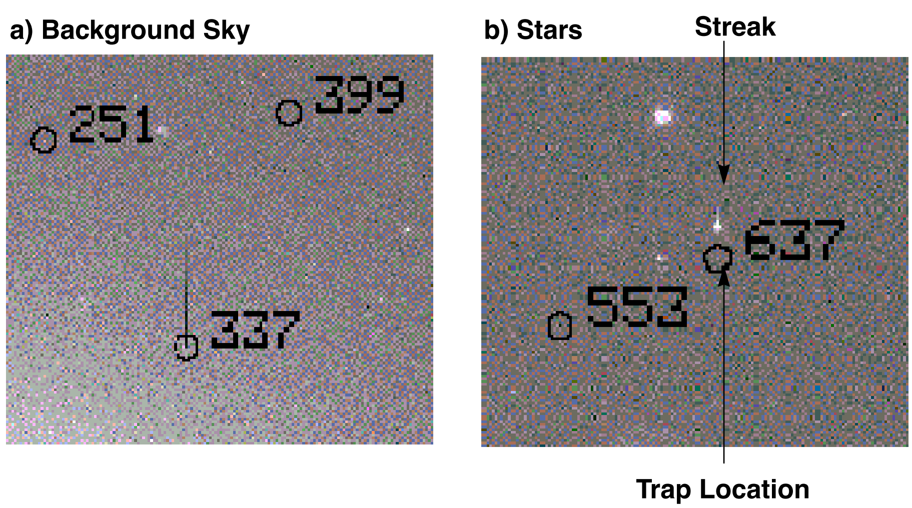
Cosmic rays are so numerous in WFPC2 data that double hits are not uncommon. For example, the combination of two 2000 second images will typically contain about 500 pixels per CCD that are affected by cosmic rays in both images; in most of these cases, the hit will be marginal in one of the two images. If the science goals require a high level of cosmic ray rejection, it will be desirable to conduct a more stringent test in pixels adjacent to detected cosmic rays (see the parameter `radius` in **crrej**). A better solution would be to break the observation into more than two exposures during the planning stage; the WFPC2 Exposure Time Calculator gives specific recommendations on the number of exposures necessary as a function of the number of pixels lost. In general, three exposures are sufficient for non-stringent programs, and four exposures for any program. The Exposure Time Calculator is available via the WWW.

3.5.4 Charge Traps

There are about 30 pixels in WFPC2 which do not transfer charge efficiently during readout, producing artifacts that are often quite noticeable. Typically, charge is delayed into successive pixels, producing a streak above the defective pixel. In the worst cases, the entire column above the pixel can be rendered useless. On blank sky, these traps will tend to produce a *dark* streak. However, when a bright object or cosmic ray is read through them, a bright streak will be produced. Figure 3.7 shows examples of both of these effects. (Note that these "macroscopic" charge traps are different from the much smaller traps believed to be responsible for the charge transfer effect discussed under "Charge Transfer Efficiency" in section 5.2.2.)

The images in figure 3.7 show streaks (a) in the background sky and, (b) stellar images produced by charge traps in the WFPC2. Individual traps have been cataloged and their identifying numbers are shown.

Figure 3.7: Streaks in a) Background Sky, and b) Stars



Bright tails have been measured on images taken both before and after the April 23, 1994 cool down and indicate that the behavior of the traps has been quite constant with time; fortunately, there is no evidence for the formation of new traps since the ground system testing in May 1993. The charge delay in each of the traps is well characterized by a simple exponential decay which varies in strength and spatial scale from trap to trap.

The positions of the traps, as well as those of pixels immediately above the traps, are marked in the `.c1h` data quality files with the value of 2, indicating a chip defect. Obviously, these pixels will be defective even in images of sources of uniform surface brightness. However, after August 1995, the entire column above traps has been flagged with the value of 256, which indicates a "Questionable Pixel." An object with sharp features (such as a star) will leave a trail should it fall on any of these pixels.

In cases where a bright streak is produced by a cosmic ray, standard cosmic ray removal techniques will usually remove both the streak and the cosmic ray. However, in cases where an object of interest has been affected, the user must be more careful. While standard techniques such as **wfixup** will interpolate across affected pixels and produce an acceptable cosmetic result, interpolation can bias both photometry and astrometry. In cases where accurate reconstruction of the true image is important, modelling of the charge transfer is required. For further information on charge traps, including the measured parameters of the larger traps, users should consult *WFPC2 ISR* 95-03, available on the WFPC2 web pages.

CHAPTER 4:

WFPC2 Error Sources

In this chapter. . .

This chapter discusses some of the error sources associated with WFPC2 data. Most of the chapter focuses on specific calibration errors, complementing and partially overlapping the discussion given in "Improving the Pipeline Calibration in section 3.5. Other subtle errors and problems which appear in WFPC2 data, but which are not directly related to data calibration, are discussed at the end of this chapter and in chapter 5.

Note that many of the error sources affecting calibrated WFPC2 data can be reduced by either recalibration with newer reference files or post-pipeline improvements, such as correction flatfields (see section 3.5.2). Recalibration can easily be accomplished by simply re-requesting the data from the Archive through OTFR (On-The-Fly Reprocessing, see section 3.4. An alternative is to use StarView to compare the recommended best reference files with the reference file names recorded in the calibrated science headers; if the names differ, it may be worthwhile to re-retrieve the data. However, finding that a reference file has changed since the data were last calibrated doesn't always mean that recalibration is necessary. The decision to recalibrate depends very much on which reference file or table has changed, and whether that kind of correction may affect the analysis. Section 3.4 gives more details on the required procedures.

4.1 Bias Subtraction Errors

All WFPC2 data retrieved from the HST Archive since May 16, 2001 have been through On-The-Fly Reprocessing and are *not* affected by the bias subtraction errors discussed in this section.

Very early in the WFPC2 mission (January 1994), it was discovered that the first few columns of the overscan region of the WFPC2 CCDs can be positively offset if a strong signal is present in the image itself. These columns were used for the bias level correction (BLEVCORR); the result was an oversubtraction of the bias level, which caused the sky background level in calibrated images to be incorrect. In a few cases, a significant part of the image had negative pixel values. The improvement was implemented in **calwp2** version 1.3.0.5 (March 1994) and is automatically performed on any image processed through OTFR.

Somewhat later in 1994, it was also realized that an improved bias level (BLEVCORR) subtraction could be obtained by using separate bias values for odd and even columns. WFPC2 data processed through the pipeline before May 4, 1994 used only a single average value for the bias level subtraction and as a result, a striated pattern with a typical amplitude of a few electrons (a fraction of a DN) remained. Observers working with versions of these images that were calibrated prior to May 1994 (e.g., from data tapes) should therefore consider re-requesting these data from the Archive. Alternatively, the images could be reprocessed manually using **calwp2**, version 1.3.0.6 or later, unless the signal of the observation is so large that the noise statistics are dominated by Poisson noise. A detailed study of the on-orbit characteristics of bias frames, the overscan region, and superbiases used in the pipeline can be found in *WFPC2 ISR* 97-04.

4.2 Flatfield Correction Errors

This section summarizes the quality of the various flatfield versions that have been used in the pipeline and, where possible, provides suggestions for improvements. Note that images taken at different times will typically use different flats (i.e., the latest flatfields are *not* the best flatfields for data taken at all times). However, the flats tend to be stable and changes over time are 2% at most, excluding small-scale features such as dust spots. As always, observers can obtain the most up-to-date calibration by re-requesting their science images from the Archive. An alternative is to check whether the flatfield files used by **calwp2** fall into one of the specific cases outlined below before submitting an Archive request.

Cursory information on the flatfielding performed can be found in the calibrated science image header keywords and HISTORY records.

“Flatfielding Linear Ramp Filter Images” provides an example of a linear ramp filter image header: the flatfield correction switch was set to PERFORM in the raw header, but since a dummy flatfield was used in the pipeline during processing, the correction was effectively skipped and is noted as such in the calibrated header and HISTORY comments. More detailed information concerning the generation of the flatfields can be found in the flatfield reference file image header HISTORY comments.

Pre-1995 flatfields

WFPC2 data processed during the first few months of the mission were calibrated using flatfields created from pre-launch ground test data, which did not take into account the large-scale structure of the flatfield. These flats have rootnames[1] that begin with "d" or “e1" and if they have the keyword, PEDIGREE (many predated the existence of this keyword), it has been set to GROUND. Flatfields installed in CDBS prior to launch were obtained purely from data taken during the pre-launch Thermal Vacuum test, and thus do not reflect properly the illumination function typical of the HST OTA; in this case, zonal errors of several percent can be encountered.

In March 1994, the WFPC2 IDT (Instrument Definition Team) delivered an updated set of flatfields. These flats have rootnames beginning with "e3" and are a combination of pre-launch calibration data and early on-orbit EARTH-CAL images (observations of the bright Earth). These on-orbit images were flatfielded with the pre-launch data, then stacked and smoothed so that a map of the OTA illumination pattern could be developed. This map, which included the chip-to-chip normalization, was then applied to the ground flatfields and the resulting flats installed in CDBS. Though they are a combination of ground and on-orbit data, the PEDIGREE of these early flatfields is also set to GROUND. The HISTORY comments at the bottom of the flatfield reference files (`.r4h`) provide more details on their generation.

Reprocessing by OTFR will provide improved flatfielding for any images calibrated with the pre-1995 flats.

Flatfields from late 1995 / early 1996

A completely new set of flatfields were delivered between late 1995 (for the filters used in Hubble Deep Field observations) and early 1996. These flatfields are more accurate than the previous ones, although users may not necessarily need to recalibrate or re-retrieve data through OTFR as a result of this change. The new flats, with rootnames beginning with "g" and having a PEDIGREE of INFLIGHT, are effectively the preflight ground data flatfields that include an improved on-orbit illumination pattern

1. The rootname of a reference file is based on the year, date, and time that the file was delivered to the Calibration Data Base System (CDBS). The first character in the rootname denotes the year, in base 36, since 1980 (i.e., files installed in CDBS in 1993 start with "d", those from 1994 start with "e") while the second and third characters are the month and day, respectively, in base 36.

correction applied to scales larger than 7 pixels. In the optical (400nm to 700nm), the new flats differ from the old by 1% or less over the vast majority of the chip, with differences growing to about 8% at all wavelengths in the outer 50 pixels of the chip. Longward of 850 nm, differences of up to 1.5% are seen across the main body of the chips; and shortward of 300 nm, the differences between the old and new flatfields are less than 3%. As always, the HISTORY comments at the bottom of the flatfield reference files (`.r4h`) provide more details on their creation.

Flatfields after 1996

The flatfields for WFPC2 are in the process of being updated (November 2001); these improvements are the result of on-going programs of WFPC2 "EARTH-CAL" observations (images of the bright Earth) that have made it possible for flatfields to be created for several different epochs. Depending upon the date of their final installation into CDBS, the new flatfields will have names beginning with the letters 'l' or 'm' (e.g., "l12" or "m1"). The availability of these new flatfields will be announced in the WFPC2 Space Telescope Analysis Newsletter (STAN), on the WFPC2 Advisory page, and via an Instrument Science Report.

The 1995 epoch flatfields, discussed in the previous section, will still be appropriate for data taken before or during 1995; however, the new flatfields will be appropriate for two new epochs. The first will cover September 1995 to November 1996, during which several strong dust spots appeared. The second covers November 1996 to May 2001, which was a relatively stable period. The new flats generally differ by less than 1-2% from the previous generation in terms of large-scale structure variations across the chips; however, the time-dependence is more pronounced for small-scale features and will allow these to be removed more effectively than with the old flats. In addition, the new flatfields offer improved pixel-to-pixel rms fluctuations of around 0.3% or less. Few users would need to recalibrate their data as a result of these changes; however, any images dating from September 1995 to May 2001 that are retrieved from the Archive after the installation of the new flatfields will automatically be calibrated with the new files.

Flatfields for special purpose filters

Flatfields for infrequently-used filters, such as the polarizers, have generally been available since late 1996 and have rootnames beginning with "g". Other filters, such as the Woods filter (F160BW) and some of the other UV filters, have flatfields with significant noise and other errors; in these cases, the application of a post-pipeline correction flat can provide significant improvement (see section 3.5.2). An alternative would be to use a new pipeline flatfield (it is possible that new flatfield reference files may be available for these filters in early 2002), as discussed in the previous section. Finally, note that by design, linear ramp filters *do not* have a flatfield applied during pipeline calibration; observers with linear ramp filter data should perform some post-pipeline processing, as recommended in “Flatfielding Linear Ramp Filter Images”.

As always, the WWW Reference File memo or the Archive’s StarView can be used to peruse the available flatfields.

The effect of WFPC2 flatfields on point source photometry

WFPC2 flatfields are defined so that a source of uniform brightness produces the same count rate per pixel across the image. However, due to geometric distortion of the image by the optics, the area of WFPC2 pixels on the sky depends on the location on the chip; the total variation across the chip is a few percent, with the largest changes occurring deep in the CCD corners. Therefore, the photometry of *point sources* is slightly corrupted by the standard flattening procedure. This effect, and its correction, are discussed in “Geometric Distortion”. The photometry and astrometry of point sources are also adversely affected by the 34th row effect, see “The 34-th Row Defect” for more details.

4.3 Dark Current Subtraction Errors

4.3.1 Electronic Dark Current

At the operating temperature of -88 C, maintained after April 23, 1994, the WFPC2 CCDs have a low dark background, ranging between 0.002 and 0.01 e^{-}/s/pixel. A relatively small number of pixels have dark currents many times this value. These *warm pixels*, and their correction, are discussed in great detail in section 3.5.1. To remove the dark current, the standard pipeline procedure takes a dark reference file (which contains the average dark background in DN/s), multiplies it by the dark time (determined by the header keyword `DARKTIME`), and subtracts this from the bias subtracted image. Prior to April 23, 1994, the CCDs were operated at –76 C. The correction procedure is the same for these early data, but the average dark current was about an order of magnitude larger due to the higher temperature. Hence, the dark current correction is both more important and less accurate for these images than for later data.

The dark time is usually close to the exposure time, but it can exceed the latter substantially if the exposure was interrupted and the shutter closed temporarily, as in the case of a loss of lock. Such instances are rare and should be identified in the header keyword, `EXPFLAG`, and in the data quality comments for each observation; it will also be indicated by a difference between the predicted exposure start (`PSTRTIME`) and end times (`PSTPTIME`), which is greater than the total exposure time (`EXPTIME`); that is, `PSTPTIME - PSTRTIME` will be larger than `EXPTIME`. The true dark time differs slightly from pixel to pixel because of the time elapsed between reset and readout (even after the first pixel is read out, the last pixel is still accumulating dark counts). To the extent that dark current is constant with time, this small differential is present both in the bias image and in the observation itself, and therefore is automatically corrected by the bias subtraction.

New dark reference files are delivered on a weekly basis. However, due to the time necessary for processing, they usually aren't available until two to four weeks after the date of their observation. The primary difference between successive darks is in the location and value of warm pixels. This difference will be most noticeable if a decontamination occurred between the images used to create the dark and the observation itself. However, because direct treatment of the warm pixels themselves can be performed via **warmpix**, many users will find that they do not need to reprocess with the most up-to-date dark file. For more details, see section 3.5.1: Warm Pixels. An alternative is to create a custom dark reference file; this procedure is described in more detail in:"Generating a custom dark reference file using "daily darks"".

In order to track variable warm pixels, the weekly standard darks, prior to August 1996, were based on a relatively small number (10) of exposures and taken over a period of two weeks. However, these darks can be a significant component of the total noise in deep images. Observers whose (pre-August 1996) images are formed from exposures totalling more than five orbits may therefore wish to recalibrate their data using one of the *superdarks*, which have been generated by combining over 100 individual exposures (see the WWW Reference File memo on the WFPC2 Web pages), or generate their own custom superdark.

Since August 1996, the weekly standard darks have been produced by combining the relevant superdark with the warm pixel information in the dark frames taken that week. The combined file is obtained by using the superdark value for all pixels that appear normal in the weekly dark, namely, for which the dark current value in the weekly dark does not differ from the superdark value by more than 3σ; for pixels that do deviate more than 3σ, the weekly dark value is used. This compromise allows a timely tracking of warm pixels while maintaining the low noise properties of the superdark for stable pixels. Recalibration may still be appropriate since the weekly standard dark is not yet available when the image is processed and archived.

4.3.2 Dark Glow

While the electronic dark current is relatively stable between observations, a variable component has also been seen. The intensity of this *dark glow* is correlated with the observed cosmic ray rate, and is believed to be due to luminescence in the MgF_2 CCD windows from cosmic ray bombardment. As a result of the geometry of the windows, the dark glow is not constant across the chip, but rather shows a characteristic edge drop of about 50%. The dark glow is significantly stronger in the PC, where it dominates the total dark background, and weakest in WF2. The average *total* signal at the center of each camera is 0.006 e^-/s in the PC, 0.004 e^-/s in WF3 and WF4, and 0.0025 e^-/s in WF2; of this, the true dark current is approximately 0.0015 e^-/s. For more details, see the *WFPC2 Instrument Handbook*, Version 6.0, pages 87-92.

Because of the variability in the dark glow contribution, the standard dark correction may leave a slight curvature in the background. For the vast majority of observations, this is not a significant problem since the level of the error is very low (worst-case center-to-edge difference of 2 e^-/pixel) and because it varies slowly across the chips. Some programs, however, may require a careful determination of the absolute background level; observers may wish to consider employing techniques developed by other groups (e.g., Bernstein et al., 2001) or contact the Help Desk (`help@stsci.edu`).

4.3.3 Pointing Information in the Image Headers

Updating the pointing information

Improved knowledge of the detector plate scales and chip rotations, as well as changes in reference pixel locations, have resulted in periodic changes to the pointing parameters, especially early in the instrument's lifetime. These header parameters, which define the mapping between the pixel and world coordinate systems, can be updated using the STSDAS task **uchcoord**. The keywords affected include the reference pixel locations (`CRPIX*`), the values of the world coordinate system at the reference location (`CRVAL*`), the partial derivatives of the world coordinate system with respect to the pixel coordinates (`CD*`), and the orientation of the chip (`ORIENTAT`).

Prior to OTFR (released to the public May 16, 2001), observers requiring the most up-to-date pointing information in their science image headers ran **uchcoord** on their calibrated images. The new OTFR system, however, automatically calculates the best values for these parameters at the time the data are requested so there is no need to run **uchcoord** on freshly-processed OTFR data. OTFR data that have not been recently retrieved (i.e. have been sitting on disk or tape for some time) or pre-OTFR data may benefit from an update; any version of **uchcoord** may be used to update pre-OTFR data, but note that only the June 2001 or later version of **uchcoord** should be run on data processed through OTFR.

Only the June 2001 (or later) version of* uchcoord *should be used on OTFR data, as older versions of the task may over-correct the images. The version of STSDAS can be verified by typing =stsdas.version at the IRAF prompt.

Possible small errors in orientation header information in some images taken prior to Sept. 1997.

All HST data, including WFPC2 images, taken prior to Sept. 15, 1997, may have slightly incorrect orientation information in the headers (keywords `PA_V3` and `ORIENTAT`). These very small errors are *not* correctable in OTFR.

For most images the errors are very small (<0.1 degrees), but for images taken during long visits, the errors can accumulate and reach many tenths of a degree. These errors affect only the rotation of the field around the proposed aperture location and otherwise have no impact on the target position in the image. The problem manifests itself in data taken during a long, multi-orbit visit containing one or more POS TARGs, slews, or other small telescope motions; the position angle information reported in the header changes slightly after each motion when in fact there was no change in orientation during the visit. The first image in a long visit contains correct header information; however, with each slew the orientation keywords in subsequent observations begin to deviate from the correct value at a rate of, at most, 1 degree per day (~7e-04 deg/min). The error also depends upon the target's position in the sky (sine of the declination); thus, keywords in images of targets near the equator will have almost no error while images taken near the poles will show larger errors. Note that moving target images appear unaffected by the problem, though further investigation is required to confirm this.

More details, including lists of possible images and visits affected, can be found in the WWW Orientation memo. Observers using the orientation information from any WFPC2 images on those lists should check the jitter data in addition to the science header. For advice on how to perform the check, please see the online FAQ "How do I best determine an observation's actual orientation?". If you have any additional questions or require further assistance, email help@stsci.edu.

4.4 Image Anomalies

In this section we present a number of features which occasionally affect WFPC2 data.

4.4.1 Bias Jumps

The average bias level for each image is obtained from the engineering data file (.x0h/.x0f) separately for even and odd columns. However, WFPC2 is subject to *bias jumps*, changes of the bias level during the readout. Large bias jumps (> 0.5 DN) are relatively rare, but small bias jumps, at the 0.1 DN level, affect about 15% of all images. figure 4.1 shows a very unusual event where the bias has jumped twice in the same image.

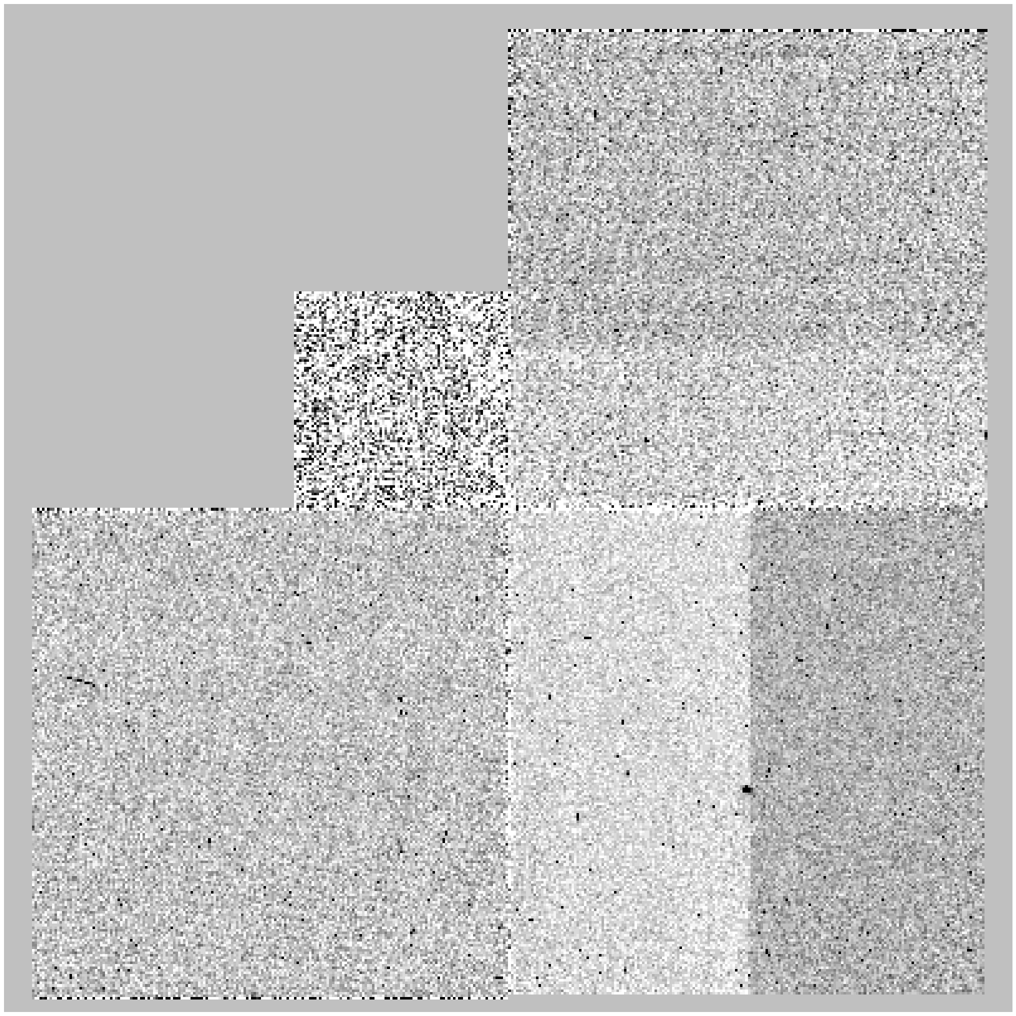
Bias jumps are fairly obvious from a cursory inspection of the image, but users are alerted to their possible presence by a comment in the data quality (.pdq) and trailer (.trl) files. Bias jumps are currently identified by an automatic procedure in **calwp2** that searches the overscan data for possible anomalies (for details see *WFPC2 ISR* 97-04) and only jumps larger than 0.09 DN are reported. Prior to August 1996, the identification of bias jumps was done manually. Some of the bias jumps found by **calwp2** and recorded in the data quality and trailer files are false positives, caused by image features such as strongly saturated stars, which affect the overscan data.

There is no standard procedure to remove this defect, but it can be corrected by measuring the jump in the .x0h (extracted engineering) file or directly in the image, provided the image is clean enough. Standard IRAF procedures such as **imexamine** or **imstat** are sufficient to obtain a good estimate of the offset. The offset can then be removed, for instance, by subtracting the bias jump and then copying out the affected chip to another image using the command:

```
im> imcalc image_in image_out "if (y.lt.YJUMP) then im1 \
>>> else (im1 - BJUMP)"
```

where *YJUMP* is the line at which the jump occurs, and *BJUMP* is its amplitude. The image image_out can then be copied back into the appropriate WFPC image group using the **imcopy** task.

Figure 4.1: Bias Jump in Two Chips



4.4.2 Residual Images

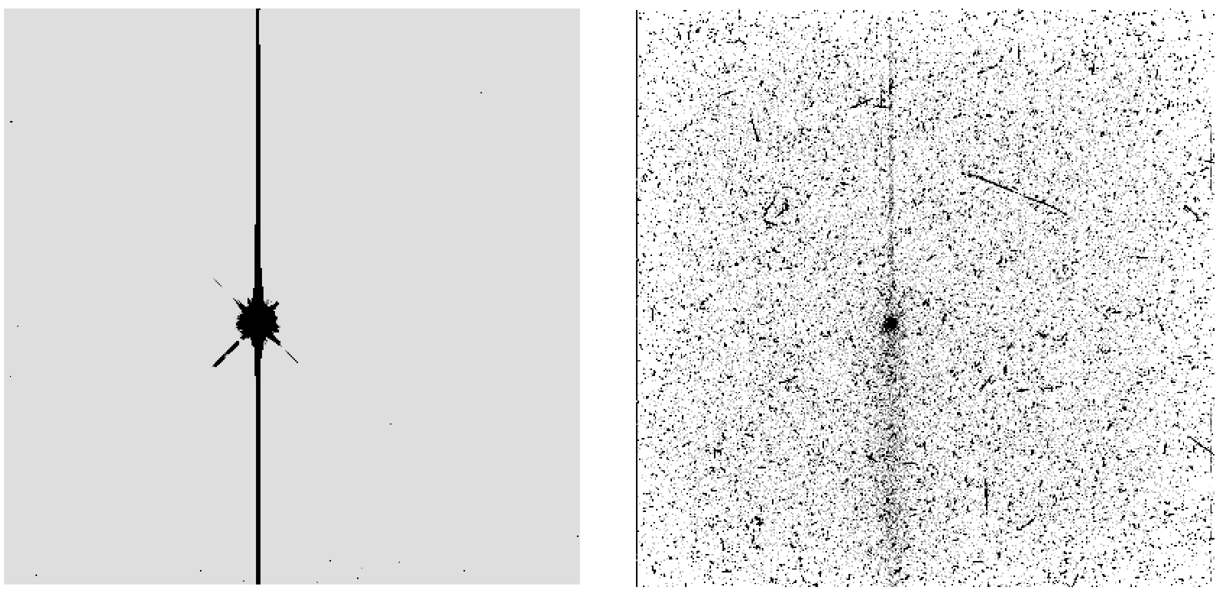
Observations of relatively bright sources can leave behind a residual image. This residual is caused by two distinct effects. In the first, charge in heavily saturated pixels is forced into deeper layers of the CCD, which are not normally cleared by readout. Over time, the charge slowly leaks back into the imaging layers and appears in subsequent images. The time scale for leakage back into the imaging region depends on the amount of over-exposure. Strongly saturated images can require several hours to clear completely. The second effect is caused by charge transfer inefficiencies. At all exposure levels, some charge becomes bound temporarily to impurities in the silicon of the CCD. The effect is most noticeable in images with high exposure levels, probably because electrons become exposed to more impurities as the wells are filled. This effect leaves behind charge both in bright regions of the image and in the part of the chip through which the bright objects were read out.

Figure 4.2 shows a saturated star on PC1 (4.2a) and the residual image seen in an 1800 second dark calibration frame started six minutes later (4.2b). Note that the residual image is bright not only where the PC image was overexposed (effect 1), but also in a wide swath below the star due to the second effect and a narrower swath above the star due to bleeding during the exposure.

Figure 4.2: Saturated Star and Residual Image

a) Saturated Star on PC1

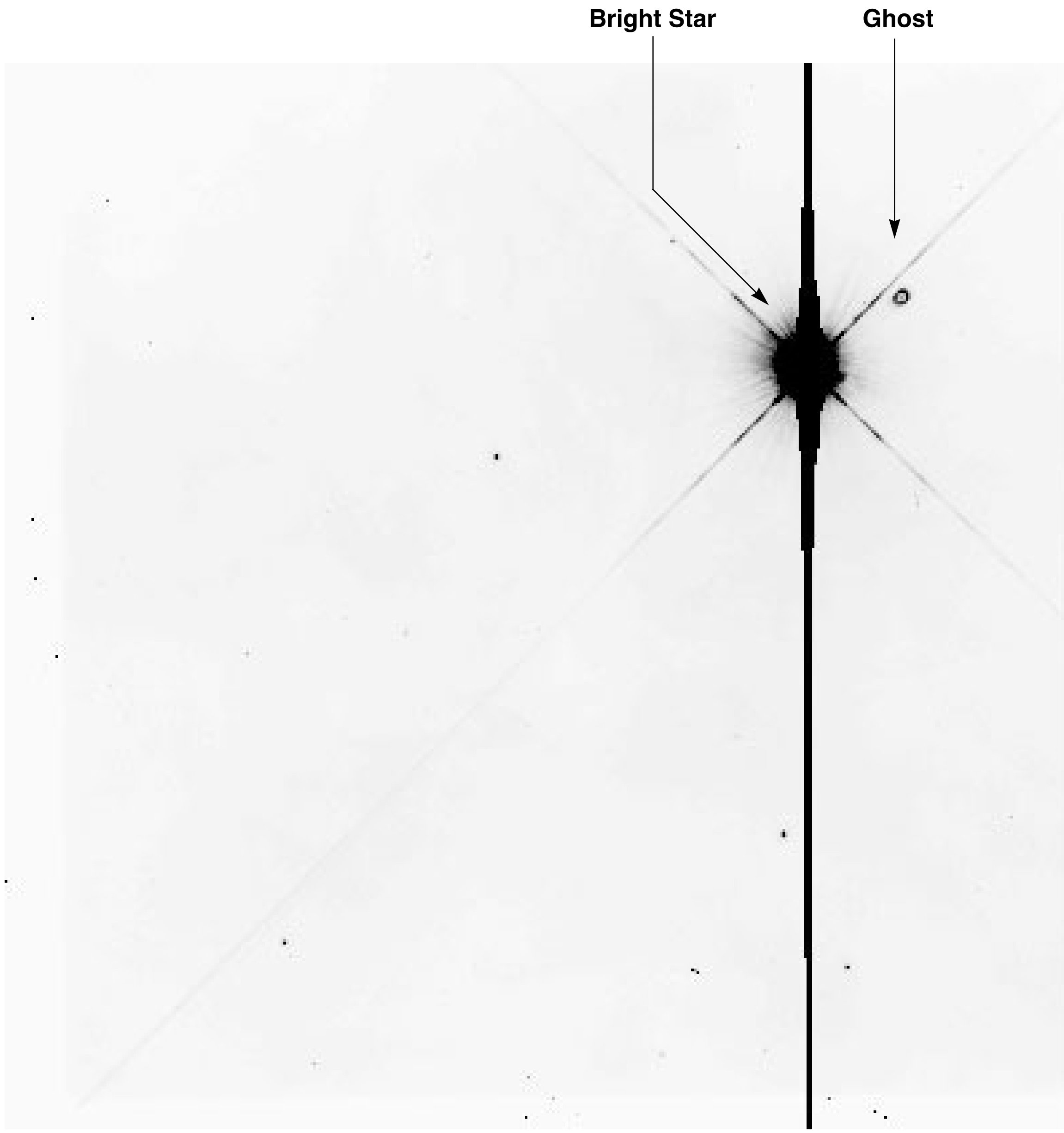
b) Residual Image on Dark Frame 6 Minutes Later



Ghosts

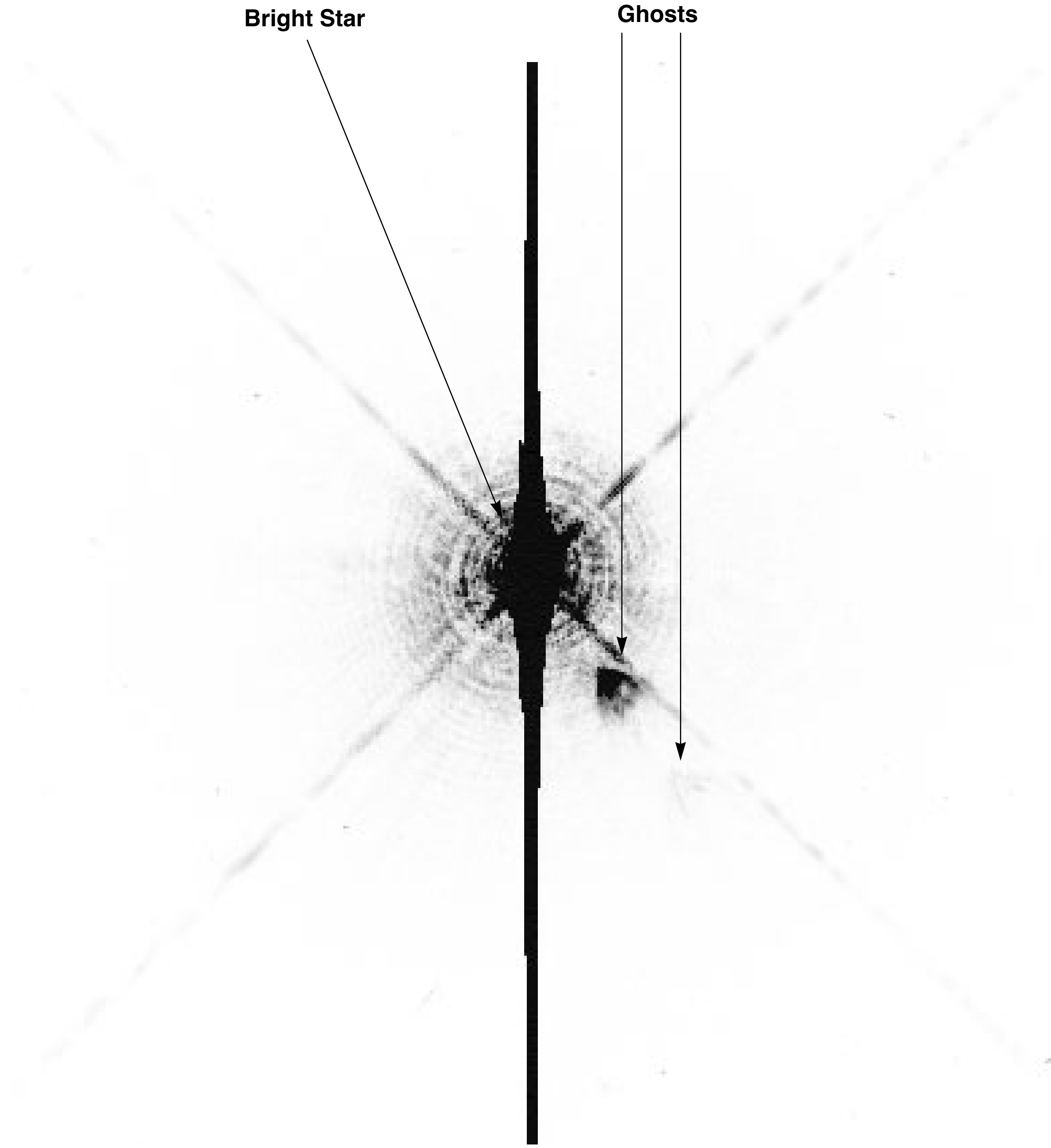
Ghost images may occur on images of bright objects due to internal reflections in the WFPC2 camera. The most common ghosts are caused by internal reflections in the MgF_2 field flatteners. In these ghosts, the line connecting the ghost and the primary image passes through the optical center of the chip. The ghost always lies further away from the center than the primary image. Figure 4.3 gives an example of one of these ghosts.

Figure 4.3: Field-Flattener Ghost in WF2—Image Shows Entire CCD



Ghosts may also occur due to reflections on the internal surfaces of a filter. The position of these ghosts will vary from filter to filter and chip to chip. For any given filter and chip combination, the direction of the offset of the ghost from the primary image will be constant, although the size of the offset may vary as a function of the position of the primary image. Filter ghosts can be easily recognized by their comatic (fan-shaped) structure. Particularly bright objects may produce multiple ghosts due to repeated internal reflections. Figure 4.4 shows an example of filter ghosts.

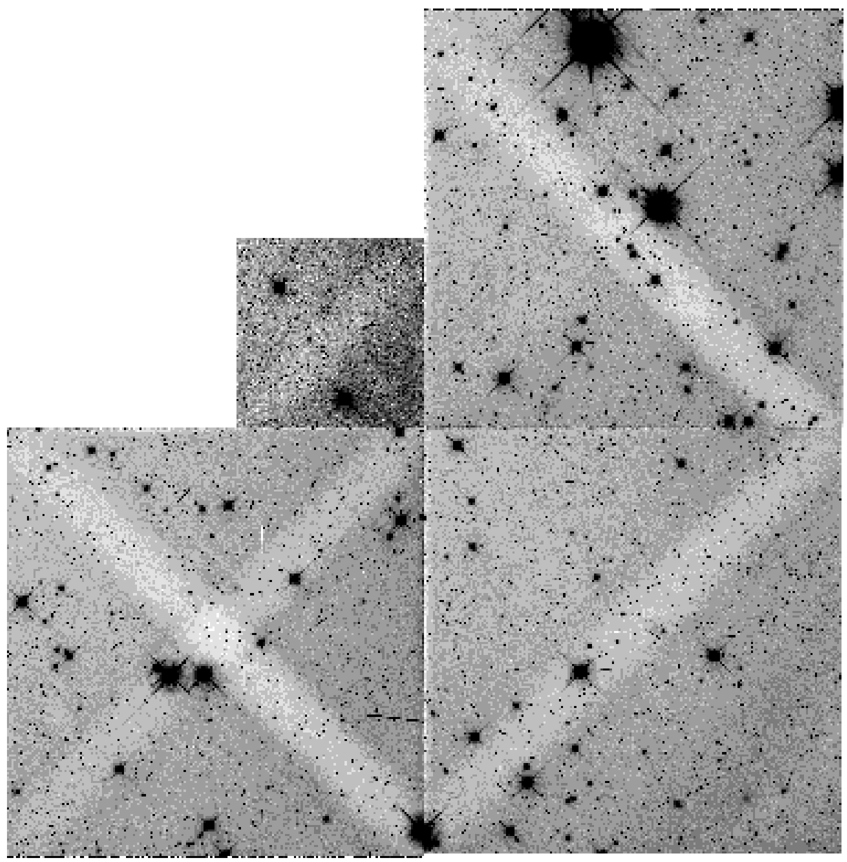
Figure 4.4: Detail of Filter Ghosts on WF4



Earth Reflections

Light from the bright sun-lit Earth is, on rare occasion, reflected off of the Optical Telescope Assembly (OTA) baffles and secondary support and into the WFPC2. These reflections can occur when the bright Earth is less than ~40 degrees from the OTA axis. (The default bright Earth limb avoidance is 20 degrees. Science observations are not scheduled at smaller limb angles to the sunlit Earth.) The light raises the overall background level of the field; however, the WFPC2 camera mirror supports can vignette the scattered light, producing either X-shaped or diagonal depressions in the level of the background. Figure 4.5 shows a typical example of the pattern formed by the scattered light. The scattered light in this image has a level of about 100 electrons. The darkest portion of the X is about 40 electrons below the average background level.

Figure 4.5: Scattered Light Pattern



4.4.3 PC1 Stray Light

The WFPC2 was originally intended to contain two separate pyramids—one for four PC cameras and the other for four WF cameras. Budget reductions caused the PC pyramid to be abandoned and the first WF camera to be replaced by a PC camera. However, the pyramid mirror corresponding to the PC camera was not reduced in size. As a result, baffling for the PC chip is not optimal and a bright star falling on the pyramid outside of the PC field of view can produce an obvious artifact, typically shaped like a broad, segmented arc. A star bright enough to produce a total count rate of 1 DN/s on the chip will produce an arc with a count rate of about 1×10^{-7} DN/pixel/s over the affected region. When scheduling observations, users should avoid placing stars brighter than $V \sim 14$ in the L-shaped region surrounding the PC.

4.4.4 Other Anomalies

Other image anomalies, such as bright streaks from other spacecraft, scattered light from bright stars near the field of view, and missing image sections due to dropped data occur on rare occasion. For more information, consult *WPFC2 ISR* 95-06, which can be obtained through the WFPC2 Web page or through the STScI Help Desk (`help@stsci.edu`)

CHAPTER 5:

WFPC2 Data Analysis

In this chapter. . .

This chapter deals with several topics pertaining to WFPC2 data analysis. We begin with a practical guide to photometry with WFPC2 where we discuss how to accurately determine the zeropoint, photometric corrections that should be made to WFPC2 data, and common problems and their solutions. We start with the most important aspects of the photometric calibration that affect all observers, largely independently of the final accuracy desired, and in later sections consider subtle effects that can produce relatively small errors. A relatively simple calibration will produce photometric errors of 5 to 10%. With attention to more subtle effects, photometric accuracy between 2 and 5% can be achieved. We then discuss the analysis of polarization data, the astrometric characteristics of WFPC2 images, and the reconstruction of dithered data via the STSDAS **dither** package. Sub-pixel dithering is widely recognized—after the success of the Hubble Deep Field observations—as a valuable way to overcome, in part, the undersampling of WFPC2 images. Finally, we summarize various accuracies to be expected from well-calibrated WFPC2 observations.

5.1 Photometric zeropoint

The zeropoint of an instrument, by definition, is the magnitude of an object that produces one count (or data number, DN) per second. The magnitude of an arbitrary object producing DN counts in an observation of length EXPTIME is therefore:

$$m = -2.5 \times \log_{10}(\mathrm{DN} / \mathrm{EXPTIME}) + \mathrm{ZEROPOINT}$$

It is the setting of the zeropoint, then, which determines the connection between observed counts and a standard photometric system (such as Cousins RI), and, in turn, between counts and astrophysically interesting measurements such as the flux incident on the telescope.

Zeropoints and Apertures

Each zeropoint refers to a count rate (DN/EXPTIME) measured in a specific way. The zeropoints published by Holtzman et al. (1995b) refer to counts measured in a standard aperture of 0.5" radius. The zeropoint derived from the `PHOTFLAM` header keyword, as well as in other STScI publications, refer—for historical continuity—to counts measured over an “infinite” aperture. Since it is not practical to measure counts in a very large aperture, we use a nominal infinite aperture, defined as having 1.096 times the flux in an aperture with 0.5" radius. This definition is equivalent to setting the aperture correction between a 0.5" radius aperture and an infinite aperture to exactly 0.10 mag.

5.1.1 Photometric Systems Used for WFPC2 Data

There are several photometric systems commonly used for WFPC2 data, often causing some confusion about the interpretation of the photometric zeropoint used—and the subsequent photometry results. Before continuing with the discussion, it is worthwhile to define these photometric systems more precisely.

The first fundamental difference between systems has to do with the filter set on which they are based. The WFPC2 filters do not have exact counterparts in the standard filter sets. For example, while F555W and F814W are reasonable approximations of Johnson V and Cousins I respectively, neither match is exact, and the differences can amount to 0.1 mag, clearly significant in precise photometric work. Other commonly used filters, such as F336W and F606W, have much poorer matches in the Johnson-Cousins system. We recommend that, whenever practical, WFPC2 photometric results be referred to a system based on its own filters. It is possible to define “photometric transformations” which convert these results to one of the standard systems; see Holtzman et al. (1995b) for some examples. However, such transformations have limited precision, and depend on the color range, metallicity, and surface gravity of the stars considered; they easily can have errors of 0.2 mag or more, depending on the filter and on how much the spectral energy distribution differs from that of the objects on which the transformation is defined, which happens frequently for galaxies at high redshift.

Two photometric systems, based on WFPC2 filters, are the WFPC2 flight system, defined by the WFPC2 IDT and detailed in Holtzman et al. (1995b), and the synthetic system, also defined by the IDT and subsequently used in **synphot** as the VEGAMAG system. For more references, see Harris et al. (1993), Holtzman et al. (1995b), *WFPC2 ISR 96-04*, and the *Synphot User's Guide*.

The WFPC2 flight system is defined so that stars of color zero in the Johnson-Cousins UBVRI system have color zero between any pair of WFPC2 filters and have the same magnitude in V and F555W. This system was established by Holtzman et al. (1995b) by observing two globular cluster fields (ω Cen and NGC 6752) with HST and from the ground, where the ground-based observations were taken both with WFPC2 flight-spare filters and with standard UBVRI filters. In practice, the system was defined by least-squares optimization of the transformation matrix. The observed stars near color zero were primarily white dwarfs, so the WFPC2 zeropoints defined in this system match the UBVRI zeropoints for stars with high surface gravity; the zeropoints for main sequence stars would differ by 0.02–0.05 mag, depending on the filter.

The zeropoints in the WFPC2 synthetic system, as defined in Holtzman et al. (1995b), are determined so that the magnitude of Vega, when observed through the appropriate WFPC2 filter, would be identical to the magnitude Vega has in the closest equivalent filter in the Johnson-Cousins system. For the filters in the photometric filter set, F336W, F439W, F555W, F675W, and F814W, these magnitudes are 0.02, 0.02, 0.03, 0.039, and 0.035, respectively. The calculations are done via synthetic photometry. In the **synphot** implementation, called the VEGAMAG system, the zeropoints are defined by the magnitude of Vega being *exactly* zero in all filters.

The above systems both tie the zeropoints to observed standards. In recent years, it has become increasingly common to use photometric systems in which the zeropoint is defined directly in terms of a reference flux in physical units. Such systems make the conversion of magnitudes to fluxes much simpler and cleaner, but have the side effect that any new determination of the absolute efficiency of the instrumental setup results in revised magnitudes. The choice between standard-based and flux-based systems is mostly a matter of personal preference.

The prevalent flux-based systems at UV and visible wavelengths are the AB system (Oke 1974) and the STMAG system. Both define an *equivalent flux density* for a source, corresponding to the flux density of a source of predefined spectral shape that would produce the observed count rate, and convert this equivalent flux to a magnitude. The conversion is chosen so that the magnitude in V corresponds roughly to that in the Johnson system. In the STMAG system, the flux density is expressed per unit *wavelength*, and the reference spectrum is flat in f_λ, while in the AB system, the flux density is expressed per unit *frequency*, and the reference spectrum is flat in f_ν. The definitions are:

$$m_{AB} = -48.60 - 2.5\log f_\nu$$

$$m_{ST} = -21.10 - 2.5\log f_\lambda$$

where f_ν is expressed in erg cm^{-2} s^{-1} Hz^{-1}, and f_λ in erg cm^{-2} s^{-1} Å^{-1}.

Another way to express these zeropoints is to say that an object with f_ν = 3.63 10^{-20} erg cm^{-2} s^{-1} Hz^{-1} will have m_{AB}=0 in every filter, and an object with f_λ = 3.63 10^{-9} erg cm^{-2} s^{-1} Å^{-1} will have m_{ST}=0 in every filter. See also the discussion in the *Synphot User's Guide*.

5.1.2 Determining the Zeropoint

There are several ways to determine the zeropoint, partly according to which photometric system is desired:

1. ***Do it yourself***: Over the operational life of WFPC2, a substantial amount of effort has gone into obtaining accurate zeropoints for all of the filters used. Nonetheless, if good ground-based photometry is available for objects in your WFPC2 field, it can be used to determine a zeropoint for these observations. This approach may be particularly useful in converting magnitudes to a standard photometric system, provided all targets have similar spectral energy distribution; in this case, the conversions are likely to be more reliable than those determined by Holtzman et al (1995b), which are only valid for stars within a limited range of color, metallicity, and surface gravity.
2. ***Use a summary list***: Lists of zeropoints have been published by Holtzman et al. (1995b), *WFPC2 ISR* 96-04, and *WFPC2 ISR* 97-10 (also reported in table 5.1). The Holtzman et al. (1995b) zeropoints essentially *define* the WFPC2 flight photometric system; as discussed above, they are based on observations of ω Cen and NGC 6752 for the five main broad band colors (i.e., F336W, F439W, F555W, F675W, F814W), as well as synthetic photometry for most other filters. Transformations from the WFPC2 filter set to UBVRI are included, although these should be used with caution, as stated above. Holtzman et al. (1995b) also includes a cookbook section describing in detail how to do photometry with WFPC2. This paper is available from the STScI WWW or by sending e-mail to

help@stsci.edu. The more recent compilations of zeropoints in *WFPC2 ISR* 96-04 and 97-10 use new WFPC2 observations, are based on the VEGAMAG system, and do not include new conversions to UBVRI.

3. ***Use the PHOTFLAM keyword in the header of your data***: The simplest way to determine the zeropoint of your data is to use the PHOTFLAM keyword in the header of your image. PHOTFLAM is the flux of a source with constant flux per unit wavelength (in erg s^{-1} cm^{-2} $Å^{-1}$) which produces a count rate of 1 DN per second. This keyword is generated by the synthetic photometry package, **synphot**, which you may also find useful for a wide range of photometric and spectroscopic analyses. Using PHOTFLAM, it is easy to convert instrumental magnitude to flux density, and thus determine a magnitude in a flux-based system such as AB or STMAG (see section 5.1.1); the actual steps required are detailed below.

Note that the zeropoints listed by Holtzman et al. (1995b) differ systematically by 0.85 mag from the **synphot** ***zeropoints in table 5.1. Most of the difference, 0.75 mag, is due to the fact that the Holtzman zeropoints are given for gain 14, while the*** **synphot** ***zeropoints are reported for gain 7, which is generally used for science observations. An additional 0.1 mag is due to the aperture correction; the Holtzman zeropoint refers to an aperture of 0.5", while the*** **synphot** ***zeropoint refers to a nominal infinite aperture, defined as 0.10 mag brighter than the 0.5" aperture***

The tables used by the **synphot** package were updated in August 1995 and May 1997. With these updates, **synphot** now provides absolute photometric accuracy of 2% rms for broad-band and intermediate-width filters between F300W and F814W, and of about 5% in the UV. Narrow-band filters are calibrated using continuum sources, but checks on line sources indicate that their photometric accuracy is also determined to 5% or better (the limit appears to be in the quality of the ground-based spectrophotometry). Prior to the May 1997 update, some far UV and narrow-band filters were in error by 10% or more; more details are provided in *WFPC2 ISR* 97-10.

Table 5.1 provides lists of the current values for PHOTFLAM. Please note that the headers of images processed before May 1997 contain older values of PHOTFLAM; the up-to-date values can be obtained by reprocessing the image (i.e., re-requesting the data via OTFR), from the table, or more directly by using the **bandpar** task in **synphot** (see "Creation of Photometry Keywords" in section 3.3.2: for an example). Note that to use **bandpar**, the **synphot** version must be up-to-date.[1] Furthermore, when using **bandpar**, it is also possible to directly incorporate the contamination correction (see "Contamination" in section 5.2.1.

The **synphot** package can also be used to determine the transformation between magnitudes in different filters, subject to the uncertainties related to how well the spectrum chosen to do the determination matches the spectrum of the actual source. The transformation is relatively simple using **synphot**, and the actual correction factors are small when converting from the WFPC2 photometric filter set to Johnson-Cousins magnitudes. A variety of spectral atlases are available on the WWW as well as via **synphot**.

---

1. For instructions on how to retrieve STSDAS **synphot** tables, see appendix section A.3.2.

Table 5.1: Current Values of PHOTFLAM and Zeropoint in the VEGAMAG system.

Filter[1]	PC		WF2		WF3		WF4	
	New photflam	Vega ZP	New photflam	Vega ZP	New photflam	Vega ZP	New photflam	Vega ZP
f122m	8.088e-15	13.768	7.381e-15	13.868	8.204e-15	13.752	8.003e-15	13.778
f160bw	5.212e-15	14.985	4.563e-15	15.126	5.418e-15	14.946	5.133e-15	15.002
f170w	1.551e-15	16.335	1.398e-15	16.454	1.578e-15	16.313	1.531e-15	16.350
f185w	2.063e-15	16.025	1.872e-15	16.132	2.083e-15	16.014	2.036e-15	16.040
f218w	1.071e-15	16.557	9.887e-16	16.646	1.069e-15	16.558	1.059e-15	16.570
f255w	5.736e-16	17.019	5.414e-16	17.082	5.640e-16	17.037	5.681e-16	17.029
f300w	6.137e-17	19.406	5.891e-17	19.451	5.985e-17	19.433	6.097e-17	19.413
f336w	5.613e-17	19.429	5.445e-17	19.462	5.451e-17	19.460	5.590e-17	19.433
f343n	8.285e-15	13.990	8.052e-15	14.021	8.040e-15	14.023	8.255e-15	13.994
f375n	2.860e-15	15.204	2.796e-15	15.229	2.772e-15	15.238	2.855e-15	15.206
f380w	2.558e-17	20.939	2.508e-17	20.959	2.481e-17	20.972	2.558e-17	20.938
f390n	6.764e-16	17.503	6.630e-16	17.524	6.553e-16	17.537	6.759e-16	17.504
f410m	1.031e-16	19.635	1.013e-16	19.654	9.990e-17	19.669	1.031e-16	19.634
f437n	7.400e-16	17.266	7.276e-16	17.284	7.188e-16	17.297	7.416e-16	17.263
f439w	2.945e-17	20.884	2.895e-17	20.903	2.860e-17	20.916	2.951e-17	20.882
f450w	9.022e-18	21.987	8.856e-18	22.007	8.797e-18	22.016	9.053e-18	21.984
f467m	5.763e-17	19.985	5.660e-17	20.004	5.621e-17	20.012	5.786e-17	19.980
f469n	5.340e-16	17.547	5.244e-16	17.566	5.211e-16	17.573	5.362e-16	17.542
f487n	3.945e-16	17.356	3.871e-16	17.377	3.858e-16	17.380	3.964e-16	17.351
f502n	3.005e-16	17.965	2.947e-16	17.987	2.944e-16	17.988	3.022e-16	17.959
f547m	7.691e-18	21.662	7.502e-18	21.689	7.595e-18	21.676	7.747e-18	21.654
f555w	3.483e-18	22.545	3.396e-18	22.571	3.439e-18	22.561	3.507e-18	22.538
f569w	4.150e-18	22.241	4.040e-18	22.269	4.108e-18	22.253	4.181e-18	22.233
f588n	6.125e-17	19.172	5.949e-17	19.204	6.083e-17	19.179	6.175e-17	19.163
f606w	1.900e-18	22.887	1.842e-18	22.919	1.888e-18	22.896	1.914e-18	22.880
f622w	2.789e-18	22.363	2.700e-18	22.397	2.778e-18	22.368	2.811e-18	22.354
f631n	9.148e-17	18.514	8.848e-17	18.550	9.129e-17	18.516	9.223e-17	18.505
f656n	1.461e-16	17.564	1.410e-16	17.603	1.461e-16	17.564	1.473e-16	17.556
f658n	1.036e-16	18.115	9.992e-17	18.154	1.036e-16	18.115	1.044e-16	18.107
f673n	5.999e-17	18.753	5.785e-17	18.793	6.003e-17	18.753	6.043e-17	18.745
f675w	2.899e-18	22.042	2.797e-18	22.080	2.898e-18	22.042	2.919e-18	22.034
f702w	1.872e-18	22.428	1.809e-18	22.466	1.867e-18	22.431	1.883e-18	22.422
f785lp	4.727e-18	20.688	4.737e-18	20.692	4.492e-18	20.738	4.666e-18	20.701
f791w	2.960e-18	21.498	2.883e-18	21.529	2.913e-18	21.512	2.956e-18	21.498
f814w	2.508e-18	21.639	2.458e-18	21.665	2.449e-18	21.659	2.498e-18	21.641
f850lp	8.357e-18	19.943	8.533e-18	19.924	7.771e-18	20.018	8.194e-18	19.964
f953n	2.333e-16	16.076	2.448e-16	16.024	2.107e-16	16.186	2.268e-16	16.107
f1042m	1.985e-16	16.148	2.228e-16	16.024	1.683e-16	16.326	1.897e-16	16.197

1. Values are for the gain 7 setting. The PHOTFLAM values for gain 14 can be obtained by multiplying by the gain ratio: 1.987 (PC1), 2.003 (WF2), 2.006 (WF3), and 1.955 (WF4) (values from Holtzman et al. 1995b). For the zeropoints, add -2.5 log(gain ratio), or -0.745, -0.754, -0.756, and -0.728, respectively. The above values should be applied to the counts referenced to a nominal ‘‘infinite aperture’’, *defined* by an aperture correction of 0.10 mag with respect to the standard aperture with 0.5" radius.

For example, the following commands can be used to determine the difference in zeropoint between F814W filter and the Cousins I band for a K0III star on WF3 using the gain=7 setting:

```
sy> calcphot “band(wfpc2,3,a2d7,f814W)” crgridbz77$bz_54
stmag
```

where the Bruzual stellar atlas is being used to provide the spectrum for the K0 III star (`file = crgridbz77$bz_54`). The output is:

```
sy> calcphot “band(wfpc2,3,a2d7,f814W)” crgridbz77$bz_54
stmag
Mode = band(wfpc2,3,a2d7,f814W)
   Pivot       Equiv Gaussian
 Wavelength          FWHM
  7982.044        1507.155    band(wfpc2,3,a2d7,f814W)
Spectrum:  crgridbz77$bz_54
    VZERO           STMAG    Mode: band(wfpc2,3,a2d7,f814W)
       0.            -15.1045
```

Comparing this result with:

```
calcphot “band(cousins,I)” crgridbz77$bz_54 vegamag
Mode = band(cousins,I)
   Pivot     Equiv Gaussian
 Wavelength        FWHM
  7891.153      898.879     band(cousins,I)
 Spectrum: crgridbz77$bz_54
   VZERO        VEGAMAG     Mode: band(cousins,I)
     0.        -16.3327
```

shows that for a star of this color, the correction is 1.2 magnitudes (note that nearly all of this offset is due to the definition of STMAG; the F814W filter is a very close approximation to the Johnson-Cousins I, and color terms between these filters are very small). The Johnson UBVRI throughput data in **synphot** are the U3, B2, and V synthetic passbands given in Buser and Kurucz (1978) and the R,I are from Johnson (1965), Table A1. The Cousins R,I throughputs are from Bessell (1983), Table AII, the Stromgren passbands from Matsushima (1969), and the Walraven bands are from Lub and Pel (1977), Table 6. For more details, please see the *Synphot User's Guide*. The tables below provide representative zeropoint transformations; typical uncertainties are ~5% (worse for U). A larger variety of spectra are available in the atlases on the WWW as well as in **synphot**.

Table 5.2: Rough Zeropoint Transformations for Johnson UBVRI

Spectral Type	Atlas File Name	U-F336W	B-F439W	V-F555W	R-F675W	I-F814W
O5V	bz_1	0.51	0.66	0.03	-0.69	-1.17
B0V	bz_5	0.45	0.66	0.03	-0.70	-1.18
B1V	bpgs_5	0.43	0.67	0.03	-0.69	-1.19
A0V	bpgs_14	-0.11	0.66	0.01	-0.70	-1.27
A0V	bz_13	-0.08	0.66	-0.00	-0.70	-1.27
F2V	bz_19	-0.02	0.61	-0.02	-0.71	-1.33
F6V	bpgs_33	0.00	0.61	-0.01	-0.71	-1.32
G0V	bpgs_36	0.04	0.58	-0.02	-0.70	-1.34
G0V	bz_24	0.00	0.57	-0.03	-0.72	-1.35
K0V	bz_28	-0.06	0.52	-0.03	-0.72	-1.36
K7V	bpgs_64	-0.00	0.42	-0.01	-0.79	-1.47
M0V	bpgs_66	-0.05	0.38	-0.02	-0.89	-1.56
M0V	bz_32	0.01	0.41	-0.02	-0.80	-1.52
M6V	bz_35	0.12	0.27	-0.05	-1.08	-1.69

Table 5.3: Rough Zeropoint Transformations For Cousins RI

Spectral Type	Atlas File Name	R-F675W	I-F814W
O5V	bz_1	-0.73	-1.28
B0V	bz_5	-0.72	-1.28
B1V	bpgs_5	-0.72	-1.28
A0V	bpgs_14	-0.70	-1.26
A0V	bz_13	-0.70	-1.26
F2V	bz_19	-0.65	-1.27
F6V	bpgs_33	-0.64	-1.28
G0V	bpgs_36	-0.62	-1.27
G0V	bz_24	-0.62	-1.27
K0V	bz_28	-0.61	-1.27
K7V	bpgs_64	-0.57	-1.27
M0V	bpgs_66	-0.57	-1.28
M0V	bz_32	-0.57	-1.26
M6V	bz_35	-0.59	-1.23

The spectra in the preceding tables were taken from the Bruzual library (BZ77) and the Bruzual-Persson-Gunn-Stryker atlas (BPGS).

5.2 Photometric Corrections

A number of corrections must be made to WFPC2 data to obtain the best possible photometry. Some of these, such as the corrections for UV throughput variability, are *time dependent*, and others, such as the correction for the geometric distortion of WFPC2 optics, are *position dependent*. Finally, some general corrections, such as the aperture correction, are needed as part of the analysis process. We describe each class in turn.

5.2.1 Time-Dependent Corrections

The most important time-dependent correction is that for the contamination of the CCD windows, which primarily affects UV observations. Other time-dependent corrections are due to the change in operating temperature in April 1994 and the variations of the PSF with focus position; the latter is also position-dependent (see "Aperture Correction" for more information).

Contamination

Contaminants adhere to the cold CCD windows of the WFPC2. Although these typically have little effect upon the visible and near infrared performance of the cameras, the effect upon the UV is quite dramatic and can reduce throughput for the F160BW filter by about 30% after 30 days. These contaminants are largely removed during periodic warmings (decontaminations) of the camera, and the effect upon photometry is both linear and stable and can be removed using values regularly measured in the WFPC2 calibration program. Table 5.4 shows the monthly contamination rates measured for each detector (*WFPC2 ISR 98-03*). Table 5.5 provides decontamination dates up until November 2001; an updated list of decontamination dates is maintained on the WWW.

Contamination is typically measured from the bimonthly observations of the WFPC2 primary standard, the white dwarf GRW+70d5824 (see table 5.4 for rates), and is therefore directly applicable to blue objects. The early observations for the standard photometric filters (F336W, F439W, F555W, F675W, and F814W) have been supplemented by observations of a stellar field in the globular cluster ω Cen (mean B−V ~0.7 mag); the contamination rates measured (in parentheses in table 5.4) are generally in good agreement with those measured for GRW+70d5824. The ω Cen data also indicate a slightly higher contamination rate towards the center of each chip (WFPC2 ISR 96-04). These results will be verified further with the analysis of UV observations of NGC 2100, a young globular cluster in the LMC.

Based on standard star observations taken 1994 to 1998, the long-term photometric throughput appears to be quite stable: fluctuations are ~2% or less peak-to-peak in filters longwards of and including F336W (ISR 98-03; and the WWW monitoring memo). However, the UV throughput has gradually been evolving; specifically, from 1994 to 1998, the clean count rates (measurements immediately after the decons) in some filters, e.g., F160BW by ~12% in the PC, and F170W by ~9%, while decreasing slightly in others, e.g., F255W by ~3%. Furthermore, the monthly contamination rates slowed slightly for the UV filters, e.g., from ~1% per day to 0.5% per day in F160BW on the PC (see table 5.4 and ISR 98-03). Both the monthly and long-term contamination rates reported in the ISR have been incorporated into the WFPC2 contamination tables in synphot.

There are three ways observers may correct UV data for the variable decline rates and small zeropoint shifts; note that in general, filters redward of F336W do not require a correction based on day since decon but may benefit from a small zeropoint correction. The first option is to use the **synphot** contamination tables (see example below), which contain both the monthly contamination effects as well as the long term zeropoint changes. Note however, that **synphot** linearly interpolates in both wavelength and date to obtain the final contamination estimate; the only wavelengths currently in the **synphot** contamination tables are the central wavelengths of the monitoring filters. The second option is to use the rates in table 5.4 to correct for contamination based upon the number of days since a decon procedure; the ISR 98-03 provides details on correcting for the small zeropoint offset. The third method is to use the WWW table of monitoring results to obtain data close in time and wavelength to the science observation and derive an independent model of the contamination effects.

Observers should be aware that the calibration pipeline does *not* automatically correct for contamination. The correction must be applied manually (e.g., using results tabulated in *WFPC2 ISR 98-03*) or using **synphot**. The example below illustrates how to use the **calcphot** task to determine the effect of contamination in an observation. In this case, the command computes the expected count rate for a WF3, F218W observation taken 20 days (MJD=49835.0) after the April 8, 1995, decontamination, with the gain=7 setup. Removing the `cont#49835.0` from the command will determine the count rate if no contamination was present. *Note that the entire photometric mode must be in double quotes*, otherwise STSDAS treats the "#" as a comment indicator and will ignore the remainder of the command line. An 8000 K black body spectrum was chosen largely as a matter of simplicity—the correction values for contamination depend only on the filter chosen and do not reflect the source spectrum.

```
sy> calcphot “wfpc2,3,f218w,a2d15,cont#49835.0” \
>>>  spec=”bb(8000)” form=counts
```

Table 5.4: Contamination Rates (Percentage Loss per Day)

Filter	Year[1]	PC		WF2		WF3		WF4	
		% decline per day	error	% decline per day	error	% decline per day	error	% decline per day	error
F160BW	4/94-4/95	-0.885	0.104	--	--	-1.277	0.038	--	--
F160BW	4/95-4/96	-0.840	0.137	-1.281	0.089	-1.227	0.057	-0.930	0.102
F160BW	4/96-4/97	-0.690	0.159	-1.303	0.094	-1.142	0.069	-1.079	0.067
F160BW	4/97-6/98	-0.613	0.138	-1.202	0.077	-1.093	0.065	-0.893	0.067
F170W	4/94-4/95	-0.564	0.009	-0.949	0.011	-0.988	0.009	-0.801	0.012
F170W	4/95-4/96	-0.516	0.012	-0.901	0.012	-0.956	0.011	-0.736	0.013
F170W	4/96-4/97	-0.509	0.012	-0.901	0.011	-0.943	0.012	-0.752	0.012
F170W	4/97-6/98	-0.452	0.013	-0.804	0.011	-0.772	0.012	-0.643	0.012
F218W	4/94-4/95	-0.478	0.028	--	--	-0.846	0.019	--	--
F218W	4/95-4/96	-0.433	0.036	-0.757	0.039	-0.787	0.026	-0.704	0.047
F218W	4/96-4/97	-0.442	0.044	--	--	-0.845	0.033	--	--
F218W	4/97-6/98	-0.398	0.046	--	--	-0.633	0.047	--	--
F255W	4/94-4/95	-0.236	0.008	--	--	-0.471	0.007	--	--
F255W	4/95-4/96	-0.235	0.007	-0.445	0.013	-0.490	0.007	-0.385	0.013
F255W	4/96-4/97	-0.215	0.008	-0.398	0.017	-0.333	0.013	-0.298	0.011
F255W	4/97-6/98	-0.183	0.007	-0.311	0.014	-0.327	0.012	-0.234	0.012
F300W	4/95-4/96	--	--	-0.260	0.015	--	--	--	--
F336W	4/94-4/95	-0.031	0.007	--	--	-0.198	0.007	--	--
F336W	4/95-4/96	-0.108	0.008	-0.188	0.013	-0.208	0.009	-0.226	0.014
		(-0.127)	(0.060)	(-0.143)	(0.030)	(-0.153)	(0.027)	(-0.157)	(0.023)
F336W	4/96-4/97	-0.068	0.009	-0.286	0.014	-0.285	0.010	-0.153	0.010
F336W	4/97-6/98	-0.062	0.008	-0.177	0.012	-0.181	0.010	-0.053	0.010
F439W	4/94-4/95	-0.008	0.008	--	--	-0.078	0.008	--	--
F439W	4/95-4/96	-0.037	0.007	-0.121	0.013	-0.080	0.009	-0.127	0.014
		(-0.007)	(0.047)	(-0.073)	(0.023)	(-0.077)	(0.030)	(-0.077)	(0.023)
F439W	4/96-4/97	-0.037	0.007	-0.146	0.017	-0.083	0.011	-0.031	0.011
F439W	4/97-6/98	-0.026	0.005	-0.147	0.017	-0.094	0.012	-0.014	0.014
F555W	4/94-4/95	-0.018	0.007	--	--	-0.067	0.007	--	--
F555W	4/95-4/96	-0.039	0.005	-0.050	0.013	-0.051	0.009	0.016	0.016
		(-0.023)	(0.043)	(-0.023)	(0.023)	(-0.030)	(0.030)	(-0.027)	(0.027)
F555W	4/96-4/97	-0.028	0.004	-0.055	0.011	-0.012	0.009	0.023	0.009
F555W	4/97-6/98	-0.010	0.004	-0.048	0.012	-0.031	0.011	-0.020	0.011
F675W	4/94-4/95	-0.009	0.008	--	--	-0.009	0.008	--	--
F675W	4/95-4/96	-0.012	0.006	-0.009	0.013	0.006	0.009	-0.020	0.016
		(-0.067)	(0.067)	(-0.003)	(0.037)	(-0.007)	(0.037)	(-0.013)	(0.037)
F675W	4/96-4/97	-0.034	0.007	--	--	0.000	0.000	--	--
F675W	4/97-6/98	0.024	0.006	--	--	--	--	0.013	0.016
F814W	4/94-4/95	0.041	0.007	--	--	0.005	0.008	--	--
F814W	4/95-4/96	-0.014	0.006	-0.001	0.012	-0.038	0.009	0.045	0.015
		(-0.043)	(0.063)	(-0.007)	(0.030)	(-0.000)	(0.030)	(-0.007)	(0.033)
F814W	4/96-4/97	-0.005	0.005	-0.035	0.015	-0.005	0.011	0.012	0.010
F814W	4/97-6/98	-0.000	0.003	-0.087	0.012	0.014	0.010	-0.043	0.010

1. Epoch boundaries are at Apr. 25, 1994 (MJD=49467), Apr. 25, 1995 (MJD=49832), Apr. 25, 1996 (MJD=50198), Apr. 25, 1997 (MJD=50563), and Jun. 29, 1998 (MJD=50993).

Table 5.5: Dates of WFPC2 Decontaminations through November 2001.[2]

Day-Month-Year	Modified Julian Date	Day-Month-Year	Modified Julian Date	Day-Month-Year	Modified Julian Date
1994		**1997**		14 Jul 99	51373.1715
22 Feb 94	49405.4840	07 Jan 97	50455.9875	10 Aug 99	51400.1667
24 Mar 94	49435.4639	09 Feb 97	50488.0006	09 Sep 99	51430.0604
24 Apr 94	49466.0340	23 Feb 97	50502.7978	05 Oct 99	51456.6437
23 May 94	49495.6250	27 Feb 97	50506.2721	03 Nov 99	51485.2854
13 Jun 94	49516.4597	04 Mar 97	50511.4278	28 Dec 99	51540.8215
10 Jul 94	49543.4861	21 Mar 97	50528.1494	**2000**	
28 Jul 94	49561.3000	05 Apr 97	50543.3681	03 Jan 00	51546.0674
27 Aug 94	49591.4069	25 Apr 97	50563.9583	17 Jan 00	51560.6854
25 Sep 94	49620.0319	15 May 97	50583.8460	31 Jan 00	51574.6583
21 Oct 94	49646.0285	07 Jun 97	50606.5461	25 Feb 00	51599.4465
19 Nov 94	49675.7285	24 Jun 97	50623.4612	23 Mar 00	51626.2035
18 Dec 94	49704.2500	24 Jul 97	50653.7795	18 Apr 00	51652.8174
1995		20 Aug 97	50680.0952	17 May 00	51681.9225
13 Jan 95	49730.6764	17 Sep 97	50708.7256	14 Jun 00	51709.4354
12 Feb 95	49760.0792	13 Oct 97	50734.7506	11 Jul 00	51736.7583
11 Mar 95	49787.6042	14 Nov 97	50766.2217	06 Aug 00	51762.9049
08 Apr 95	49815.4368	10 Dec 97	50792.4027	10 Aug 00	51766.9992
07 May 95	49844.0507	**1998**		07 Sep 00	51794.2986
02 Jun 95	49870.7708	08 Jan 98	50821.0025	04 Oct 00	51821.0758
27 Jun 95	49895.8333	01 Feb 98	50845.8021	06 Oct 00	51823.6767
30 Jul 95	49928.3681	06 Mar 98	50878.3877	02 Nov 00	51850.4931
27 Aug 95	49956.2382	31 Mar 98	50903.5376	08 Nov 00	51856.0000
22 Sep 95	49982.1528	02 May 98	50935.5186	28 Nov 00	51876.7903
17 Oct 95	50007.4053	07 Jun 98	50971.8757	30 Dec 00	51908.3093
15 Nov 95	50036.3706	09 Jun 98	50973.9993	**2001**	
14 Dec 95	50065.2929	12 Jun 98	50975.3340	23 Jan 01	51932.7141
1996		25 Jun 98	50989.2910	20 Feb 01	51960.1909
11 Jan 96	50093.9750	28 Jun 98	50992.5881	07 Mar 01	51975.2090
11 Feb 96	50124.0208	22 Jul 98	51016.7889	21 Mar 01	51989.5163
10 Mar 96	50152.0147	21 Aug 98	51046.5161	17 Apr 01	52016.9421
02 Apr 96	50175.0111	15 Sep 98	51071.0963	15 May 01	52044.9744
04 May 96	50207.7146	14 Oct 98	51100.1104	17 Jun 01	52077.4614
28 May 96	50231.2614	10 Nov 98	51127.2090	11 Jul 01	52101.8466
22 Jun 96	50256.9277	08 Dec 98	51155.5969	10 Aug 01	52131.5526
28 Jul 96	50292.5653	**1999**		05 Sep 01	52157.2317
23 Aug 96	50318.4242	28 Jan 99	51206.0458	05 Oct 01	52187.2807
18 Sep 96	50344.6840	23 Feb 99	51232.9471	02 Nov 01	52215.1989
18 Oct 96	50374.3236	25 Mar 99	51262.8441		
12 Nov 96	50399.4031	20 Apr 99	51288.9910		
15 Dec 96	50432.0417	19 May 99	51317.3528		
19 Dec 96	50436.5229	16 Jun 99	51345.2965		

2. A list of decontamination dates is kept updated on the WWW.

Cool Down on April 23,1994

The temperature of the WFPC2 was lowered from –76˚ C to –88˚ C on April 23, 1994, in order to minimize the CTE problem. While this change increased the contamination rates, it also improved the photometric throughput, especially in the UV, reduced the CTE losses, and greatly reduced the impact of warm pixels. Table 5.6 provides a partial list of corrections to table 5.1 for the pre-cool down throughput. Including the MJD in a **synphot** calculation (as shown in appendix A of the *Synphot User's Guide*) using up-to-date synphot contamination tables will correct PHOTFLAM for this change.

Table 5.6: Ratio Between Pre- and Post-Cool Down Throughput

Filter	PC	PC (mag)	WF	WF (mag)
F160BW	0.865	–0.157	0.895	–0.120
F170W	0.910	–0.102	0.899	–0.116
F218W	0.931	–0.078	0.895	–0.120
F255W	0.920	–0.091	0.915	–0.096
F336W	0.969	–0.034	0.952	–0.053
F439W	0.923	–0.087	0.948	–0.058
F555W	0.943	–0.064	0.959	–0.045
F675W	0.976	–0.026	0.962	–0.042
F814W	0.996	–0.004	0.994	–0.007

PSF Variations

The point spread function (PSF) of the telescope varies with time, and these variations can affect photometry that relies on very small apertures and PSF fitting. Changes in focus are observed on an orbital timescale due to thermal *breathing* of the telescope and due to desorption, which causes a continual creeping of the focal position. This change had been about 0.7 μm per month until mid-1996, when it greatly slowed. Currently the focus drift is less than 0.3 μm per month. The effect of focus position on aperture photometry is described in *WFPC2 ISR* 97-01. About twice a year, the focal position of the telescope is moved by several microns to remove the effect of the desorption; the focus history is available online.

In addition, *jitter*, or pointing motion, can occasionally alter the effective PSF. The Observatory Monitoring System (OMS) files provide information on telescope jitter during observations (see appendix C). These files are now regularly provided to the observer with the raw data. Observations taken after October 1994 have jitter files in the Archives. Limited requests for OMS files for observations prior to October 1994 can be handled by the STScI Help Desk (E-mail `help@stsci.edu`).

Remy et al. (1997) have been able to obtain high-quality photometry of well-exposed point sources by modeling the point spread function with TinyTim (Krist, 1995), and taking into account focus and jitter terms via a chi-squared minimization method. Similar results have been obtained using observed PSFs (Surdej et al., 1997), provided that the PSF used is less than 10" from the observed star and corresponds to a spectral energy distribution similar to that of the target. The WFPC2 PSF library was established to help users find suitable PSFs, if they exist, or carry out experiments with what is available.

5.2.2 Position-Dependent Corrections

In this Section we discuss the Charge Transfer Efficiency (CTE) correction and the possibly related long vs. short anomaly, the geometric distortion, the gain differences between different chips, and the effect of pixel centering.

Charge Transfer Efficiency

The CTE problem (or CTI, charge transfer inefficiency) results in targets losing counts as the WFPC2 chips are read out. The effect is most pronounced for objects near the top (Y~800) of the chip where the more rows the target must be clocked through, the more charge is lost. The problem has been attributed to impurities in the silicon which trap the charge, preventing it from being read out immediately (Holtzman et al., 1995). During on-orbit calibrations early in WFPC2's mission, the Investigation Definition Team (Holtzman et al., 1995) discovered the presence of CTI in the CCDs and at that time, with an operating temperature of -76^{o}C, it was measured at ~10-15%. Lowering the operating temperature reduces the CTI, so the camera temperatures were set as low as possible, -88^{o} C, which reduced the CTE (charge transfer efficiency) losses to ~3-4% in the worst case (top of the chip, in 1994).

After the acquisition of several more years of calibration data, the CTI was found to be increasing over time (Whitmore & Heyer, 1997). Stellar aperture photometry of ω Cen showed that the CTE loss for faint stars (20-50 DN in a 2 pixel radius aperture, filter F814W, gain 15) at the top of the chip had gone from 3+/-3% in 1994 to 22+/-3% in 1997, while the CTE loss over time had remained stable for brighter (more than 200 DN) stars. A later study (Whitmore et al., 1999) confirmed that the CTE losses continue to increase for faint stars, up to 40% in February 1999, and the loss for bright targets remains stable. The effect appears to be correctable using the X- and Y-positions of the targets, the count levels in the background, the brightness of the stars, the date of the observation, and the formulae given in Whitmore et al., 1999. The sections below discuss photometric CTE corrections which can be applied during data analysis, including the new

Dolphin (2000) CTE corrections and their relation to the Whitmore et al. (1999) corrections.

Effect on Point Sources

Since the April 1994 cool down, the CTE loss rate has been steadily worsening. Extensive observations made during Cycles 5 through 9 have provided a monitor of the CTE calibration over time; while the effect was about 5% in 1996-1997, the losses are up to 50% or more (peak-to-peak) in 2001 for the faintest targets[3]. Recent publications (PASP, **112**, 1397, PASP **111**, 1559, and *WFPC2 ISR*s 01-09, 97-08) quantify the CTE effect under various observational circumstances and provide empirically-derived correction formulae. After these corrections, the residual CTE effect for well-exposed stars is estimated to be less than 2%.

The correction for CTE depends on a number of variables, including the average background, the average counts over the chip, the counts in the source itself, and the target position on the chip. Assuming a 2 pixel radius aperture, the corrected counts are given by:

$$CTS_{corr} = \left[1 + \frac{Y_{CTE}}{100} \times \frac{Y}{800} + \frac{X_{CTE}}{100} \times \frac{X}{800}\right] CTS_{obs}$$

where X and Y are the coordinates of the star center in pixels, and X_{CTE} and Y_{CTE} are the percentile loss over 800 pixels in the x and y direction, respectively. For observed counts less than 4000 DN and backgrounds greater than 0.1 DN, the *Y* and *X CTE* components are given by:

$$Y_{CTE} = 2.3 \times 10^{-0.256 \times \log BKG} \times [1 + 0.245(0.0313 - 0.0087 \log CTS_{obs}) \times (MJD - 49471)]$$

$$X_{CTE} = 2.5 \times [1 + 0.341(0.00720 - 0.0020 \log CTS_{obs}) \times (MJD - 49471)]$$

For observed counts higher than 4000 DN and blank sky backgrounds greater than 0.1 DN, the *Y* and *X CTE* contributions are as follows:

$$Y_{CTE} = 2.3 \times 10^{-0.256 \times \log BKG}$$

$$X_{CTE} = 2.5$$

where *MJD* is the Modified Julian Date and *BKG* is the mean number of counts in DN for a blank region of the background.

For details on the use of these formulae, see Whitmore et al. (PASP **111**, 1559). Note that the equations are for gain = 7, the mode most commonly

3. In general, typical WFPC2 exposures are much longer than the short calibration images, resulting in a higher background which significantly reduces the CTE loss and minimizes the CTE problem for most science exposures.

used for science observations. Multiply CTS_{obs} and *BKG* by 2 before using either set of equations for gain=15. Also note that due to small uncertainties in the bias level, negative *BKG* can sometimes occur when the background is very low (i.e., ≤ 0.05 DN). For *BKG* < 0.1 DN, Whitmore et al. (PASP **111**, 1559) recommend linearly scaling the value based on observations using the same filters but with longer exposures of the same field. When longer exposures are not available and the background is blank sky, approximate background levels can be estimated by scaling values provided in Table 1 of the reference given above, though changes in zodiacal light and scattered Earth light may limit their accuracy. Another option is to set *BKG* to some threshold value (e.g., 0.1 DN) though this will provide only a rough approximation of X_{CTE} and Y_{CTE}.

Other correction formulae for CTE losses in point source photometry have been developed by Dolphin (PASP, **112**, 1397). This new study compared WFPC2 observations with ground based observations of ω Cen and NGC 2419, deriving CTE corrections using a baseline through March 2000, a time line roughly a year longer than available for the Whitmore et al. analysis (PASP **111**, 1559). In general, the two studies are in good agreement, except for recent (1998 and later) data at low count levels. A preliminary comparison of the results of the two studies showed that for bright stars (>15,000 e^-), the Whitmore et al. formulae tend to overestimate the correction by a few percent while for faint stars (100-500 e^-), the Whitmore et al. formulae underestimate the corrections. For extremely faint stars (20-50 e^-), the Dolphin formulae overestimate the corrections by tens of percent, likely due to the lack of faint stars in the sample. *For now, the best compromise is to use the Dolphin corrections for stars brighter than 100* e^- *and the Whitmore et al. corrections for fainter stars.*

Effect on Extended Sources

The effect of CTE on the shape and structure of extended sources has also been studied (ISR 00-04). Pairs of images of individual galaxies observed near and far from the read-out amplifier were subtracted. The average profile of such galaxy residuals is distinctly asymmetric and indicates that the charge is primarily lost from the leading (amplifier-side) of the galaxy image. The side of the galaxy away from the amplifier suffers little charge loss because the charge traps encountered during the read-out have already been filled (by the leading edge) and because some trapped charge is being released. Preliminary results of aperture photometry on faint galaxy cores show effects consistent with those predicted for CTE in stellar photometry.

The analysis of how CTE affects galaxies is still at a relatively early stage and it is difficult at this point to provide a quantitative correction which can be employed by WFPC2 observers. Nevertheless, observers may wish to consider that the total CTE loss expected for a galaxy applies only to the half of the galaxy near the amplifier, with the other half experiencing negligible losses.

Long vs. Short Anomaly (non-linearity)

A comparison of repeated images of the same stellar field can appear to give higher count rates for the faint stars on longer exposures. The effect was first noted by Stetson, as reported in Kelson et al. (1996) and Saha et al. (1996). These authors used a 5 % correction factor for the effect in their papers. A more detailed study was made by Casertano and Mutchler, as reported in ISR 98-02. They found that this apparent non-linearity appears to be strictly a function of total counts in each source. The magnitude errors produced are less than 1% for well-exposed stars (over 30,000 e^-), but may be much larger for faint stars. However, subsequent studies have not been able to confirm the existence of the so called "long vs. short" anomaly (e.g., Saha, Labhart, & Prosser 2000; and Dolphin 2000).

Based on a recent study by Whitmore and Heyer, it now appears that the effect may only be present for very crowded fields, where accurate sky subtraction becomes difficult or impossible. Hence, it may be largely a function of the photometric parameters and algorithms that are used for a particular study. On typical fields, where the stars are not so crowded that they overlap, the effect appears to be less than a few percent, if it exists at all. Further investigation of this topic is continuing and the reader is referred to a new ISR on the subject that will be out in early 2002.

Geometric Distortion

Geometric distortion near the edges of the chips results in a change of the surface area covered by each pixel. The flatfielding corrects for this distortion so that surface photometry is unaffected. However, integrated point-source photometry using a fixed aperture *will* be affected by 1 to 2% near the edges, with a maximum of about 4-5% in the corners. A correction image has been produced and is available from the Archive (`f1k1552bu.r9h`). The counts measured for a star centered at a given pixel position must be multiplied by the value of these same pixels in the correction image (simply multiplying your image by the correction image and then measuring the counts is easiest). A small residual effect, due to the fact that the aperture radius differs from the nominal size, depends on the aperture used and is generally well below 1%. Please see section 5.4 for additional discussion on geometric distortion and astrometry.

The 34-th Row Defect

Approximately every 34th row on the WFPC2 detectors possesses a reduced sensitivity (Trauger et al., 1993); these features are likely due to a manufacturing defect that resulted in the affected rows being somewhat narrower than the rest. The pipeline flatfields contain these features and produce calibrated images appropriate for surface brightness measurements. Point source photometry, however, can suffer 1-2% errors; and, the narrow rows have a significant effect on astrometry, causing periodic errors of up to 0.03 pixel. A recent paper by Anderson & King

(1999) provides photometric and astrometric correction formulae for this 34th row effect.

Gain Variation

The absolute sensitivities of the four chips differ somewhat. Flatfields have been determined using the gain=14 setup, normalized to 1.0 over the region [200:600,200:600]. However, most science observations are taken using the gain=7 setup. Because the gain ratio varies slightly from chip to chip, PHOTFLAM values will be affected. The count ratios for the different chips from Holtzman (1995b) are:

- ***PC1***: 1.987
- ***WF2***: 2.003
- ***WF3***: 2.006
- ***WF4***: 1.955

These count ratios should be included in the zeropoint calculation if using values from Holtzman et al. (1995b) on gain=7 data. Conversely, their reciprocals should be applied when using **synphot** zeropoints on gain=14 data. If you use the value of PHOTFLAM from the header to determine your zeropoint, the different gains for the different chips will already be included. Remember to use the new PHOTFLAM values provided in table 5.1 or the post-May 1997 **synphot** tables; those included in the header for data taken before May 1997 will have less accurate values.

Pixel Centering

Small, sub-pixel variations in the quantum efficiency of the detector could affect the photometry. The position of star relative to the sub-pixel structure of the chip is estimated to have an effect of less than 1% on the photometry. At present there is no way to correct for this effect.

Possible Variation in Methane Quad Filter Transmission

Based on results from Jupiter and Uranus archival WFPC2 data, the extended wings of the methane filter transmission curve appear to vary across the field of view (Karkoshka, priv. comm.). While this is unimportant for objects with flat spectra, it can have a major impact on photometry of objects with methane bands, where a significant fraction of photons comes from the wings. To provide data to check the methane filter, a set of eight 40-sec Saturn images in a 3x3 grid around the FQCH4W3 methane quad filter aperture (one of the 9 positions falls outside of the filter) is planned as part of the Cycle 10 calibration program (proposal 9256). The magnitude and direction of the effect will be quantified by comparing results from the rings of Saturn (flat spectrum) to results from Saturn itself (deep methane band spectrum).

Anomalous Rotational Offset in the Linear Ramp Filters

For completeness, this effect is included here though we expect no impact on observations as any photometric effect is estimated to be less than 1%. Analysis of FR533N VISFLAT images has revealed an apparently randomly occurring offset of about 0.5 degrees in the filter wheel rotation for some images, a quantity that corresponds to one filter step. The pivot point of the rotation implicates the filter wheel as the source of the inconsistency. A handful of other filters, on different filter wheels as well, appear to exhibit the same problem; at this time, the source of this anomaly, whether it is mechanical or due to a software error, is unknown. A detailed report is in progress (Nov. 2001); a preliminary report is available in ISR 01-04.

5.2.3 Other Photometric Corrections

Miscellaneous corrections that must be taken into account include: aperture corrections, color terms if transforming to non-WFPC2 filters, digitization noise and its impact on the estimate of the sky background, the effect of red leaks and charge traps, and the uncertainty of exposure times on short exposures taken with serial clocks on.

Aperture Correction

It is difficult to measure directly the total magnitude of a point source with the WFPC2 because of the extended wings of the PSF, scattered light, and the small pixel size. One would need to use an aperture far larger than is practical. A more accurate method is to measure the light within a smaller aperture and then apply an offset to determine the total magnitude. Typically, magnitudes will be measured in a small aperture well-suited to the data at hand—a radius of 2–4 pixels, with a background annulus of 10–15 pixels, has been found adequate for data without excessive crowding—and the results corrected to the aperture for which the zeropoint is known. The aperture correction can often be determined from the data themselves, by selecting a few well-exposed, isolated stars. If these are not available, encircled energies and aperture corrections have been tabulated by Holtzman et al. (1995a). If PSF fitting is used, then the aperture correction can be evaluated directly on the PSF profile used for the fitting.

For very small apertures (1–2 pixels), the aperture correction can be influenced by the HST focus position at the time of the observation. The secondary mirror of HST is known to drift secularly towards the primary and to move slightly on time scales of order of an orbit. The secular shift is corrected by biannual moves of the secondary mirror, but the net consequence of this motion is that WFPC2 can be out of focus by up to 3–4 μm of secondary mirror displacement at the time of any given observation. This condition affects the encircled energy at very small radii, and thus the aperture corrections, by up to 10% in flux (for 1 pixel aperture in the PC);

see *WFPC2 ISR* 97-01 for more details. If the use of very small apertures is required—because of crowding, S/N requirements, or other reasons—users are strongly advised to determine the aperture correction from suitable stars in their images. If such are not available, an *approximate* aperture-focus correction can be obtained as described in *WFPC2 ISR* 97-01.

A standard aperture radius of 0."5 has been adopted by Holtzman et al. (1995b; note that Holtzman et al. 1995a used a radius of 1."0). For historic consistency, the WFPC2 group at STScI and the synphot tasks in STSDAS refer all measurements to the total flux in a hypothetical infinite aperture. In order to avoid uncertain correction to such apertures, both in calibration and in science data, this infinite aperture is defined by an aperture correction of exactly 0.10 mag with respect to the standard 0."5 aperture. This value (0.10 mag) is close to the values tabulated in Holtzman et al. (1995a) as well as consistent with Whitmore (1995); only extended sources larger than ~1" are likely to require a more accurate aperture correction (ISR 97-01). Equivalently, the total flux is defined as 1.096 times the flux in the standard aperture of 0."5 radius. In practice, this means that observers wishing to use our tables or the synphot zeropoints should:

1. Correct the measured flux to a 0."5 radius aperture.
2. Apply an additional aperture correction of –0.10 mag (equivalently, multiply the flux by 1.096).
3. Determine the magnitude using the zeropoints given.

See also the example in section 5.2.4.

Color Terms

In some cases it may be necessary to transform from the WFPC2 filter set to more conventional filters (e.g., Johnson UBV or Cousins RI) in order to make comparisons with other datasets. The accuracy of these transformations is determined by how closely the WFPC2 filter matches the conventional filter and by how closely the spectral type (e.g., color, metallicity, surface gravity) of the object matches the spectral type of the calibration observations. Accuracies of 1–2% are typical for many cases, but much larger uncertainties are possible for certain filters (e.g., F336W, see "Red Leaks" section below), and for certain spectral types (e.g., very blue stars). Transformations can be determined by using **synphot**, or by using the transformation coefficients in Holtzman et al. (1995b).

Digitization Noise

The minimum gain of the WFPC2 CCDs, 7 e^-/ADU, is larger than the read noise of the chip. As a result, digitization can be a source of noise in WFPC2 images. This effect is particularly pernicious when attempting to determine sky values, because the measured values tend to cluster about a few integral values (dark subtraction and flatfielding cause the values to differ by slightly non-integral amounts). As a result, using a median filter to remove objects that fall within the background annulus in crowded fields, can cause a substantial systematic error, whose magnitude will depend on the annulus being measured. It is generally safer to use the mean, though care must then be taken to remove objects in the background annulus.

A more subtle effect is that some statistics programs assume Gaussian noise characteristics when computing properties such as the median and mode. Quantized noise can have surprising effects on these programs. Based upon the analysis of a variety of possible strategies for sky determination (WFPC2 ISR 96-03), the centroid and the optimal filter ("ofilter") of the histogram of sky pixel values were found to produce the least biased result for typical WFPC2 data with low background levels.

Red Leaks

Several of the UV filters have substantial red leaks that can affect the photometry. For example, the U filter (F336W) has a transmission at 7500 Å that is only about a factor of 100 less than at the peak transmission at about 3500 Å. The increased sensitivity of the CCDs in the red, coupled with the fact that most sources are brighter in the red, makes this an important problem in many cases. The **synphot** tasks can be used to estimate this effect for any given source spectrum.

Charge Traps

There are about 30 macroscopic charge transfer traps, where as little as 20% of the electrons are transferred during each time step during the readout. These defects result in *bad pixels*, or in the worst cases, *bad columns* and should not be confused with microscopic charge traps which are believed to be the cause of the CTE problem. The traps result in dark tails just above the bad pixel, and bright tails for objects farther above the bad pixel that get clocked out through the defect during the readout. The tails can cause large errors in photometric and astrometric measurements. In a random field, about 1 out of 100 stars are likely to be affected. Using a program which interpolates over bad pixels or columns (e.g., **wfixup** or **fixpix**) to make a cosmetically better image can result in very large (e.g., tenths of magnitude) errors in the photometry in these rare cases. See also section 3.5.4.

Exposure Times: Serial Clocks

The serial clocks option (i.e., the optional parameter CLOCKS = YES in the Phase II proposal instructions) is occasionally useful when an extremely bright star is in the field of view, in order to minimize the effects of bleeding. However, the shutter open time can have errors of up to 0.25 second due to the manner in which the shutters are opened when CLOCKS=YES is specified. If the keyword SERIALS = ON is in the image header, then the serial clocks were employed. Header information can be used to correct this error. The error in the exposure time depends on the SHUTTER keyword. If the value of this keyword is "A", then the true exposure time is 0.125 second less than that given in the header. If instead the value is "B", then the true exposure time is 0.25 second less than the header value.

Users should also note that exposure times of non-integral lengths in seconds cannot be performed with the serial clocks on. Therefore, if a non-integral exposure time is specified in the proposal, it will be rounded to the nearest second. The header keywords will properly reflect this rounding, although the actual exposure time will still be short as discussed above.

F1042M Extended Halo

Observers using the F1042M filter should be aware that it possesses an anomalous PSF containing additional light in a broad halo component. The defocused halo is likely due to the CCD detector becoming transparent at this wavelength, so that the light is reflected and scattered by the back of the CCD. The scattering will impact photometry in the F1042M filter relative to other filters, since a greater fraction of the counts will lie outside the 1 arcsecond diameter aperture used for photometry on standard stars. The WFPC2 Instrument Handbook provides a comparison of azimuthal averages for an observed F1042M and F953N PSF; additional PSF examples are in the WFPC2 PSF Library.

5.2.4 An Example of Photometry with WFPC2

This example shows the steps involved in measuring the magnitude of the star #1461 (Harris et al., 1993) in the Cousins I passband. The image used for this example can be obtained from the HST Archive, or from the WWW. The WWW directory contains the materials for *WFPC2 ISR* 95-04, *A Demonstration Analysis Script for Performing Aperture Photometry.* Table 5.7 shows the results from an analysis script similar to *WFPC2 ISR* 95-04, but including some of the corrections discussed above.

```
Images: u2g40o09t.c0h[1] and u2g40o0at.c0h[1]
Position: (315.37,191.16)
Filter: F814W
Exposure Time: 14 seconds
Date of observation: MJD - 49763.4
```

Table 5.7: Magnitude of Star #1461 in ω Cen

Value	Description
2113.49 counts	Raw counts in 0.5" radius aperture (11 pixels for PC)
–48.63 = 2064.86 counts	Background subtraction (0.12779 counts x 380.522 pix obtained from a 40-pixel radius aperture with an annulus of 5 pixels)
x 0.9915 = 2047.31 counts	Correction for geometric distortion. Not needed if doing surface photometry.
=> 15.481 mag	Raw magnitude (=-2.5 x $\log_{10}$(2047.31 / 14 sec) + 20.894) NOTE: -2.5 x $\log_{10}$(1.987) has been added to the zeropoint from section 5.2.2, "Gain Variation" since these calibrations were taken using the gain=14 setup. Most science observations use gain=7.
–0.10 = 15.381 mag	Aperture correction to total magnitude, estimated from Holtzman (1995a).
–0.028 = 15.353 mag	CTE correction (using formulas 1, 2d, 3d from *WFPC2 ISR 97-08* with this data). Note that this example uses relatively old CTE corrections which do not include a time dependence. Please see section 5.2.2 for the most up-to-date corrections.
–0.000 => m_{F814W} = 15.353 mag	Contamination correction (0.000 x [49763.4 – 49760.1]). An additional correction to transform to e.g., Cousin I, could be applied using the method described in "Contamination".

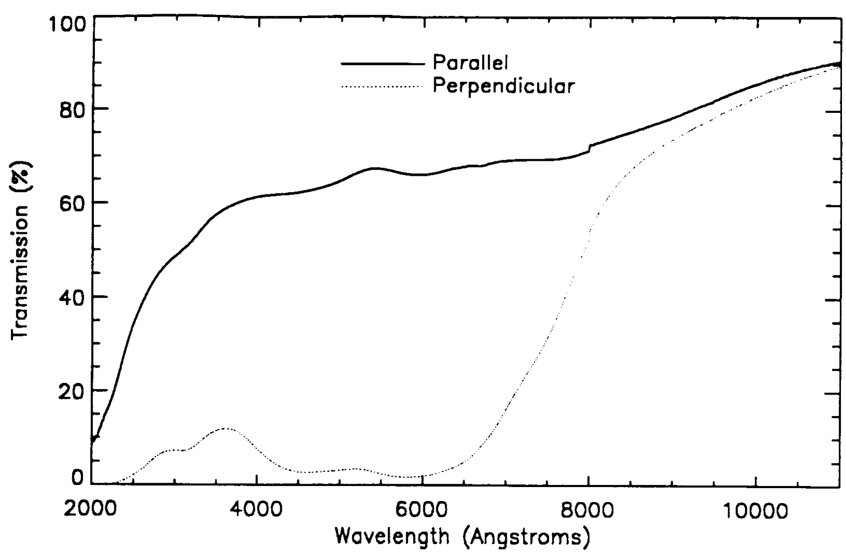
5.3 Polarimetry

WFPC2 has a polarizer filter which can be used for wide-field polarimetric imaging from about 200 through 700 nm. This filter is a *quad*, meaning that it consists of four panes, each with the polarization angle oriented in a different direction, in steps of 45^{o}. The panes are aligned with the edges of the pyramid, thus each pane corresponds to a chip. However, because the filters are at some distance from the focal plane, there is significant vignetting and cross-talk at the edges of each chip. The area free from vignetting and cross-talk is about 60" square in each WF chip, and 15" square in the PC. It is also possible to use the polarizer in a partially rotated configuration, which gives additional polarization angles at the expense of more severe vignetting.

Each polarimetry observation consists of several images of the same object with different orientations of the polarizer angle. A minimum of three observations is required to obtain full polarimetry information. This can be achieved by observing the target in different chips, by rotating the filter wheel (partial rotation), or by changing the orientation of the HST field of view in the sky, using a different roll angle. In the latter case, observations must frequently occur at different times, as the solar array constraints on HST allow only a limited range of roll angles at any given time.

Accurate calibration of WFPC2 polarimetric data is rather complex, due to the design of both the polarizer filter and the instrument itself. WFPC2 has an aluminized pick-off mirror with a 47° angle of incidence, which rotates the polarization angle of the incoming light, as well as introducing a spurious polarization of up to 5%. Thus, both the HST roll angle and the polarization angle must be taken into account. In addition, the polarizer coating on the filter has significant transmission of the perpendicular component, with a strong wavelength dependence (see figure 5.1).

Figure 5.1: Parallel and Perpendicular Transmission of the WFPC2 Polarizer



A calibration accuracy of about 2% rms for well-exposed WFPC2 polarimetry data has been achieved (*WFPC2 ISR* 97-11). The method uses a Mueller matrix approach to account for the orientation of both telescope and polarizer, the effect of the pick-off mirror, and the significant perpendicular transmission of the polarizer itself. A full description of the motivation behind this approach, the implementation details, and the necessary caveats are given in the ISR mentioned above. A web-based tool to aid in the calibration of polarization data has also been developed. With the aid of this tool, polarization properties can be derived for point sources and extended sources from an arbitrary combination of polarized images.

The procedure to obtain polarization information begins with the calibrated images, as they come out of the pipeline (plus cosmic ray and warm pixel rejection, if appropriate). The circumstances of the polarized images and the fluxes in each image are entered in the Web tool, and the calculation started. The tool then reports the values of the Stokes parameters I, Q, and U, as well as fractional polarization and position angle. The optional **synphot** values in the first part of the tool can be used to fine-tune the results to a specific spectral energy distribution, but are in most cases not necessary.

The tool also reports expressions for *I*, *Q*, and *U* as a function of fluxes in the three images. These can be used to test the sensitivity of the results to errors in the individual fluxes, or to combine images in order to obtain pixel-by-pixel values of the Stokes parameters for extended objects, resulting in I, Q, and U images.

More details will be provided in a future ISR, as well as in the extensive help available in the web tool itself.

5.4 Astrometry

Astrometry with WFPC2 means primarily *relative* astrometry. The high angular resolution and sensitivity of WFPC2 makes it possible, in principle, to measure precise positions of faint features with respect to other reference points in the WFPC2 field of view. On the other hand, the absolute astrometry that can be obtained from WFPC2 images is limited by the positions of the guide stars, usually known to about 0."5 rms in each coordinate, and by the transformation between the FGS and the WFPC2, which introduces errors of order of 0."1 (see *Instrument Science Report* OSG-006).

Because WFPC2 consists of four physically separate detectors, it is necessary to define a coordinate system that includes all four detectors. For convenience, sky coordinates (right ascension and declination) are often used; in this case, they must be computed and carried to a precision of a few mas, in order to maintain the precision with which the relative positions and scales of the WFPC2 detectors are known. It is important to remember that the coordinates are *not* known with this accuracy. The absolute accuracy of the positions obtained from WFPC2 images is typically 0."5 rms in each coordinate and is limited primarily by the accuracy of the guide star positions.

The recommended way to convert pixel coordinates into relative coordinates is to use the task,* metric*, which can handle both WF/PC-1 and WFPC2 images. The task* xy2rd*, will provide rough coordinates only and does not take geometric distortion into account.

For WFPC2 images, **metric** corrects the geometric distortion introduced by the camera optics, primarily the field flattening lenses, and brings the four chips into the metachip reference system, defined so as to have the same orientation and plate scale as the WF2 chip at its center. These coordinates are then converted into right ascension and declination by using the position and orientation of the WF2 chip. A related task, **invmetric**, can be used to effect the opposite transformation, from right ascension and declination to chip and pixel position. The final relative positions are accurate to better than 0."005 for targets contained on one chip, and 0."1 for targets on different chips. Note that both **metric** and **invmetric** include specialized information about the geometry of WFPC2 (see ISR 95-02). They do *not* use the header parameters that describe the world coordinate system (`CRVAL1` and `2`, `CRPIX1` and `2`, and the CDMATRIX) to relate positions in different chips. Of these parameters, only the values for WF2 are used to convert the metachip positions to and from right ascension and declination. As a side effect, neither task can work on images that do not contain WF2, for which the **xy2rd** task can be used.

Observers should be aware that the task **xy2rd** provides rough coordinates only. It uses the world coordinate system parameters in each group to determine the coordinates associated with a given pixel position. However, **xy2rd** does *not* use the most recent information on the relative chip positions, and it does *not* apply the geometric correction. Each can result in an error of about 0."3, especially near the edges of the chip; typical errors are closer to 0."1.

Astrometric measurements may be improved in several ways. First, the processing epoch of the images should be evaluated. Early WFPC2 images, particularly non-OTFR data, may contain header parameters with less accurate values of the plate scale and of the chip-to-chip rotations; section 4.3.3 provides detailed recommendations on updating such WFPC2 image headers. Images retrieved via OTFR will contain the most up-to-date parameters available at the time of processing. A significant improvement can be achieved by correcting the systematic errors caused by the 34th row defect, discussed in "The 34-th Row Defect"; this can be accomplished by using the formulae developed by Anderson & King (PASP **111**, 1095). And finally, observers may wish to use the improved geometric distortion solution provided in ISR 01-10 and/or correct for any possible wavelength dependence (Trauger et al. (1995)), as discussed below.

Though the original solution, which is based upon a relatively sparse field, provides an adequate measure of the WFPC2 geometric distortion, it has significant residuals at a level of 5 mas overall and 10-15 mas in the detector corners. The improved solution is based upon multiple observations of a rich star field in ω Cen; the new coefficients are tabulated in table 5.8 (see ISR 01-10 for details).

Table 5.8: Parameters of the new astrometric solution (taken from WFPC2 ISR 01-10). The functional form of the solution and the coefficient nomenclature are the same as those in Holtzman et al. (1995) and Trauger et al. (1995).

#	C			
	PC	WF2	WF3	WF4
1	3.543560e+2	-8.096405e+2	-8.052758e+2	7.708965e+2
2	1.000210e+0	21.667040e-3	-2.186307e+0	11.503445e-3
3	1.685097e-3	-2.186781e+0	-10.318882e-3	2.187646e+0
4	-0.476421e-6	-1.081274e-6	-0.467968e-6	1.410633e-6
5	-0.128977e-6	4.875708e-6	2.360098e-6	-3.662324e-6
6	-1.119461e-6	1.160592e-6	-1.881792e-6	-0.820634e-6
7	-38.989762e-9	-1.068123e-9	73.972588e-9	-0.388185e-9
8	0.495226e-9	75.463250e-9	0.110498e-9	-77.222274e-9
9	-36.277270e-9	0.099408e-9	76.882580e-9	-1.794536e-9
10	-0.075298e-9	72.628997e-9	0.003372e-9	-76.141940e-9

#	D			
	PC	WF2	WF3	WF4
1	3.436460e+2	7.667990e+2	-7.692243e+2	-7.708547e+2
2	2.649830e-3	2.185899e+0	4.282145e-3	-2.186289e+0
3	0.999790e+0	16.771070e-3	-2.185173e+0	16.304679e-3
4	-0.915545e-6	-3.953135e-6	-1.588401e-6	1.692025e-6
5	-0.347576e-6	-2.815106e-6	2.574760e-6	2.596669e-6
6	0.532097e-6	0.309766e-6	0.404571e-6	-1.059466e-6
7	-2.592636e-9	-73.394946e-9	-0.208263e-9	75.750980e-9
8	-34.967762e-9	-1.715681e-9	77.114768e-9	0.528052e-9
9	-1.570711e-9	-75.104144e-9	0.162718e-9	75.946626e-9
10	-41.901809e-9	-0.423891e-9	74.483675e-9	-0.237788e-9

Systematic residuals in this new solution are very small, about 1.2 mas in WF and less than 4.0 mas in PC. Note, however, that neither solution addresses any possible wavelength dependence - which is predicted to be a change in overall scale rather than higher-order distortions; for this, observers should refer to the ray-tracing solution presented by Trauger et al. (1995) and the PC chip UV scale correction factors in Barstow et al. (2001).

There is also clear evidence for long-term variations in the relative detector positions, based upon an analysis of WFPC2 K-spot images (internal exposures producing eleven fixed artificial stars along the chip quadrant boundaries). The spot positions are found to vary regularly over time, in a systematic fashion. All spot images within each chip move similar amounts, implying that the changes are due to a lateral motion of the image with respect to the detector rather than a rotation. The shifts were relatively large at first, about 2-4 pixels in the first few months of WFPC2 operation, and later decreased to about 0.1-0.2 pixel/year(*WFPC2 ISR 01-10*). Note that these long-term variations are not accounted for in the pointing information in the headers.

5.5 Dithering

The pixels of the PC undersample the point spread function (PSF) of the HST by a factor of about two, and the pixels of the WF are a factor of two coarser yet. Thus WFPC2 does not recover a substantial fraction of the spatial information that exists at the focal plane of the instrument. However, this information is not completely lost. Some of it can be recovered by *dithering* or *sub-stepping* the position of the chips by non-integral pixel amounts.

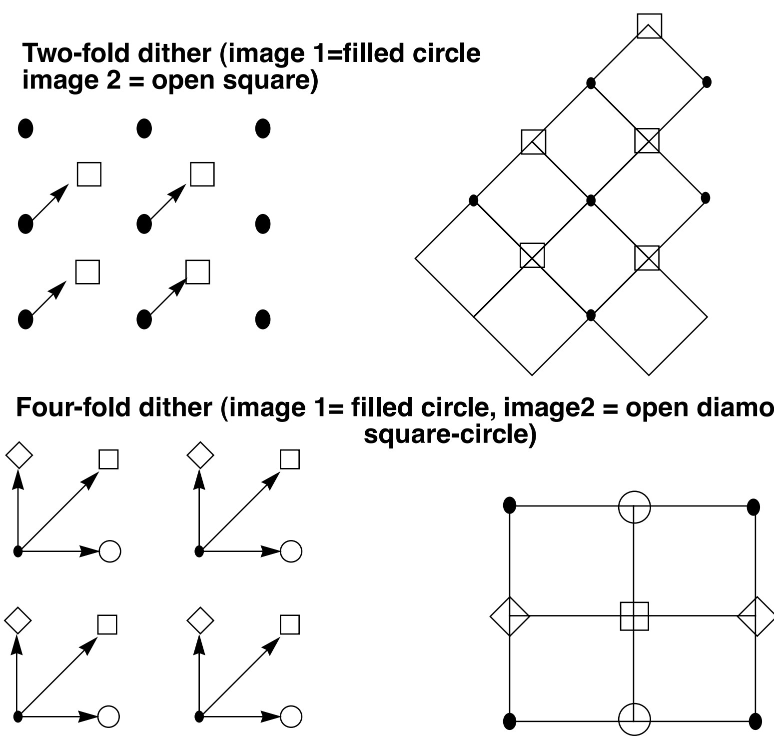
The recovery of high frequency spatial information is fundamentally limited by the pixel response function (PRF). The PRF of an ideal CCD with square pixels is simply a square boxcar function the size of the pixel. In practice, the PRF is a function not only of the physical size of the pixels, but also the degree to which photons and electrons are scattered into adjacent pixels, as well as smearing introduced by telescopic position wandering. The image recorded by the CCD is the “true” image (that which would be captured by an ideal detector at the focal plane) convolved with this PRF. Thus, at best, the image will be no sharper than that allowed by an ideal square pixel. In the case of WFPC2, in which at least 20% of the light falling on a given pixel is detected in adjacent pixels, the image is even less sharp.

The PRF of an ideal square pixel, that is a boxcar function, severely suppresses power on scales comparable to the size of the pixel. According to the Shannon-Nyquist theorem of information theory the sampling interval required to capture nearly all of the information passed by square pixels is 1/2 the size l of a pixel. This corresponds to dithering the CCD from its starting position of (0,0) to three other positions, (0,1/2 l), (1/2 l, 0) and (1/2 l, 1/2 l); however, in practice, much of the information can be regained by a single dither to (1/2 l, 1/2 l).

The process of retrieving high-spatial resolution information from dithered images can be thought of as having two stages. The first, reconstruction, removes the effect of sampling and restores the image to that produced by the convolution of the PSF and PRF of the telescope and detector. The more demanding stage, deconvolution (sometimes called restoration), attempts to remove much of the blurring produced by the optics and detector. In effect, deconvolution boosts the relative strength of the high-frequency components of the Fourier spectrum to undo the suppression produced by the PSF and PRF.

If your observations were taken with either of the two dither patterns discussed above, and if the positioning of the telescope was accurate to about a tenth of a pixel (this is usually but not always the case), then you can reconstruct the image merely by interlacing the pixels of the offset images. In the case of a two-fold dither—that is images offset by a vector (n + 1/2, n + 1/2) pixels, where n is an integer—the interlaced images can be put on a square grid rotated 45˚ from the original orientation of the CCD (see figure 5.2, top). In the case of a four-fold dither, the images are interlaced on a grid twice as fine as the original CCD and coaligned with it (see figure 5.2, bottom).

Figure 5.2: Interlacing Pixels of Offset Images (filled circles and open squares in the top plots represent pixels in image 1 and 2, respectively; filled circles, open squares, open diamonds, and open circles represent pixels in images 1,2,3,4, respectively, in the lower two plots).



As part of the Hubble Deep Field project, a new method was developed to linearly reconstruct multiple offset images. This method, variable pixel linear reconstruction (also known as *drizzle*), can be thought of as shifting and adding with a variable pixel size. For poorly sampled data, the shifted pixels retain the initial pixel size—the final image combines the shifts correctly, but the gain in resolution is minimal. For a well-sampled field, such as that of the Hubble Deep Field, the size of the shifted pixels can be made quite small, and the image combination becomes equivalent to interlacing. Drizzling also corrects for the effects of the geometric distortion of WFPC2; correction of geometric distortion is important if shifts between dithered images are of order ten pixels or more.

The drizzle algorithm was implemented as the STSDAS task **drizzle**, as part of the **dither** package, which helps users combine dithered images. The **dither** package is included in STSDAS release v2.0.1 and later, and includes the following tasks:

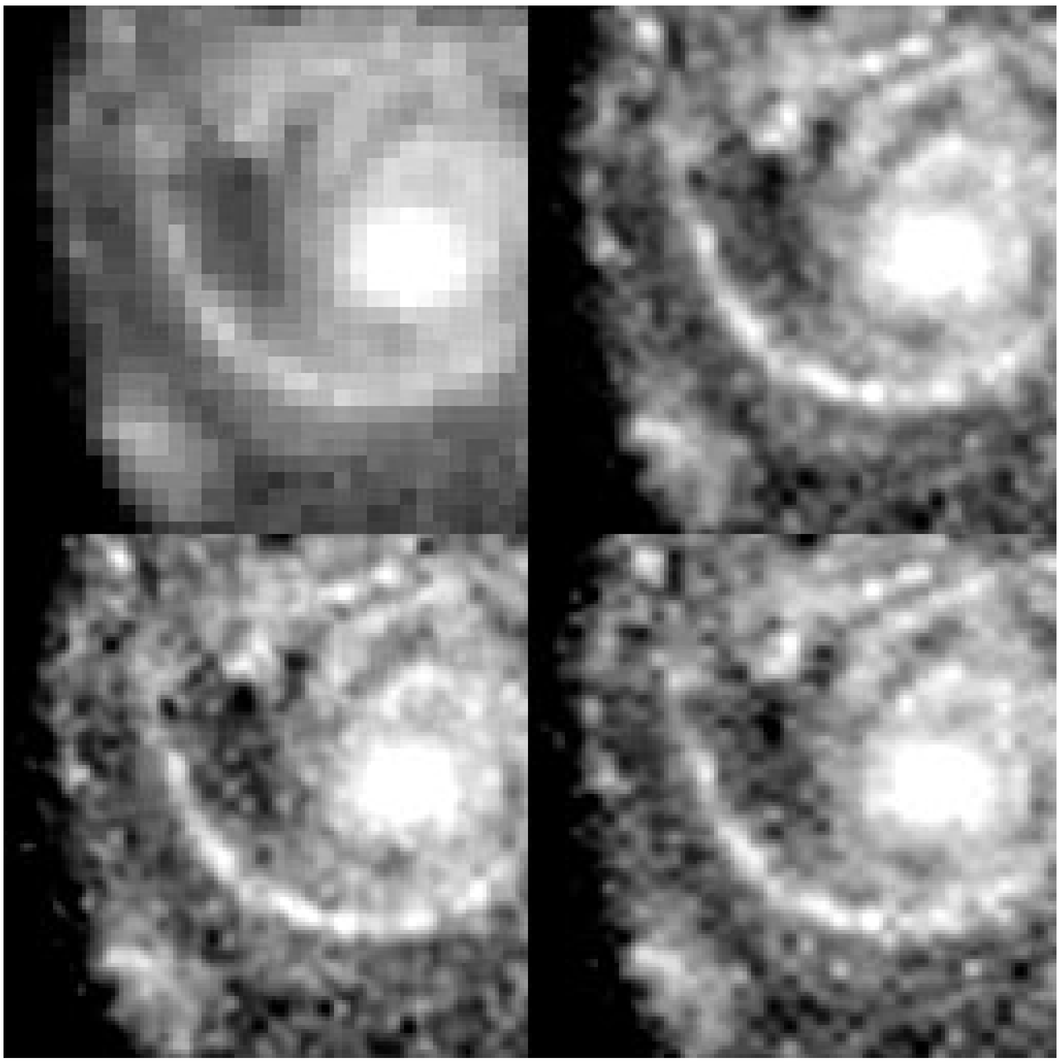
- **precor**: Determines regions of the image containing astrophysical objects and nulls the remainder of the image, substantially reducing the effect of cosmic rays and chip defects on the offset measurement. The output from **precor** is only used for offset determination and not final image creation.
- **offset**: Cross-correlates all four images in a WFPC image, creating output cross-correlation images with names that can be appropriately grouped by later tasks. Uses the task **crossdriz** to perform the cross-correlation.
- **crossdriz**: Cross-correlates two images, after preprocessing which includes trimming, and, if requested, drizzling to remove geometric distortion or rotation. **crossdriz** will also perform a loop over a range of test rotation angles.
- **shiftfind**: Locates the peak in a cross-correlation image and fits for sub-pixel shift information. The search region and details of the fitting can be adjusted by the user.
- **rotfind**: Fits for the rotation angle between two images. **rotfind** is called when **crossdriz** has been used to loop over a range of test rotation angles between two images.
- **avshift**: Determines the shifts between two WFPC2 images by averaging the results obtained on each of the groups after adjusting for the rotation angles between the four groups. **avshift** can also be used to estimate the rotation angle between two different WFPC2 images, when the rotation angle is a small fraction of a degree.
- **blot**: Maps a drizzled image back onto an input image. This is an essential part of the tasks we are developing for removing cosmic rays from singly-dithered images.

Additional information on these tasks is available in Fruchter et al. (1997) and Mutchler and Fruchter (1997), the on-line help files for the task, and the HST Dither Handbook.

Although reconstruction largely removes the effects of sampling on the image, it does not restore the information lost to the smearing of the PSF and PRF. Deconvolution of the images, however, does hold out the possibility of recapturing much of this information. Figure 5.3, supplied by

Richard Hook of the ST-ECF, shows the result of applying the Richardson-Lucy deconvolution scheme to HST data, used extensively in the analysis of WF/PC-1 data. The upper-left image shows one of four input images. The upper-right image shows a deconvolution of all of the data, and the lower two images show deconvolutions of independent subsets of the data. A dramatic gain in resolution is evident.

Figure 5.3: Richardson-Lucy Deconvolution of HST Data



A version of the Richardson-Lucy (RL) deconvolution scheme capable of handling dithered WFPC2 data is already available to STSDAS users. It is the task **acoadd** in the package **stsdas.contrib**. In order to use **acoadd**, users will need to supply the program both with a PSF (which in practice should be the convolution of the PRF with the optical PSF) and with the offsets in position between the various images. The position offset between the two images can be obtained using the task **crossdriz** in the **dither** package.

In principle, image deconvolution requires an accurate knowledge of both the instrument PSF and PRF. At present, our best models of the WFPC2 PSF come from the publicly available TinyTim software (Krist, 1995). The quality of the TinyTim model can be improved substantially by taking into account the exact position of the source within the pixel. Remy et al. (1997) discuss how this can be accomplished by generating multiple TinyTim images at various focus and jitter values, oversampled with respect to the camera pixels. At present, this is very labor-intensive, and the results cannot be easily integrated into the existing deconvolution software. Another limitation of the existing software is that it cannot incorporate the significant variation of the PSF across the field of view. As a result, the Richardson-Lucy approach can only be applied to limited regions of a chip at a time. Nonetheless, tests done on WFPC2 images suggest that RL deconvolution can give the WFPC2 user a substantial gain in resolution even in the presence of typical PSF and PRF errors. Users interested in more information on dithering, reconstruction, and deconvolution should consult the HST Dither Handbook.

5.6 Accuracy of WFPC2 Results

Table 5.9 summarizes the accuracy to be expected from WFPC2 observations in several areas. The numbers in the table should be used with care, and only after reading the relevant sections of this handbook and the documents referenced therein; they are presented in tabular form here for easy reference.

Table 5.9: Accuracy Expected in WFPC2 Observations

Procedure	Estimated Accuracy	Notes
Calibration (flatfielding, bias subtraction, dark correction)		
Bias subtraction	0.1 DN rms	Unless bias jump is present
Dark subtraction	0.1 DN/hr rms	Error larger for warm pixels; absolute error uncertain because of dark glow
Flatfielding	<1% rms large scale	Visible, near UV
	0.3% rms small scale	
	~10%	F160BW; however, significant noise reduction achieved with use of correction flats
Relative photometry		
Residuals in CTE correction	< 3% for the majority (~90%) of cases	
	up to 1-% for extreme cases (e.g., very low backgrounds)	
Long vs. short anomaly (uncorrected)	< 5%	Magnitude errors <1% for well-exposed stars but may be larger for fainter stars. Some studies have failed to confirm the effect (see “Long vs. Short Anomaly (non-linearity)”)
Aperture correction	4% rms focus dependence (1 pixel aperture)	Can (should) be determined from data
	<1% focus dependence (> 5 pixel)	
	1-2% field dependence (1 pixel aperture)	
Contamination correction	3% rms max (28 days after decon) (F160BW)	
	1% rms max (28 days after decon) (filters bluer than F555W)	
Background determination	0.1 DN/pixel (background > 10 DN/pixel)	May be difficult to exceed, regardless of image S/N
Pixel centering	< 1%	
Absolute photometry		
Sensitivity	< 2% rms for standard photometric filters	Red leaks are uncertain by ~10%
	2% rms for broad and intermediate filters in visible	
	< 5% rms for narrow-band filters in visible	
	2-8% rms for UV filters	
Astrometry		
Relative	0.005" rms (after geometric and 34th-row corrections)	Same chip
	0.1" (estimated)	Across chips
Absolute	1" rms (estimated)	

References

- Anderson, J., and King, I.R. 1999, Astrometric and Photometric Corrections fo the 34th Row Error in HST's WFPC2 Camera, *PASP* 111, 1095.
- Baggett, S., et al., 1997, WFPC2 SYNPHOT Update, *ISR* 97-10.
- Baggett, S., and Gonzaga, S., 1998, WFPC2 Long-Term Photometric Stability, *ISR* 98-03.
- Barstow, M.A., et al., 2001, Resolving Sirius-like Binaries with the Hubble Space Telescope, *MNRAS* 322, 891.
- Bernstein, R.A., Freedman, W.L., Madore, B.F, The First Detection of the Extragalactic Background Light at 3000, 5500 and 8000 A: Results, ApJ. 2001 in press (astro-ph 0112153)
- Bessell, M.S., 1983, PASP 95, 480.
- Biretta, J., and McMaster, M., 1997, WFPC2 Polarization Calibration, *ISR* 97-11.
- Biretta, J., et al., 1996, A Field Guide to WFPC2 Image Anomalies, *ISR* 95-06.
- Biretta, J., et al. 2001, WFPC2 Instrument Handbook, Version 6.0 (Baltimore: STScI).
- Buser, R. and Kurucz, R.L., 1978, A&A 70, 555.
- Casertano, S., and Mutchler, M., 1998, The Long vs. Short Anomaly in WFPC2 Images, *ISR* 98-02.
- Casertano, S., 1998, in *The 1997 HST Calibration Workshop*, eds. S. Casertano et al., (Baltimore: Space Telescope Science Institute), in press.
- Casertano, S., and Wiggs, M., 2001, An Improved Geometric Solution for WFPC2, *ISR* 01-10.
- Dolphin, A., 2000, The Charge-Transfer Efficiency and Calibration of WFPC2, *PASP* 112, 1397.
- Ferguson, H.C., 1996, Background Subtraction in WFPC2 Frames, *ISR* 96-03.

- Fruchter, A.S., et al., in *The 1997 HST Calibration Workshop*, eds. S. Casertano et al., (Baltimore: Space Telescope Science Institute), in press.
- Gonzaga, S., Baggett, S., and Biretta, J., 2001, Preliminary Assessment of the FR533N Filter Anomaly, *ISR* 01-04.
- Harris, H.C., et al., 1993, *AJ*, 105, 1196.
- Heyer, I., 2001, The WFPC2 Photometric CTE Monitor, *ISR* 01-09.
- Holtzman, J.A., et al., 1995a, *PASP*, 107, 156.
- Holtzman, J.A., et al., 1995b, *PASP*, 107, 1065.
- Johnson, H.L., 1965, ApJ 141, 923.
- Karkoschka, E., and Biretta, J., WFPC2 Flatfields with Reduced Noise, *ISR* 01-07.
- Kelson, D. D. et al., 1996, ApJ, 463, 26.
- Krist, J., 1995, "Simulation of HST PSF Using TinyTim," in *Astronomical Data Analysis, Software, and Systems IV*, Shaw et al., eds. (San Francisco: Astronomical Society of the Pacific), p. 349.
- Lub, J. and Pel, J.W., 1977, A&A 54, 137.
- Mack, J., Baggett, S., and Biretta, J., Creating WFPC2 Dark Reference Files: Addendum, *ISR* 01-09.
- Mack, J., and Wiggs, M., Creating WFPC2 Dark Reference Files, *ISR* 01-01.
- Matsushima, S., 1969, ApJ 158, 1137.
- Mutchler, M., and A. Fruchter, 1998, in *The 1997 HST Calibration Workshop*, eds. S. Casertano et al., (Baltimore: Space Telescope Science Institute), in press.
- O'Dea, C.P., et al., 1997, Properties of WFPC2 Bias Frames, *ISR* 97-04.
- Oke, J.B., 1974, *ApJS*, 27, 21.
- Ratnatunga, K.U., et al., 1998, in *The 1997 HST Calibration Workshop*, eds. S. Casertano et al., (Baltimore: Space Telescope Science Institute), in press.
- Reiss, A., 2000, How CTE Affects Extended Sources, *ISR* 00-04.
- Remy, M., et.al., 1998, in *The 1997 HST Calibration Workshop*, eds. S. Casertano et al., (Baltimore: Space Telescope Science Institute), in press.
- Saha, A. et al., 1996, ApJ, 466, 55.

- Saha, A., Labhart, L. & Prosser, C. 2000, PASP, 112, 163.
- Suchkov, A., and Casertano, S., 1997, Impact of Focus Drift on Aperture Photometry, *ISR* 97-01.
- Surdej, J., et al., 1998, in *The 1997 HST Calibration Workshop*, eds. S. Casertano et al., (Baltimore: Space Telescope Science Institute), in press.
- Trauger, J.,T., et al., 1993, *WFPC2 Science Calibration Prelaunch Report*, by WFPC2 Investigation Definition Team.
- Trauger, J.T., et al., 1994, *ApJ*, 435, L3.
- Trauger, J.T., et al., 1995, in *The 1995 HST Calibration Workshop*, eds. Koratkar, A., and Leitherer, C., (Baltimore: Space Telescope Science Institute).
- Trauger, J.T., 1998, in *The 1997 HST Calibration Workshop*, eds. S. Casertano et al., (Baltimore: Space Telescope Science Institute), in press.
- Whitmore, B., 1995, in Calibrating Hubble Space Telescope: Post Servicing Mission, eds. A. Koratkar & C. Leitherer (Baltimore: STScI), 269.
- Whitmore, B., and Heyer, I., 1995, A Demonstration Analysis Script for Performing Aperture Photometry, *ISR* 95-04.
- Whitmore, B., and Heyer, I., 1997, New Results on CTE and Constraints on Flatfield Accuracy, *ISR* 97-08.
- Whitmore, B., Heyer, I., and Baggett, S., 1996, Effects of Contamination on WFPC2 Photometry, *ISR* 96-04.
- Whitmore, B., Heyer, I., and Casertano, S., 1999, Charge-Transfer Efficiency of WFPC2, *PASP* 111, 1559.
- Whitmore, B., and Wiggs, M., Charge Transfer Traps in the WFPC2, *ISR* 95-03.
- Wiggs, M.S., et al., 1998, in *The 1997 HST Calibration Workshop*, eds. S. Casertano et al., (Baltimore: Space Telescope Science Institute), in press.

WWW References

Space Telescope HST page

http://hst.stsci.edu.

Space Telescope Astronomy Resources page

http://resources.stsci.edu/

Space Telescope Archive page

http://archive.stsci.edu/

StarView Page

http://starview.stsci.edu/html/

Paper Products Page

http://archive.stsci.edu/hst/pdf_search.html

HST Program Information Page

http://www.stsci.edu/public/propinfo.html

Keyword Dictionary

http://www.dpt.stsci.edu/cgi-bin/kdct-keyword_form?db=Operational

Science Instrument Aperture File (SIAF)

http://www.stsci.edu/instruments/observatory/siaf.html

Spectral Atlases Page

http://www.stsci.edu/instruments/observatory/cdbs/astronomical_catalogs_alt.html

SYNPHOT Users Guide

http://ra.stsci.edu/Files

Sites below begin with " http://www.stsci.edu/instruments/wfpc2" unless otherwise noted.

Site Map of WFPC2 WWW pages	/wfpc2_site.html
WFPC2 Advisories	/wfpc2_advisory.html
WFPC2 Documentation	/wfpc2_doc.html
WFPC2 Software Tools	/wfpc2_tools.html
WFPC2 User Support	http://hst.stsci.edu/acs/performance/cte_workgroup/cte_workshop.html
Frequently Asked Questions	/wfpc2_top_faq.html
WFPC2 Instrument Handbook	/wfpc2_handbook.html
WFPC2 Tutorial	/wfpc2_doc.html#Hand
Dither Handbook	/Wfpc2_driz/dither_handbook.html
WFPC2 Exposure Time Calculators	/Wfpc2_etc/wfpc2-etc.html
WFPC2 Reference Files	Wfpc2_memos/wfpc2_reffiles.html
IDT Reference Files	/Wfpc2_memos/wfpc2_idtrefs.html
WFPC2 PSF page	/Wfpc2_psf/wfpc2_psf_page.html
Warmpixel Tables	/wfpc2_warmpix.html
Instrument Science Reports (ISRs)	/wfpc2_bib.html
Polarizer Calibration Tools	/wfpc2_pol_top.html
Calibrating Linear Ramp Filter data	/Wfpc2_lrf/lrf_calibration.html
Linear Ramp Filter Calculator	/Wfpc2_lrf/wfpc2_lrfcalc.html
Photometric Monitoring Memo	Wfpc2_memos/wfpc2_stdstar_phot3.html
Orientation Memo	/orient.html
Decontamination Memo	/Wfpc2_memos/wfpc2_history.html
STAN, the Space Telescope Analysis Newsletter	/wfpc2_stan.html
Workshop on Hubble Space Telescope CCD Detector CTE (Jan. 2000)	http://hst.stsci.edu/acs/performance/cte_workgroup/cte_workshop.html

To subscribe to the STAN Newsletter, send a message to majordomo@stsci.edu with the Subject: line blank and the following in the body: subscribe wfpc_news).

PART III:

Appendixes

APPENDIX A:

IRAF Primer

In this appendix . . .

The Image Reduction and Analysis Facility (IRAF), developed by the National Optical Astronomy Observatories (NOAO), forms the basis of the Space Telescope Science Data Analysis System (STSDAS). IRAF contains numerous packages of programs, called *tasks*, that perform a wide range of functions from reading data tapes to producing plots and images. Most astronomers will already be familiar with IRAF, but we provide this tutorial for HST observers who are beginners with IRAF. It includes information on:

- How to set up IRAF the first time you use the software.
- How to start and stop an IRAF session.
- Basic concepts, such as loading packages, setting parameters, etc.
- How to use the on-line help facility.

Additional information on IRAF, in particular *A Beginner's Guide to Using IRAF* is available through the NOAO IRAF Home Page at: http://iraf.noao.edu

A.1 Initiating IRAF

This section explains:

- How to set up your IRAF working environment.
- How to start and logout of the IRAF program.

We assume that your site has IRAF and STSDAS installed. If not, you must obtain and install the software. See appendix section A.3 for details.

A.1.1 Setting Up IRAF

Before running IRAF for the first time you need to follow these three steps:

1. Create your IRAF root directory.
2. Move to that directory and set the necessary environment variables or system logicals and symbols.
3. Run **mkiraf** to create a `login.cl` file and a `uparm` subdirectory.

Users generally name their IRAF home directory `iraf` (also referred to as your IRAF *root* directory) and set it up in their account's root directory (i.e., the default directory that you are in when you log in to the system). The IRAF home directory doesn't need to be in your account's root directory, nor does it need to be called `iraf`, but you should *not* put it on a scratch disk that is periodically erased.

If you call your root IRAF directory "`iraf`", you can set up IRAF as follows:

Under Unix:

```
% mkdir iraf
% cd iraf
% setenv iraf /usr/stsci/iraf/
% source $iraf/unix/hlib/irafuser.csh
% mkiraf
```

Can be placed in .login file (setenv and source lines)

The directory name is site-dependent—check with your system staff

Under VMS:

```
$ CREATE/DIR [.IRAF]
$ SET DEFAULT [.IRAF]
$ IRAF
$ MKIRAF
```

Can be placed in LOGIN.COM file (the $ IRAF line)

The **mkiraf** command initializes IRAF by creating a `login.cl` file and a subdirectory called `uparm`. After typing the **mkiraf** command, you will see the following:

```
% mkiraf
-- creating a new uparm directory
Terminal types: gterm=ttysw+graphics,vt640...
Enter terminal type:
```

Enter the type of terminal or workstation you will most often use with IRAF. [1] Generic terminal types that will work for most users are:

- `vt100` for most terminals.
- `xtermjhs` for most workstations running under X-Windows.

`xgterm` for sites that have installed X11 IRAF and IRAF v2.10.3 BETA or later.

You can change your terminal type at any time by typing set term=new_type during an IRAF session. You can also change your default type by editing the appropriate line in your login.cl file.

After you enter your terminal type, you will see the following output before getting your regular prompt:

```
A new LOGIN.CL file has been created in the current ...
You may wish to review and edit this file to change ...
```

The `login.cl` file is the *startup file* used by the IRAF command language (CL). It is similar to the `LOGIN.COM` file used by VMS or the `.login` file used by Unix. Whenever IRAF starts, it looks at the `login.cl` file. You can edit this file to customize your IRAF environment. In fact, you should look at it to make sure that everything in it is correct. In particular, there is a line starting with `set home =` that tells IRAF where to find your IRAF home directory. You should verify that this statement does, in fact, point to your IRAF directory. If you will be working with standard IRAF format images you should also insert a line saying `set imdir = "HDR$"`. The `imdir` setting is ignored when working with GEIS format images.

The `uparm` directory will contain your own copies of IRAF task parameters. This directory allows you to customize your IRAF

1. Users at STScI should consult the *STScI Site Guide for IRAF and STSDAS*.

environment by setting certain parameter values as defaults. Once you set up IRAF, you should rarely need to do it again, expect when updated version of IRAF are installed.

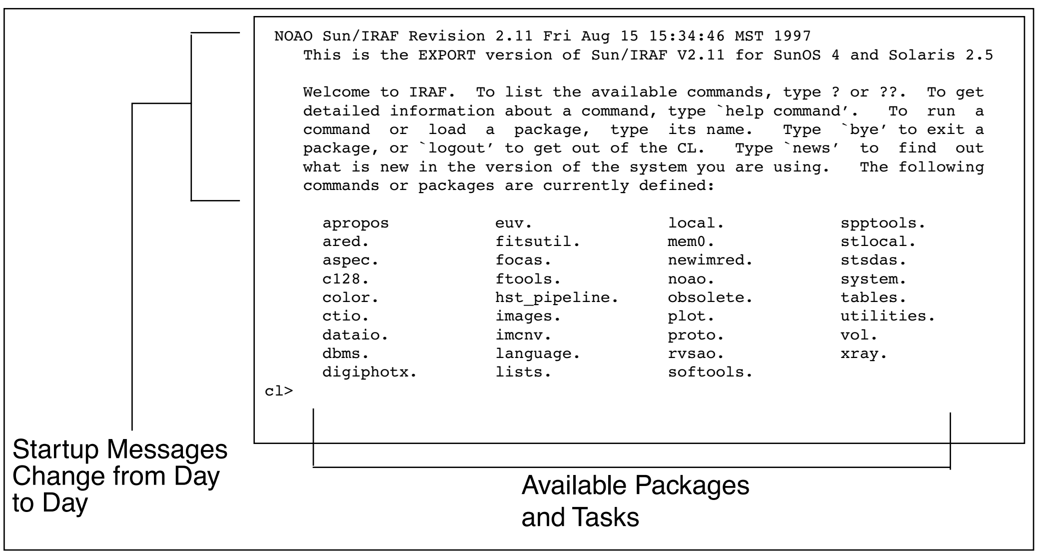
A.1.2 Starting and Stopping an IRAF Session

To start an IRAF session:

1. Move to your IRAF home directory.
2. Type `cl`.

IRAF starts by displaying several lines of introductory text and then puts a prompt at the bottom of the screen. Figure A.1 is a sample IRAF startup screen.

Figure A.1:IRAF Startup Screen



To quit an IRAF session:

1. Type `logout`.

A.2 IRAF Basics

This section describes basic IRAF techniques such as:

- Loading packages (below).
- Running tasks and commands.
- Getting online help.
- Viewing and setting parameters (see appendix section A.2.4).

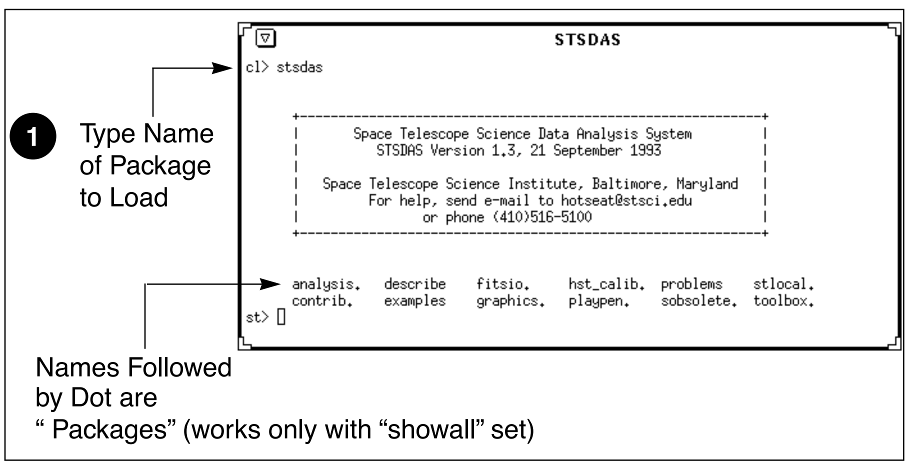
- Setting and using environment variables (see section A.2.5).
- File management
- Troubleshooting

A.2.1 Loading Packages

In IRAF jargon, an application is called a *task* and logically related tasks are grouped together in a *package*. Before you can use a task, you must load the package containing that task. To load a package, type the name of the package. The prompt will then change to the first two letters of the package name, and the screen will display the names of all the newly available tasks and subpackages. Even though the prompt has changed, previously loaded packages remain loaded, and all their tasks remain available.

Note that the standard way to specify a path through the IRAF package hierarchy to a task in a particular subpackage is to separate the package names with periods (e.g., **stsdas.hst_calib.foc.focgeom.newgeom**).

Figure A.2:Loading Packages



Some helpful commands for managing packages are:

- `?` - Lists tasks in the most recently-loaded package.
- `??` - Lists all tasks loaded, regardless of package.
- `package` - Lists names of all loaded packages.
- `bye` - Exits the current package.

A.2.2 Running Tasks

This section explains how to run tasks, background tasks, and system-level commands, and how to use piping and redirection.

Running a Task

The simplest way to run a task is to type its name or any unambiguous abbreviation of it. The task will then prompt you for the values of any required *parameters*, such as the names of input files. Alternatively, you can specify the values for the required *parameters* on the command line when you run the task. For example, if you want the task `imheader` to print header information on the file `myfile.hhh`, you can type

```
st> imhead myfile.hhh
```

IRAF does not require you to type the complete command name—only enough of it to make it unique. For example, dir is sufficient for directory.

Escaping System-Level Commands

To run an operating system-level command (i.e., Unix or VMS commands) from within the IRAF CL, precede the command with an exclamation point (!). This procedure is called *escaping* the command. For example:

```
st> !system_command
```

Piping and Redirection

You can run tasks in sequence if you desire, with the output of one task being used as the input for another. This procedure, called *piping*, and is done by separating commands with a vertical bar (|), using the following syntax:

```
st> task1 filename | task2
```

For example, if a particular task prints a large volume of textual output to the screen, you will often want to pipe it to `page`, which allows you to read the output one page at a time:

```
st> task1 filename | page
```

You can also redirect output from any task or command to a file by using the greater-than symbol (>) as follows:

```
st> command > outputfile
```

Background Tasks

To run a task as a background job, freeing your workstation window for other work, add an ampersand (&) to the end of the command line, like this:

```
st> taskname &
```

A.2.3 Getting Help

This section describes:

- How to use IRAF's on-line help facility.
- How to find a task that does what you want (see "Finding Tasks" on page A-8).

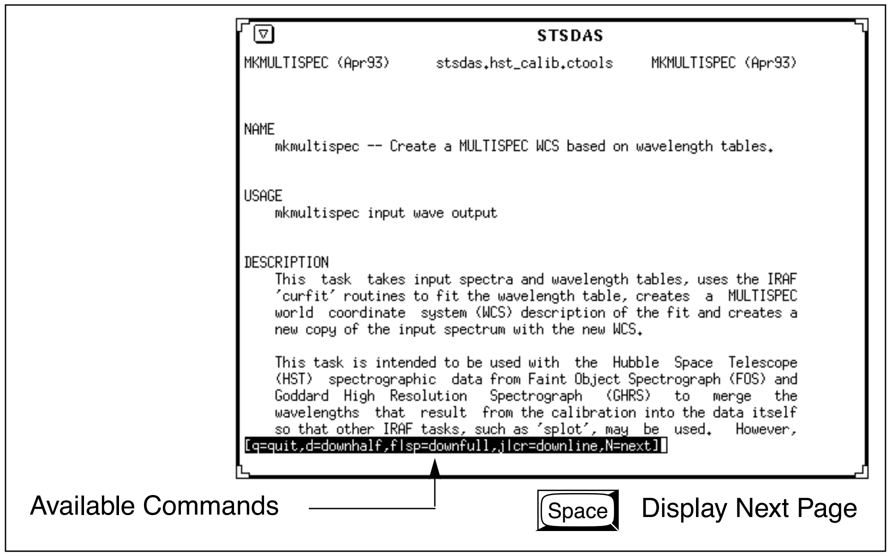
On-Line Help

You can get on-line help with any IRAF task or package by using the **help** command,[2] which takes as an argument the task or package name about which you want help. Wildcards are supported. For example, to display the on-line help for the STSDAS **mkmultispec** task, you would type:

```
fi> help mkmultispec
```

2. There is an optional *paging* front-end for help called **phelp**. For more information, type `help phelp` from within IRAF.

Figure A.3:Displaying On-line Help



Two STSDAS tasks that display only certain sections of the help file are also available:

- **examples** - Displays only the examples for a task.
- **describe** - Displays only the description of the task.

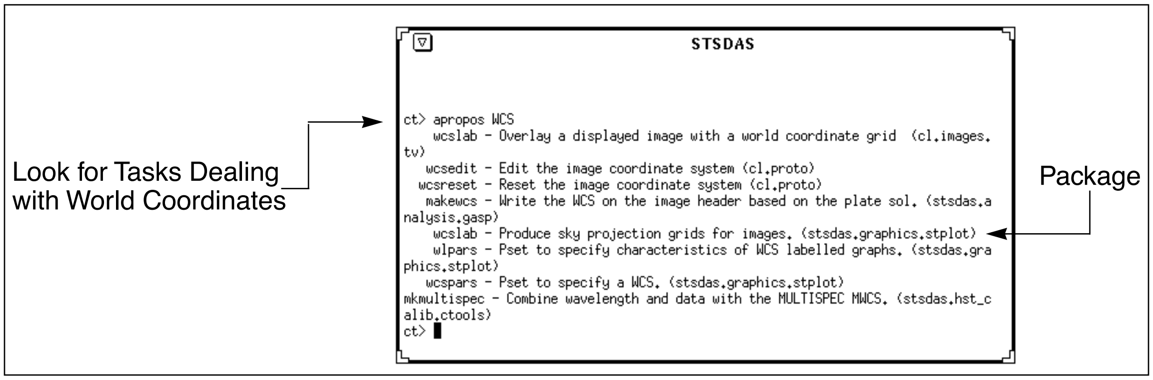
Typing `help` *package* will produce one-line descriptions of each task in the package.

Finding Tasks

There are several ways to find a task that does what you need:

- Use `help` *package* to search through the IRAF/STSDAS package structure.
- Use the **apropos** task as shown in figure A.4 to search the online help database. This task looks through a list of IRAF and STSDAS package menus to find tasks that match a specified keyword. Note that the name of the package containing the task is shown in parentheses.
- Ask more experienced user, who can usually point you in the right direction.

Figure A.4:The **apropos** task Using apropos



A.2.4 Setting Parameters

Parameters specify the input information for IRAF tasks. They can be the names of input or output files, particular pixel numbers, keyword settings, or many other types of information that control the behavior of the task.

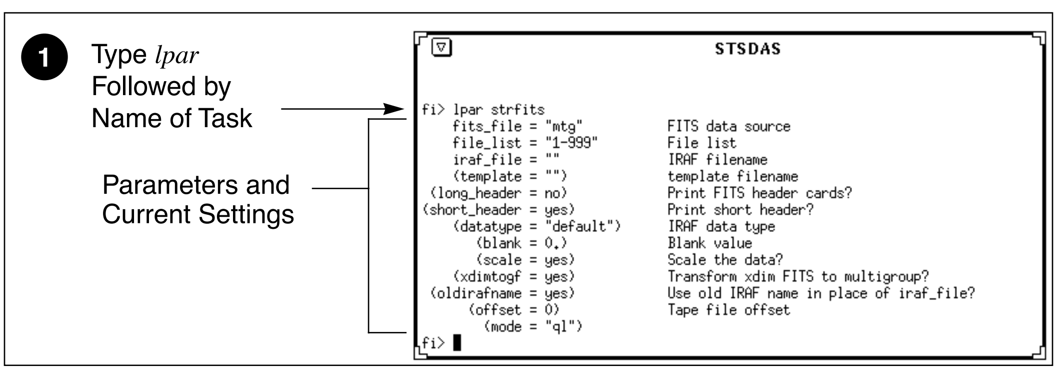
The two most useful commands for handling parameters are:

- **lparam** to display the current parameter settings (often abbreviated **lpar**).
- **eparam** to edit parameters (often abbreviated **epar**).

Viewing Parameters with lparam

The **lpar** command lists the current parameter settings for a given task (figure A.5).

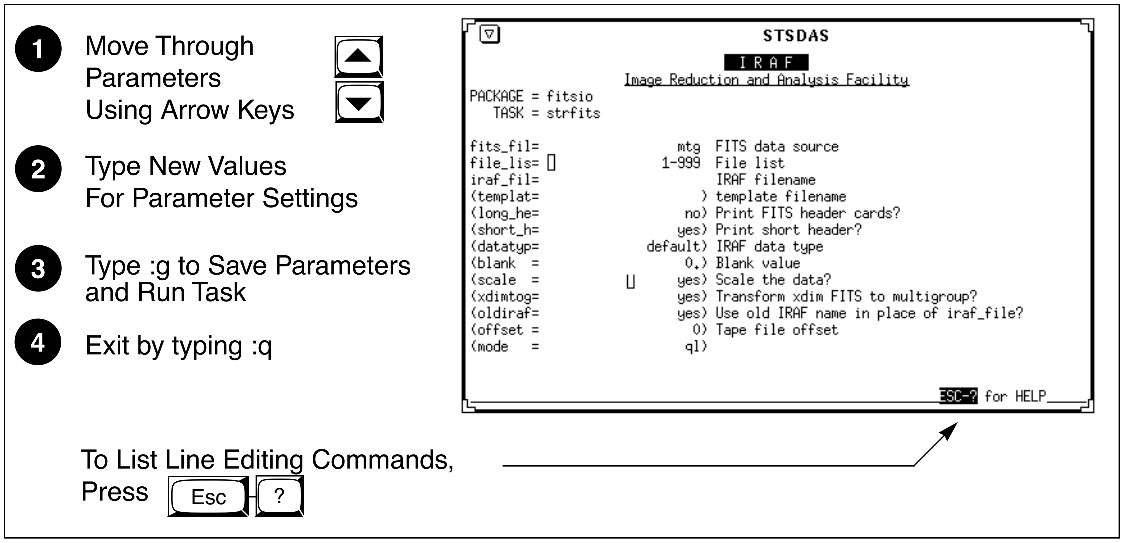
Figure A.5:Displaying Parameter Settings with lpar



Setting parameters with eparam

The **epar** command is an interactive parameter set editor. It displays all of the parameters and their current settings on the screen. You can move around the screen using the arrow keys (also called *cursor* keys) and type new settings for any parameters you wish to change. Figure A.6 shows a sample of the **epar** editor at work (invoked by typing `epar strfits`).

Figure A.6:Editing Parameters with epar



Parameter Data Types—What to Specify

Parameters are either *required* or *hidden*, and each parameter expects information of a certain *type*. Usually, the first parameter is required, and very often it expects a file name. Parameters are described in the online help for each task [include reference to help]. Hidden parameters, shown in parentheses in the online help and the **lpar** and **epar** listings, need not be specified at each execution because their default values frequently suffice.

Wise IRAF users will check the values of hidden parameters, as they often govern important aspects of a task's behavior.

If you specify the wrong type of information for a parameter, **epar** will usually display an error message saying something like "Parameter Value is Out of Range." The message is displayed when you move to another parameter or if you press Return. Table A.1 lists the different parameter types.

Table A.1: Parameter Data Types

Type	Description
`File Name`	Full name of the file. Wild card characters (* and ?) are often allowed. Some tasks allow you to use special features when specifying file names, including "@" lists, IRAF networking syntax, and image section or group syntax. (See "File Management" below).
`Integer`	Whole number. Often the task will specify minimum or maximum values (see the help pages).
`Real`	Floating point numbers, can be expressed in exponential notation. Often will have minimum and maximum values.
`Boolean`	Logical "yes" or "no" values.
`String`	Any characters. Sometimes file names are specified as string.
`Pset`	Parameter set.

Restoring Parameter Default Values

Occasionally, IRAF (or you) will get confused by your parameter values. To alleviate this confusion, you can restore the default parameters with the **unlearn** command. You can use **unlearn** on either a task or on an entire package.

The unlearn command generally will restore the parameters to reasonable values, a big help if you are no longer sure which parameter values you have changed in a complicated task.

A.2.5 Setting Environment Variables

IRAF uses *environment variables* to define which devices are used for certain operations. For example, your terminal type, default printer, and the disk and directory used for storing images are all defined through environment variables. Environment variables are set using the **set** command and are displayed using the **show** command. Table A.2 lists some of the environment variables that you might want to customize.

Table A.2: Environment Variables

Variable	Description	Example of Setting
`printer`	Default printer for text	`set printer = lp2`
`terminal`	Terminal type	`set term = xterm`
`stdplot`	Default printer for all graphics output	`set stdplot = ps2`
`stdimage`	Default terminal display setting for image output (most users will want this set to either imt512 or imt800)	`set stdimage = imt800`
`stdgraph`	Default graphics device	`set stdgraph = xterm`
`clobber`	Allow or prevent overwriting of files	`set clobber = yes`
`imtype`	Default image type for output images. “imh” is original IRAF format, “hhh” is STSDAS GEIS format.	`set imtype = ”hhh”`

If you are working with GEIS files, you should set imtype to “hhh”. If you are working with STIS and NICMOS data in FITS files, you can set imtype to “fits”

You can set your environment variables automatically each time you login to IRAF by adding the appropriate commands to your `login.cl` file. Use your favorite text editor to specify each variable on its own line. The **show** command with no arguments prints the names and current values of all environment variables.

A.2.6 File Management

This section describes:

- File formats commonly used with STSDAS and IRAF.
- Specification of file names.
- Navigation through directories.

File Formats

IRAF recognizes a number of different file structures. Among them are the standard HST file formats known as GEIS and FITS (see chapter 2 of the HST Introduction), both of which differ from the original IRAF format (OIF). GEIS is closer to OIF, in that two files are *always* used together as a pair:

- A *header file*, which consists of descriptive information. IRAF header files are identified by the suffix `.imh`. GEIS header files are in ASCII text format and are identified by the suffix `.hhh` or another suffix ending in "`h`", such as `.c0h` or `.q1h`.
- A *binary data file*,[3] consisting of pixel information. IRAF data file names end with a `.pix` suffix. STSDAS data files end with an suffix of `.hhd` or another suffix that ends with "d", such as `.c0d` or `.q0d`.

STSDAS always expects both component files of a GEIS image to be kept together in the same directory. A single FITS file contains both the header information and the data.

When working with IRAF or STSDAS images, you need only specify the header file name—the tasks will automatically use the binary data file when necessary.

File Specification

Most tasks in IRAF and STSDAS operate on files and expect you to specify a file name for one or more parameters. Several types of special syntax can be used with certain tasks when specifying file names. These syntax features include:

- **Wild card characters**, often called *templates*, which are used to specify multiple files using pattern matching techniques. The wild cards are:
  - * Matches any number of characters, e.g.: `z*.c0h`
  - ? Matches any single character, e.g.: `z01x23x.c?h`

3. The binary data file format is host-dependent and may require translation before it can be moved to a computer using a different architecture.

When using wildcards with image-processing tasks, be sure to exclude the binary pixel files by ending your file name specification with an "h", for example: y*.??h

- **List files**, often called *@-files*, which are ASCII file that contain lists of file names, one per line. If your task supports the list file feature, you would type the name of your list file, preceded by the "@" character. For example: `@files.txt`
- **Image section** specification. Tasks that work with image data will often let you specify that you want to work on only a small area of the image rather than the entire image. To extract a particular image section, specify each axis range in square brackets, for example: `image.hhh[10:200,20:200]`
- **IRAF networking** specification. IRAF is capable of reading and writing files to and from remote systems on a network. This feature is often used with tasks in the **fitsio** and **convfile** packages, or with image display tasks. The *STSDAS Users Guide* and the online help (type `help networking`) describe how to enable this feature. To specify that you want to use the IRAF networking feature, type the remote host name followed by an exclamation point (!), followed by the file or device name. For example: `ra!mta`.

Directory Navigation

To navigate through directories, you can use the following commands:

- **path** or **pwd** - Lists the current working directory.
- **cd** *directory* - Move to the named directory.

A.2.7 Troubleshooting

There are a couple of easy things you can do to make sure that you don't have a simple memory or parameter conflict—common causes of problems.

- Look at the parameter settings and make sure that you have specified reasonable values for every parameter.

- When you run an IRAF task for the first time in a session, IRAF stores the executable file in its *process cache*. If IRAF appears not to be running your tasks properly, you may need to use the **flprcache** command to clear the process cache. To do this type: `flpr` Sometimes you will need to execute this command twice in succession.
- Occasionally, you may need to logout of the CL, restart IRAF, and try your command again.

If you still have a problem, contact the STScI Help Desk at `help@stsci.edu`

A.3 Getting IRAF and STSDAS

Both IRAF and STSDAS are provided free of charge to the astronomical community. You must have IRAF to run STSDAS. Detailed information about installing and retrieving STSDAS is found in the *STSDAS Site Manager's Installation Guide and Reference*. If you have any problems getting and installing STSDAS, TABLES, or any other packages or data described in this handbook, please contact the Help Desk by sending e-mail to: `help@stsci.edu`.

A complete description of how to install the **synphot** data files is provided in section A.3.2.

A.3.1 Retrieving the IRAF and STSDAS Software

There are three ways to get the software:

- Use the World Wide Web.
- Use anonymous FTP.
- Request a tape.

World Wide Web

The STSDAS World Wide Web page:

`http://stsdas.stsci.edu/STSDAS.html`

provides links and instructions for downloading the appropriate files to your local system or to display the software directory, from which you can select the series of smaller files.

Anonymous FTP

- **IRAF**: `iraf.noao.edu` (140.252.1.1)
- **STSDAS**: `ftp.stsci.edu` (130.167.1.2)

There are two points to remember when using FTP to retrieve STSDAS:

- You must retrieve and install the TABLES package before STSDAS.
- You should retrieve the `README` file from the directory `/software/ stsdas/v2.0` and read it to find out which files you should retrieve.

You must have IRAF installed on your system to install TABLES and STSDAS. When you retrieve STSDAS, you must also retrieve the TABLES package, and TABLES must be installed first.

Instructions for installing STSDAS are available in the `doc` subdirectory of the directory where you find STSDAS. The complete instructions for installing STSDAS, TABLES, and all of the supporting software and reference files (including instrument reference files and the **synphot** dataset) are found in the *STSDAS Site Manager's Installation Guide and Reference*.

Registration

The software can also be registered and requested using on-line forms available through World Wide Web at the following URL:

`http://stsdas.stsci.edu/RegistForm.html`

When you request the STSDAS software, you can also ask for the appropriate version of IRAF, which will be requested for you— simply check the appropriate box on the form under "Do You Already Have IRAF Installed?" If you prefer to request the IRAF software independent of STSDAS, you can do so by sending e-mail to: `iraf@iraf.noao.edu`

A.3.2 Getting the Synphot Database

This manual sometimes refers to the **synphot** dataset, which must be available in order to run tasks in the STSDAS **synphot** package. These data files are not included with the STSDAS software and must be retrieved independently. To do this, you need to retrieve a series of compressed tar files from the STScI FTP site (ftp.stsci.edu) in the directory `software/stsdas/refdata/synphot`. After uncompressing and extracting the tar files (see below), you need to unpack the FITS files as described below.

The synthetic photometry data are read in similar way as the instrument datasets, using the script `unpack.cl` provided in the top directory. This script is run within IRAF to convert data from FITS format into the format used by the **synphot** task. This script assumes you have the logical `crrefer` set up in your `extern.pkg` file (which is in the directory `$iraf/unix/hlib` (Unix) or `$iraf/vms/hlib` (VMS)) or have it set up in your session. You do this by placing the command below in `extern.pkg` or by typing it on the command line:

```
set crrefer = "/node/partition/stdata/synphot/"
```

Figure A.7 shows how to convert the files.

Figure A.7:Unpacking Synthetic Photometry Files

```
% cl
cl> cd /node/partition/stdata/synphot
cl> set crrefer = "/node/partition/stsdata/synphot/"
cl> task $unpack = unpack.cl
cl> tables
ta> fitsio
fi> unpack
```

Just in case...

The “$” is used because the task has no parameter file

Note that all three synphot files must be unloaded for the script to complete successfully.

A.3.3 Extracting the synphot Unix Tar Files

If you retrieved the **synphot** database as compressed tar files, you will need to copy them to an appropriate subdirectory and then expand and unpack the files. The tar and compress utilities that do this are are commonly available on most Unix systems, but are not standard in the VMS environment. The examples shown below reflect Unix usage. If you are on a VMS system, you should consult with your systems support staff regarding the availability and usage of these commands. To process the files on a Unix system:

1. Get the compressed tar file that you want, as described in previous sections.
2. Make an appropriate subdirectory using the `mkdir` command.
3. Pipe the compressed tar file through the `uncompress` and `tar` files to expand and unpack the file.

The following example shows how to do this. The example assumes that you are putting the files in a subdirectory under `/usr/iraf/stdata` (note that the name of your file here is assumed to be `XXX.tar.Z`).

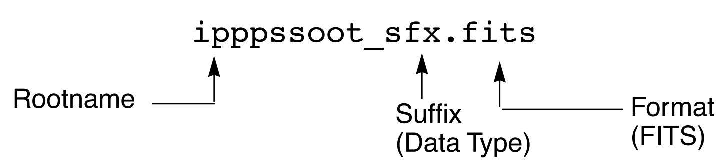
```
% pwd
/usr/iraf/stdata
% mkdir XXX
% mv XXX.tar.Z XXX/
% cd XXX
% cat XXX.tar.Z | uncompress | tar -xf -
```

APPENDIX B:

HST File Names

In this appendix. . .

This appendix describes the syntax of HST data file names, which encode a large amount of information about the files themselves. Datasets retrieved from the Archive as described in consist of multiple files in FITS format, each with a name that looks like this:



- ***Rootname***: The first part of the file name (`ipppssoot`) is the *rootname* of the dataset to which the file belongs. All files belonging to a given dataset share the same rootname.
- ***Suffix***: The three-character second part of the name (`sfx`) is called the *suffix*, and it indicates the type of data the file contains.
- ***Format***: The identifier `.fits` indicates that this file is in FITS format.

For example, an FOC data file named `x3l80101t_d0f.fits` is a FITS file belong to the dataset with rootname `x3l80101t`, and its suffix `d0f` indicates that it contains raw science data.

In order to use IRAF/STSDAS tasks to work with data from instruments other than NICMOS and STIS, you will want to convert these FITS files into GEIS format. See section 2.2 in the HST Introduction for instructions on how to convert FITS files to GEIS files using **strfits**. Like FITS files, the names of GEIS files also derive from a file's rootname and suffix, and they look like this:

```
ipppssoot.sfx
```

Generally the suffixes of GEIS files end either in "`d`", indicating a binary data file, or "`h`", indicating an ASCII header file. The two GEIS files `x3l80101t_d0h` and `x3l80101t_d0d` together contain the same information as the single FITS file `x3l80101t_d0f.fits`.

The identifier referred to here as a "suffix" has often been called an "extension" in the past. However, the individual pieces of FITS files are also known as "extensions" (see section 2.2.1 in the HST Introduction). For clarity, this handbook will use the term "extension" when refering to a component of a FITS file and the term "suffix" when referring to the three character identifier in a filename.

B.1 Rootnames

Rootnames of HST data files follow the naming convention defined in table B.1, which expands on the previous convention as follows: an initial "N" indicates a NICMOS exposure, an intial "O" indicates a STIS exposure, and the rootnames of files containing association products (see below) end in a number (0-8).

Table B.1: IPPPSSOOT Root File Names

Character	Meaning
I	Instrument used, will be one of: ***E*** - Engineering data ***F*** - Fine Guidance Sensors ***N*** - Near Infrared Camera and Multi-Object Spectrograph ***O*** - Space Telescope Imaging Spectrograph ***S*** - Engineering subset data ***T*** - Guide star position data ***U*** - Wide Field/Planetary Camera-2 ***V*** - High Speed Photometer ***W*** - Wide Field/Planetary Camera ***X*** - Faint Object Camera ***Y*** - Faint Object Spectrograph ***Z*** -Goddard High Resolution Spectrograph
PPP	Program ID; can be any combination of letters or numbers (46,656 combinations possible). There is a unique association between program ID and proposal ID.
SS	Observation set ID; any combination of letters or numbers (1,296 possible combinations).
OO	Observation ID; any combination of letters or numbers (1,296 possible combinations).
T	Source of transmission or association product number ***M*** - Merged real time and tape recorded ***N*** - Retransmitted merged real time and tape recorded ***O*** - Retransmitted real time (letter 'O') ***P*** - Retransmitted tape recorded ***R*** - Real time (not recorded) ***T*** - Tape recorded ***0*** - Primary association product (number zero) ***1-8*** - NICMOS background association product

B.2 Suffixes of Files Common to all Instruments

The three-character suffix of a data file (e.g., `d0h`) identifies the type of data that a file contains. Because the meanings of these suffixes change from instrument to instrument, please refer to the appropriate instrument-specific Data Structures chapter for their definitions. Several types of file suffixes are, however, common to all instruments.

OMS Files

Observatory Monitoring System (OMS) files, having suffixes `cm*` or `ji*`, contain Observation Logs describing how the HST spacecraft behaved during a given observation. OMS headers, which you can read with the IRAF task **imheader** (see section 2.3.3 in the HST Introduction), are divided into groups of keywords that deal with particular topics such as SPACECRAFT DATA, BACKGROUND LIGHT, POINTING CONTROL DATA, and LINE OF SIGHT JITTER SUMMARY. The headers themselves provide short descriptions of each keyword.OMS tables and images record spacecraft pointing information as a function of time. For more information on OMS files, you can consult Appendix C or the STScI Observation Logs WWW pages at:

`http://www.stsci.edu/ftp/instrument_news/Observatory/obslog/OL_1.html`

PDQ Files

The suffix `pdq` denotes Post Observation Summary and Data Quality Comment files—*PDQ files*—which contain predicted as well as actual observation parameters extracted from the standard header and science headers. These files may also contain comments on any obvious features in the spectrum or image, as noted in the OPUS data assessment, or automatically extracted information about problems or oddities encountered during the observation or data processing. These comments may include correction to the keywords automatically placed in the OMS files.

OCX Files

The suffix `ocx` denotes Observer Comment Files—*OCX files*—which are produced by STScI personnel to document the results of real-time commanding or monitoring of the observation, along with keywords and comments. Prior to April 17, 1992, OCX files were not always archived separately and, in some cases, were prepended to the trailer file.

After early February 1995, OCX files were produced only when an observation was used to locate the target for an Interactive Target Acquisition. At this time, mission and spacecraft information were moved to the PDQ reports and the Observation Logs (OMS jitter image and jitter table).

Trailer Files

Trailer files (suffix `trl`) are FITS ASCII tables that log the processing of your data by the OPUS pipeline.

Note that trailer files are formatted with 132 columns

B.3 Associations

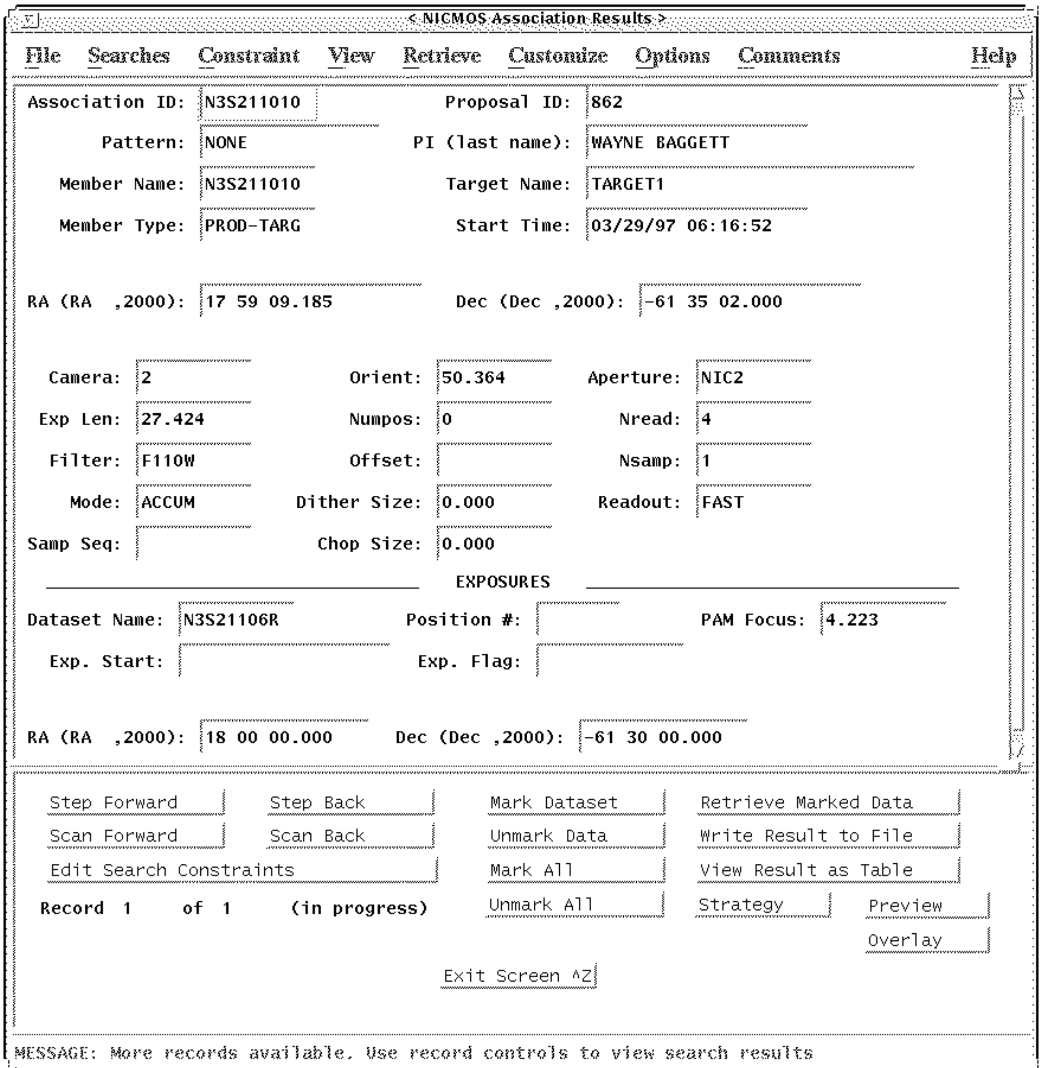
The STIS and NICMOS calibration pipelines sometimes produce single calibrated images from *associations* of many exposures. These associations allow HST pipeline processing to proceed further than it has in the past. For example, a NICMOS observer might specify a dithering pattern in a Phase II proposal. NICMOS would then take several exposures at offset positions, and the pipeline would combine them into a single mosaic. In this case, the original set of exposures constitutes the association, and the mosaic is the *association product*. Similarly, a STIS observer might specify a CR-SPLIT sequence in a Phase II proposal. STIS would gather several exposures at the same pointing, and the STIS pipeline would process this association of exposures into single image, free of cosmic rays, that would be the association product.

When you search the Archive with StarView for observations involving associations of exposures, your search will identify the final association product. The rootnames of association products always end in zero (see figure B.1 above.) If you request both Calibrated and Uncalibrated data from the Archive, you will receive both the association product and the exposures that went into making it. The corresponding association table, located in the file with suffix `asn` and the same rootname as the association product, lists the exposures belonging to the association. You can read this file using the STSDAS **tprint** or **tread** tasks (see table 3.1 in the HST Introduction). The exposure IDs in the association table share the same `ipppss` sequence as the association rootname, followed by a base 36 number `nn` (`n` = 0-9,A-Z) that uniquely identifies each exposure, and a character `t` that denotes the data transmission mode (see figure B.1).

In practice, STIS and NICMOS store the exposures belonging to associations differently. The exposures belonging to a STIS association all reside in the same file, while the exposures belonging to a NICMOS association reside in separate datasets. See the relevant Data Structures chapters for more details.

Information on the exposures belonging to an association is also available through StarView (see chapter 1 of the HST Introduction). From the <Welcome> Screen, click on **[HST Instrument Searches]** to get the <HST Instruments> screen, and then click on the **[Associations]** button for the instrument of interest. You can then search for the various exposures belonging to an association by entering the rootname of the association in the Association ID field and clicking on **[Begin Search]** . An Association Results Screen will display the results of the search, which you can step though using the **[Step Forward]** button. Figure B.1 below gives an example of a NICMOS Association Results Screen. Note the differences between the association rootname and coordinates and those of the individual exposure.

Figure B.1:Association Results Screen from StarView



APPENDIX C:

Observation Logs

In this appendix . . .

This Appendix describes the *Observation Log Files,* also known as OMS or *jitter* files. These files record pointing, jitter, and other Pointing Control System (PCS) data taken during an HST observation. You can use them to assess the behavior of the HST spacecraft during your observation, and in particular, to evaluate the jitter of the spacecraft while it was taking data. Here we describe the contents and structure of the observation log files, how to retrieve them from the Archive, and how to work with the data they contain.

C.1 Observation Log Files

Observation log files associated with each HST dataset contain pointing and specialized engineering data taken during the observation. These data files are produced by the Observatory Monitoring System (OMS), an automated software system that interrogates the HST engineering telemetry and correlates the time-tagged engineering stream with HST's Science Mission Schedule (SMS), the seven-day command and event list that drives all spacecraft activities. This system reports the status of the instruments and observatory and flags discrepancies between planned and executed actions. OMS provides observers with information about guide star acquisition, pointing, and tracking that is not normally provided in the science headers.

The observation log files share the same rootname as the observation they are associated with, except for the final character, which for observation log files is always a "`j`" (see appendix B for more on the names of HST data files). When OMS was installed in October 1994, it initially generated files with the suffixes `cmh`, `cmj`, `cmi`, which contained header information, high time resolution pointing data, and three-second average pointing data, respectively (see table C.1). OMS observation logs changed to the `jih/jid/jif` image format after August 1995, at which time the `cmi` table was renamed `jit` to keep the naming convention consistent. In the OMS version of August 1995, `cmj` tables were replaced with a jitter image, which is a two-dimensional histogram of jitter excursions during the observation. The suffixes of the GEIS jitter image are `jih` for the header and `jid` for the image data. The `jit` table accompanies the jitter image. The header file of the image replaces the `cmh` file but includes the same information with the addition of some image-related keywords.

A detailed description of the observation log files can be found on-line: http://www.stsci.edu/instruments/observatory/obslog/OL_1.html.

Table C.1: OMS Observation Log Files

Suffix	Contents
October 1994 to August 1995	
`cmh`	OMS header
`cmj`	High time resolution (IRAF table)
`cmi`	Three-second averages (IRAF table)
`_cmh.fits`	Archived FITS file of `cmh`
`_cmj.fits`	Archived FITS file of `cmj`
`_cmi.fits`	Archived FITS file of `cmi`
August 1995 to February 1997	
`jih/jid`	Two-dimensional histogram and header (GEIS)
`jit`	Three-second averages (IRAF table)[1]
`_jif.fits`	Archived FITS file which bundles the `jih/jid` files.
`_jit.fits`	Archived FITS file of `jit`.
February 1997 onward	
`_jif.fits`	Two-dimensional histogram (FITS)
`_jit.fits`	Three-second averages table (FITS)

1. After May 11, 1995, the `jit` tables for exposures shorter than 6 seconds contain higher-resolution, one-second average pointing data.

Pointing and tracking information prior to October 1994 is not routinely available. Interested observers with data from this epoch, can send E-mail to help@stsci.edu.

C.1.1 Observation Log File Contents (October 1994 version)

Observation logs created between October 1994 and August 1995 contain:

- *rootname*`j.cmh`: This ASCII header file contains the time interval, the rootname, averages of the pointing and spacecraft jitter, the guiding mode, guide star information, and alert or failure keywords. Figure C.1 shows a representative observation log header file.
- *rootname*`j.cmj`: This table presents the data at the highest time resolution for the telemetry mode in use. It contains the reconstructed pointing, guide star coordinates, derived jitter at the instrument aperture, and guiding-related flags. The intent is: (1) to provide high-time resolution jitter data for deconvolution or for assessing small aperture pointing stability, and (2) to display the slew and tracking anomaly flags with the highest resolution. Table C.2 lists the table column heading, units and a brief definition.
- *rootname*`j.cmi`: This table contains data that were averaged over three-second intervals. It includes the same information as the `.cmj` table and also includes orbital data (e.g., latitude, longitude, limb angle, magnetic field values, etc.) and instrument-specific items. It is best suited for a quick-look assessment of pointing stability and for studying trends in telescope or instrument performance with orbital environment. Table C.3 lists the table column heading, units and a brief definition.
- rootnamej_cmi`/j/h.fits`: The above three GEIS files are actually archived as FITS files. They may be worked with as such, or run through the STSDAS task **strfits**, to convert them.
- Observation Log File Contents (August 1995 version)
- The contents of observation log files created between August 1995 and February 1997 are as follows:

- *rootname*`j.jih`: This GEIS header file, the analog to the `cmh` file, contains the time interval, the rootname, averages of the pointing and spacecraft jitter, the guiding mode, guide star information, and alert or failure keywords. Figure C.1 shows a representative observation log header file.
- *rootname*`j.jid`: This GEIS image—a significant enhancement of the old `cmj` file—presents a two-dimensional histogram of the pointing fluctuations during the observation. You can display it to visualize the spacecraft stability during you observation, and is information for deconvolutions and PSF analyses.
- *rootname*`j.jit`: This table, the analog to the `cmi` table, contains data that were averaged over three-second intervals. Its content is identical (see table C.3).
- *rootname*`j_jif.fits`: FITS file that is actually the de-archived product. This file can be converted to the `jih/jid` GEIS file via the **strftis** routine.
- *rootname*`j_jit.fits`: The de-archived FITS file corresponding to the `jit` IRAF table. It can be converted via **strfits**.

C.1.2 Observation Log File Contents (February 1997 version)

The contents of observation log files created since February 1997 are as follows:

- *rootname*`j_jif.fits`: The de-archived FITS file. Unlike the previous OMS epoch, this FITS file does not bundle a GEIS file and cannot be converted with **strfits**. This was done to more closely correlate the observation log files with the STIS and NICMOS FITS files with extensions and associations. OMS will normally put all associated observation logs into a single file, to correspond to the associated science exposures. However, if even one science exposure is orphaned (not associated) then an individual observation log FITS file will be produced for every exposure in that association. For a description of STIS and NICMOS association files, see appendix B. All of the information contained in the old `cmh/jih` ASCII header is now available as keywords in the FITS files.
- *rootname*`j_jit.fits`: The FITS file containing the table information. The comments for the `_jif` file apply here as well.

Table C.2: Contents of .cmj Table

Parameter	Units	Description
seconds	seconds	Time since window start
V2 dom	arcseconds	Dominant FGS V2 coordinate
V3 dom	arcseconds	Dominant FGS V3 coordinate
V2 roll	arcseconds	Roll FGS V2 coordinate
V3 roll	arcseconds	Roll FGS V3 coordinate
SI V2	arcseconds	Jitter at aperture reference
SI V3	arcseconds	Jitter at aperture reference
RA	degrees	Right ascension of aperture reference
DEC	degrees	Declination of aperture reference
Roll	degrees	Angle between North and +V3
DayNight	0,1 flag	Day (0) or night (1)
Recenter	0,1 flag	Recentering status
TakeData	0,1 flag	Vehicle guiding status
SlewFlag	0,1 flag	Vehicle slewing status

Figure C.1:A Representative .jih or .cmh Header

```
dSIMPLE  =                    F / data conforms to FITS standard              !
BITPIX   =                   32 / bits per data value                        !
DATATYPE= 'INTEGER*4          ' / datatype of the group array                !
NAXIS    =                    2 / number of data axes                        !
NAXIS1   =                   64 / length of the 1st data axis                !
NAXIS2   =                   64 / length of the 2nd data axis                !
GROUPS   =                    T / image is in group format                   !
GCOUNT   =                    1 / number of groups                           !
PCOUNT   =                    0 / number of parameters                       !
PSIZE    =                    0 / bits in the parameter block                !
OMS_VER = '16.2C              ' / OMS version used to process this observation
PROCTIME= '1994.133:06:24:18.35' / date-time OMS processed observation
                                / date-times format (yyyy.ddd:hh:mm:ss.ss)

                                / IMAGE PARAMETERS
CRVAL1   =                  0.0 / right ascension of zero-jitter pixel (deg)
CRVAL2   =                  0.0 / declination of zero-jitter pixel (deg)
CRPIX1   =                   32 / x-coordinate of zero-jitter pixel
CRPIX2   =                   32 / y-coordinate of zero-jitter pixel
CTYPE1   = 'RA---TAN          ' / first coordinate type
CTYPE2   = 'DEC--TAN          ' / second coordinate type
CD1_1    =                  0.0 / partial of ra w.r.t. x (deg/pixel)
CD1_2    =                  0.0 / partial of ra w.r.t. y (deg/pixel)
CD2_1    =                  0.0 / partial of dec w.r.t. x (deg/pixel)
CD2_2    =                  0.0 / partial of dec w.r.t. y (deg/pixel)
COORDSYS= 'WFPC2              ' / image coordinate system
XPIXINC =                   2.0 / plate scale along x (mas per pixel)
YPIXINC =                   2.0 / plate scale along y (mas per pixel)
PARITY  =                    -1 / parity between V2V3 frame and image frame
BETA1   =                134.72 / angle from +V3 to image +x (toward +V2)
BETA2   =                224.72 / angle from +V3 to image +y (toward +V2)

                                / OBSERVATION DATA
PROPOSID=                 05233 / PEP proposal identifier
PROGRMID= '288                ' / program id (base 36)
OBSET_ID= '02                 ' / observation set id
OBSERVTN= '03                 ' / observation number (base 36)
TARGNAME= 'NGC3379-PO         ' / proposer's target name
STARTIME= '1994.133:06:24:18.35' / predicted observation window start time
ENDTIME = '1994.133:06:39:18.35' / predicted observation window end time
SOGSID  = 'U2880203           ' / SOGS observation name                      !

                                / SCIENTIFIC INSTRUMENT DATA
CONFIG  = 'WFPC2              ' / proposed instrument configuration
PRIMARY = 'SINGLE             ' / single, parallel-primary, parallel-secondary
OPERATE = '1994.133:06:22:46.91' / predicted time instr. entered operate mode
TLMFORM = 'PN                 ' / telemetry format
APERTURE= 'UWFALL             ' / aperture name
APER_V2 =                 1.565 / V2 aperture position in vehicle frame (arcsec)
APER_V3 =                 7.534 / V3 aperture position in vehicle frame (arcsec)

                                / SPACECRAFT DATA
ALTITUDE=                593.23 / average altitude during observation (km)
LOS_SUN =                106.08 / minimum line of sight to Sun (deg)
LOS_MOON=                 77.11 / minimum line of sight to Moon (deg)
SHADOENT= '1994.133:05:11:29.00' / predicted Earth shadow last entry
SHADOEXT= '1994.133:05:42:45.00' / predicted Earth shadow last exit
LOS_SCV =                 12.46 / minimum line of sight to S/C veloc. (deg)
LOS_LIMB=                  58.0 / average line of sight to Earth limb (deg)


                                / BACKGROUND LIGHT
ZODMOD  =                  22.3 / zodiacal light - model (V mag/arcsec2)
EARTHMOD=                  20.2 / peak Earth stray light - model (V mag/arcsec2)
MOONMOD =                  35.5 / moon stray light - model (V mag/arcsec2)
GALACTIC=                  -1.0 / diffuse galactic light - model (V mag/arcsec2)

                                / POINTING CONTROL DATA
GUIDECMD= 'FINE LOCK          ' / commanded guiding mode
GUIDEACT= 'FINE LOCK          ' / actual guiding mode at end of GS acquisition
GSD_ID  = '0084900235         ' / dominant guide star id
GSD_RA  =             161.70720 / dominant guide star RA (deg)
GSD_DEC =              12.45407 / dominant guide star DEC (deg)
```

Figure C.2:Representative .jih or .cmh Header

```
GSD_MAG =               12.867 / dominant guide star magnitude
GSR_ID  = '0085201189        ' / roll guide star id
GSR_RA  =            161.93314 / roll guide star RA (deg)
GSR_DEC =             12.78141 / roll guide star DEC (deg)
GSR_MAG =               12.977 / roll guide star magnitude
GSACQ   = '1994.133:06:31:02.92' / actual time of GS acquisition completion
PREDGSEP=             1420.775 / predicted guide star separation (arcsec)
ACTGSSEP=             1421.135 / actual guide star separation (arcsec)
GSSEPRMS=                  3.8 / RMS of guide star separation (milli-arcsec)
NLOSSES =                    0 / number of loss of lock events
LOCKLOSS=                  0.0 / total loss of lock time (sec)
NRECENT =                    0 / number of recentering events
RECENTR =                  0.0 / total recentering time (sec)

                               / LINE OF SIGHT JITTER SUMMARY
V2_RMS  =                  4.5 / V2 axis RMS (milli-arcsec)
V2_P2P  =                 51.6 / V2 axis peak to peak (milli-arcsec)
V3_RMS  =                 20.9 / V3 axis RMS (milli-arcsec)
V3_P2P  =                267.3 / V3 axis peak to peak (milli-arcsec)
RA_AVG  =            161.85226 / average RA (deg)
DEC_AVG =             12.58265 / average dec (deg)
ROLL_AVG=            293.01558 / average roll (deg)

                               / PROBLEM FLAGS, WARNINGS and STATUS MESSAGES
                               / (present only if problem exists)
ACQ2FAIL= '                 T' / target acquisition failure
GSFAIL  = 'DEGRADED          ' / guide star acquisition failure  (*1)
TAPEDROP= '                 T' / possible loss of science data
TLM_PROB= '                  ' / problem with the engineering telemetry
TM_GAP  =               404.60 / duration of missing telemetry (sec)
SLEWING = '                 T' / slewing occurred during this observation
TAKEDATA= '                 F' / take data flag NOT on throughout observation
SIPROBnn= '                  ' / problem with specified science instrument (*2)

END
-----------------------------------------------------------------------------

notes
*1 - GSFAIL appears only once in a single header file.
     The following table lists all current possible values for the GSFAIL
     keyword:
     -----------------------------------------------------------------
     GSFAIL    |DEGRADED          |  / guide star acquisition failure
               |IN PROGR          |  / guide star acquisition failure
               |SSLEXP            |  / guide star acquisition failure
               |SSLEXS            |  / guide star acquisition failure
               |NOLOCK            |  / guide star acquisition failure
               |                  |
               |SREXCS?           |  / guide star acquisition failure
               |SREXCS1           |  / guide star acquisition failure
               |SREXCS2           |  / guide star acquisition failure
               |SREXCS3           |  / guide star acquisition failure
               |                  |
               |SREXCP?           |  / guide star acquisition failure
               |SREXCP1           |  / guide star acquisition failure
               |SREXCP2           |  / guide star acquisition failure
               |SREXCP3           |  / guide star acquisition failure
               |                  |
               |UNKNOWN           |  / guide star acquisition failure
               |VEHSAFE           |  / guide star acquisition failure
     -----------------------------------------------------------------

*2 - The SIPROBnn keywords appear in the header file with nn = 01 - 99.
     The following table lists all current possible values for the SIPROBnn
     keyword:
     -------------------------------------------------------------------------
     SIPROBnn  |DCF_NUM unchanged|  / This observation may not have been taken
               |FOS Safing!       |  / This observation affected when FOS Safed!
               |HRS Safing!       |  / This observation affected when HRS Safed!
               |WFII Safing!      |  / This observation affected when WFII Safed!
               |FOC Safing!       |  / This observation affected when FOC Safed!
               |Shut              |  / FOS aperture door is not Open!
               |FAILED            |  / FGS astrometry target acquisition failed
     -------------------------------------------------------------------------
```

Table C.3: Contents of .jit or.cmiTable, Three-Second Averaging

Parameter	Units	Description
seconds	seconds	Time since window start
V2 dom	arcseconds	Dominant FGS V2 coordinate
V3 dom	arcseconds	Dominant FGS V3 coordinate
V2 roll	arcseconds	Roll FGS V2 coordinate
V3 roll	arcseconds	Roll FGS V3 coordinate
SI V2 AVG	arcseconds	Mean jitter in 3 seconds
SI V2 RMS	arcseconds	rms jitter in 3 seconds
SI V2 P2P	arcseconds	Peak jitter in 3 seconds
SI V3 AVG	arcseconds	Mean jitter in 3 seconds
SI V3 RMS	arcseconds	rms jitter in 3 seconds
SI V3 P2P	arcseconds	Peak jitter in 3 seconds
RA	degrees	Right ascension of aperture reference
DEC	degrees	Declination of aperture reference
Roll	degrees	Angle between North and +V3
LimbAng	degrees	Angle between earth limb and target
TermAng	degrees	Angle between terminator and target
LOS_Zenith	degrees	Angle between HST zenith and target
Latitude	degrees	HST subpoint latitude
Longitude	degrees	HST subpoint longitude
Mag V1,V2,V3	degrees	Magnetic field along V1, V2, V3
EarthMod	V Mag/arcsec^2	Model earth background light
SI_Specific	–	Special science instrument data
DayNight	0,1 flag	Day (0) or night (1)
Recenter	0,1 flag	Recentering status
TakeData	0,1 flag	Vehicle guiding status
SlewFlag	0,1 flag	Vehicle slewing status

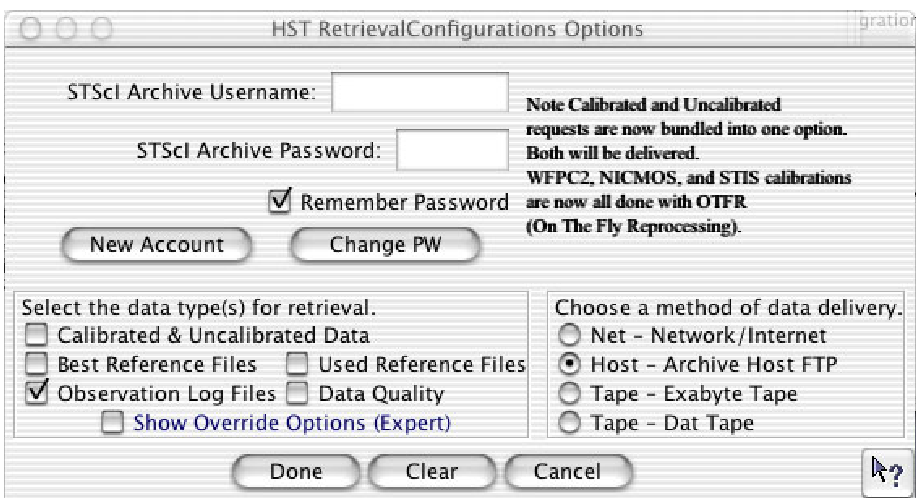
C.2 Retrieving Observation Logs

You can retrieve observation log files for data taken after October 20, 1994 from the HST Archive using StarView as described in chapter 1 of the HST Introduction. Unlike science data, which generally has a one-year proprietary period, observation log files become public as soon as they are archived.

The easiest way to get OMS files through StarView is to identify the observation of interest and proceed with your request as described in chapter 1 of the HST Introduction, until you reach the "HST Retrieval Configurations Options" screen, reproduced in figure C.3. You can then check the Observation Log Files box, along with any other desired boxes, and continue with your request. StarView will then deliver the associated observation log files.

For observations logged between October 1994 to August 1995, you will be delivered the `cmi`, `cmj`, and `cmh` files in FITS form (e.g., `_cmi.fits`). Observations archived from August 1995 to February 1997 will return `_jif.fits` and `_jit.fits` files. These, and the earlier FITS files can be worked with as such, or converted to their GEIS counterparts via the STSDAS **strfits** task. However, as of February 1997, the `_jif.fits` and `_jit.fits` files are standard FITS files with extensions and cannot be converted to GEIS.

Figure C.3:Choosing Observation Log Files in StarView



C.3 Using Observation Logs

Here are some simple examples of what can be learned from the observation log files. Note that for FITS format observation logs, current versions of STSDAS tools will handle the files with extensions properly. Keywords can be viewed with tools such as **imheader** or **hedit**, and data viewed, plotted, or displayed using the same tasks one might have for the GEIS files. For more information on FITS file structures, see chapter 2 of the HST Introduction.

C.3.1 Guiding Mode

Unless requested, all observations will be scheduled with FINE LOCK guiding, which may be one or two guide stars (dominant and roll). The spacecraft may roll slightly during an observation if only one guide star is acquired. The amount of roll depends upon the gyro drift at the time of the observation, the location during an orbit, and the lever arm from the guide star to the center of the aperture.

There are three commanded guiding modes: FINE LOCK, FINE LOCK/GYRO, and GYRO. OMS header keywords GUIDECMD (commanded guiding mode) and GUIDEACT (actual guiding mode) will usually agree. If there was a problem, they won't agree and the GUIDEACT value will be the guiding method actually used during the exposure. If the acquisition of the second guide star fails, the spacecraft guidance, GUIDEACT, may drop from FINE LOCK to FINE LOCK/GYRO, or even to GYRO, which may result in a target rolling out of an aperture. Check the OMS header keywords to verify that there was no change in the requested guiding mode during the observation.

Until new flight software (version FSW 9.6) came online in September 1995, if the guide star acquisition failed, the guiding dropped to COARSE track. After September 1995, if the guide star acquisition failed, the tracking did not drop to COARSE track. Archival researchers may find older datasets that were obtained with COARSE track guiding.

The dominant and roll guide star keywords (GSD and GSR) in the OMS header can be checked to verify that two guide stars were used for guiding, or in the case of an acquisition failure, to identify the suspect guide star. The dominant and roll guide star keywords identify the stars that were scheduled to be used, and in the event of an acquisition failure, may not be the stars that were actually used. The following list of `cmh` keywords is an example of two star guiding.

```
GSD_ID  = '0853601369        ' / Dominant Guide Star ID
GSD_RA  =            102.42595 / Dominant Guide Star RA (deg)
GSD_DEC =            -53.41362 / Dominant Guide Star DEC (deg)
GSD_MAG =               11.251 / Dominant Guide Star Magnitude
GSR_ID  = '0853602072        ' / Roll Guide Star ID
GSR_RA  =            102.10903 / Roll Guide Star RA (deg)
GSR_DEC =            -53.77683 / Roll Guide Star DEC (deg)
GSR_MAG =               12.426 / Roll Guide Star Magnitude
```

If you suspect that a target has rolled out of the aperture during an exposure, you can quickly check the counts in each group of the raw science data. As an example, the following IRAF commands can be used to determine the counts in each group.

```
cl> grlist z2o4040dt.d0h 1-24 > groups.lis
cl> imstat @groups.lis
```

Some observations can span several orbits. If during a multiple orbit observation the guide star reacquisition fails, the observation may be terminated with possible loss of observing time, or switch to other less desirable guiding modes. The GSACQ keyword in the `cmh` header will state the time of the last successful guide star acquisition.

```
GSACQ   = '136:14:10:37.43   ' / Actual time of GS Acquisition Completion
```

C.3.2 Guide Star Acquisition Failure

The guide star acquisition at the start of the observation set could fail if the FGS fails to lock onto the guide star. The target may not be in the aperture, or maybe only a piece of an extended target is in the aperture. The jitter values will be increased because FINE LOCK was not used. The following list of `cmh` header keywords indicate that the guide star acquisition failed.

```
V3_RMS =                    19.3 / V3 Axis RMS (milli-arcsec)
V3_P2P =                   135.7 / V3 Axis peak to peak (milli-arcsec)
GSFAIL = '            DEGRADED' / Guide star acquisition failure!
```

The observation logs for all of the following observations in the observation set will have the "DEGRADED" guide star message. This is not a Loss of Lock situation but an actual failure to acquire the guide star in the desired guiding mode. For the example above, the guiding mode dropped from FINE LOCK to COARSE TRACK.

```
GUIDECMD= 'FINE LOCK         ' / Commanded Guiding mode
GUIDEACT= 'COARSE TRACK      ' / Actual Guiding mode at end of GS acquisition
```

If the observational dataset spans multiple orbits, the guide star will be re-acquired, but the guiding mode will not change from COARSE TRACK. In September 1995, the flight software was changed so that COARSE TRACK is no longer an option. The guiding mode drops from two guide star FINE LOCK to one guide star FINE LOCK , or to GYRO control.

C.3.3 Moving Targets and Spatial Scans

A type 51 slew is used to track moving targets (planets, satellites, asteroids, and comets). Observations are scheduled with FINE LOCK acquisition, i.e., with two or one guide stars. Usually, a guide star pair will stay within the pickle during the entire observation set, but if two guide stars are not available, a single guide star may be used, assuming the drift is small or the proposer says that the roll is not important for that particular observing program. An option during scheduling is to drop from FGS control to GYRO control when the guide stars move out of the FGS. Also, guide star handoffs (which are not a simple dropping of the guide stars to GYRO control) will affect the guiding and may be noticeable when the jitter ball is plotted.

The jitter statistics are accumulated at the start of the observation window. Moving targets and spatial scan motion will be seen in the jitter data and image. Therefore, the OMS header keywords V2_RMS and V3_RMS values (the root mean square of the jitter about the V2 and V3 axis) can be quite large for moving targets. Also, a special anomaly keyword (SLEWING) will be appended to the OMS header stating movement of the telescope during the observation. This is expected for observing moving targets. The following list of .cmh header keywords is an example of expected values while tracking a moving target.

```
                     / LINE OF SIGHT JITTER SUMMARY
V2_RMS  =        3.2 / V2 Axis RMS (milli-arcsec)
V2_P2P  =       17.3 / V2 Axis peak to peak (milli-arcsec)
V3_RMS  =       14.3 / V3 Axis RMS (milli-arcsec)
V3_P2P  =       53.6 / V3 Axis peak to peak (milli-arcsec)
RA_AVG  =  244.01757 / Average RA (deg)
DEC_AVG =  -20.63654 / Average DEC (deg)
ROLL_AVG=  280.52591 / Average Roll (deg)
SLEWING = '       T' / Slewing occurred during this observation
```

C.3.4 High Jitter

The spacecraft may shake during an observation, even though the guiding mode is FINE LOCK. This movement may be due to a micro-meteorite hit, jitter at a day-night transition, or for some other unknown reasons. The FGS is quite stable and will track a guide star even during substantial spacecraft motion. The target may move about in an aperture, but the FGS will continue to track guide stars and reposition the target into the aperture. For most observations, the movement about the aperture during a spacecraft excursion will be quite small, but sometimes, especially for observations with the spectrographs, the aperture may move enough that the measured flux for the target will be less than a previous group. Check the OMS header keywords (V2_RMS, V3_RMS) for the root mean square of the jitter about the V2 and V3 axis. The following list of .cmh header keywords is an example of typical guiding rms values.

```
                                / LINE OF SIGHT JITTER SUMMARY
V2_RMS  =                   2.6 / V2 Axis RMS (milli-arcsec)
V2_P2P  =                  23.8 / V2 Axis peak to peak (milli-arcsec)
V3_RMS  =                   2.5 / V3 Axis RMS (milli-arcsec)
V3_P2P  =                  32.3 / V3 Axis peak to peak (milli-arcsec)
```

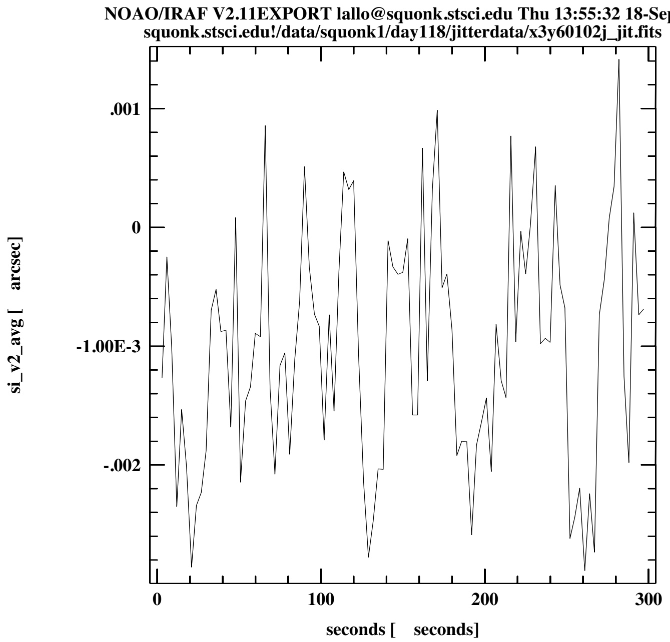
Recentering events occur when the spacecraft software decides that shaking is too severe to maintain lock. The FGS will release guide star control and within a few seconds reacquire the guide stars. It is assumed the guide stars are still within the FGS field of view. During the recentering time, INDEF will be written to the OMS table. Recentering events are tracked in the OMS header file.

Be careful when interpreting “Loss of Lock” and “Recentering” events that occur at the very beginning or at the end of the OMS window. The OMS window is larger than the observation window. These events might not affect the observation since the observation start time will occur after the guide stars are acquired (or re-acquired), and the observation stop time may occur before the “Loss of Lock” or “Recentering” event that occurred at the end of an OMS window.

The **sgraph** commend in the **stsdas.graphics.stplot** package will plot time vs. jitter along the direction of HST’s V2 axis (see figure C.4):

```
cl> sgraph "x3y60102j_jit.fits seconds si_v2_avg"
```

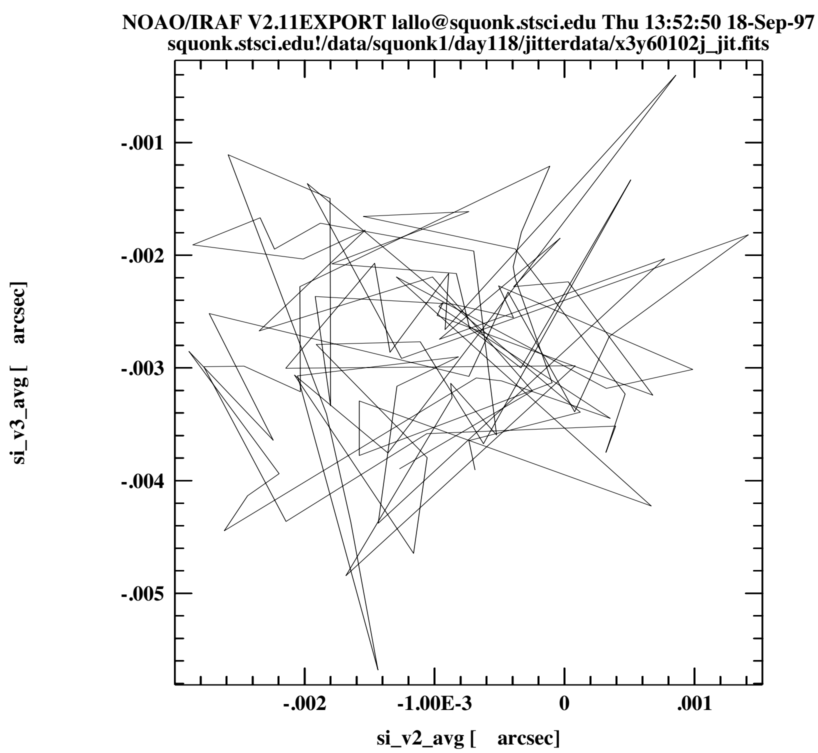
Figure C.4:Plotting Jitter Along V3 Axis



To get an idea of pointing stability, you can create a *jitter ball* by plotting jitter along the V2 axis vs. jitter along the V3 axis (see figure C.5):

```
st> sgraph "x3660102j_jit.fits si_v2_avg si_v3_avg"
```

Figure C.5:Plotting V2 vs. V3 Jitter



The **tstatistics** task can be used to find the mean value of the `si_v3_avg` column—the amount of jitter (in arcseconds) in the direction of the V3. This value can be used to model jitter in a PSF. In this example, the mean jitter is ~3 mas, which is typical for post-servicing mission data:

Figure C.6:Averaging a Column with tstatistics

```
tt> tstat u26m0801j.cmi si_v3_avg
# u26m0801j.cmi  si_v3_avg
#
nrows             mean       stddev      median         min        max
   11   -0.003006443888  0.00362533  -7.17163E-4  -0.00929515  0.00470988
```

Understanding and interpreting the meaning of the table columns and header keywords is critical to understanding the observation logs. Please read the available documentation and contact the STScI Help Desk (help@stsci.edu.) if you have any questions about the files. Documentation is available via the WWW at: http://www.stsci.edu/instruments/observatory/obslog/OL_1.html.

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