Introduction to Reducing HST Data

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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.

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Michael Corbin (Editor, Chapter 1)
Jin-chung Hsu (Editor, Chapters 2 and 3)

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 <u>before</u> their observations are made. GTO and GO observations normally remain proprietary for a period of one year, which means that during this period

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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 <u>public </u>(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
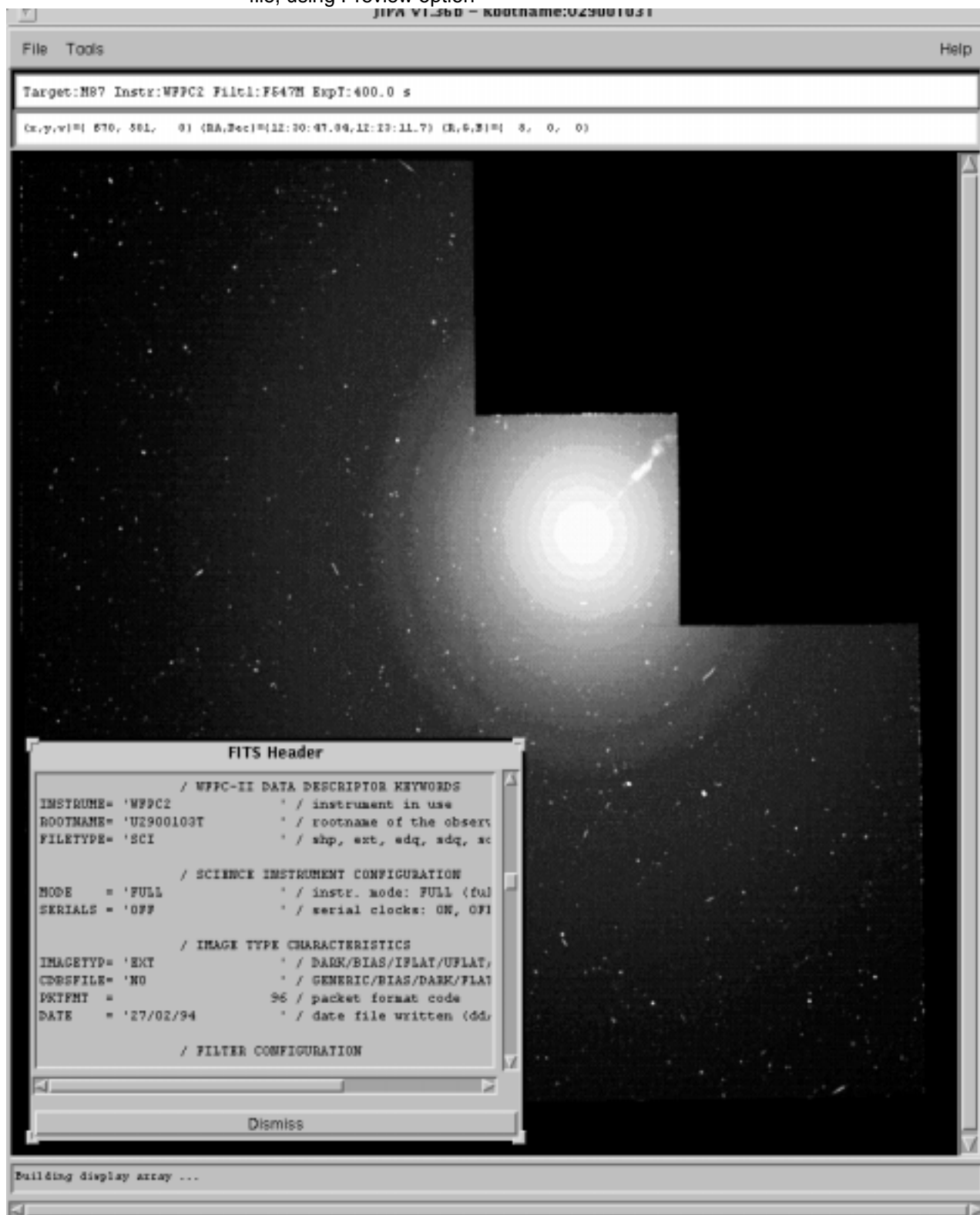
1.2.3 Marking and Retrieving Data with StarView

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.

StarView Cross Qualification

Query Results from

Mapped to Query in

Results for: Quick Search ▼

Results for: Quick Search [2] ▼

Available Fields

Selected Fields

View Fields as

Selected Fields

Available Fields

Dataset Name:
RA:
Dec :
Instrument:
Flag:
Apertures:
Central Wavelen
Proposal ID:
Release Date:
PI (last name):
Target Name:
Target Descriptic
Config:
Start Time:

Target Name:

Labels ▼

Target Name:

Dataset Name:
RA:
Dec :
Instrument:
Flag:
Apertures:
Central Wavelen
Proposal ID:
Release Date:
PI (last name):
Target Name:
Target Descriptic
Config:
Start Time:

X-Qualify

Cancel

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.

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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
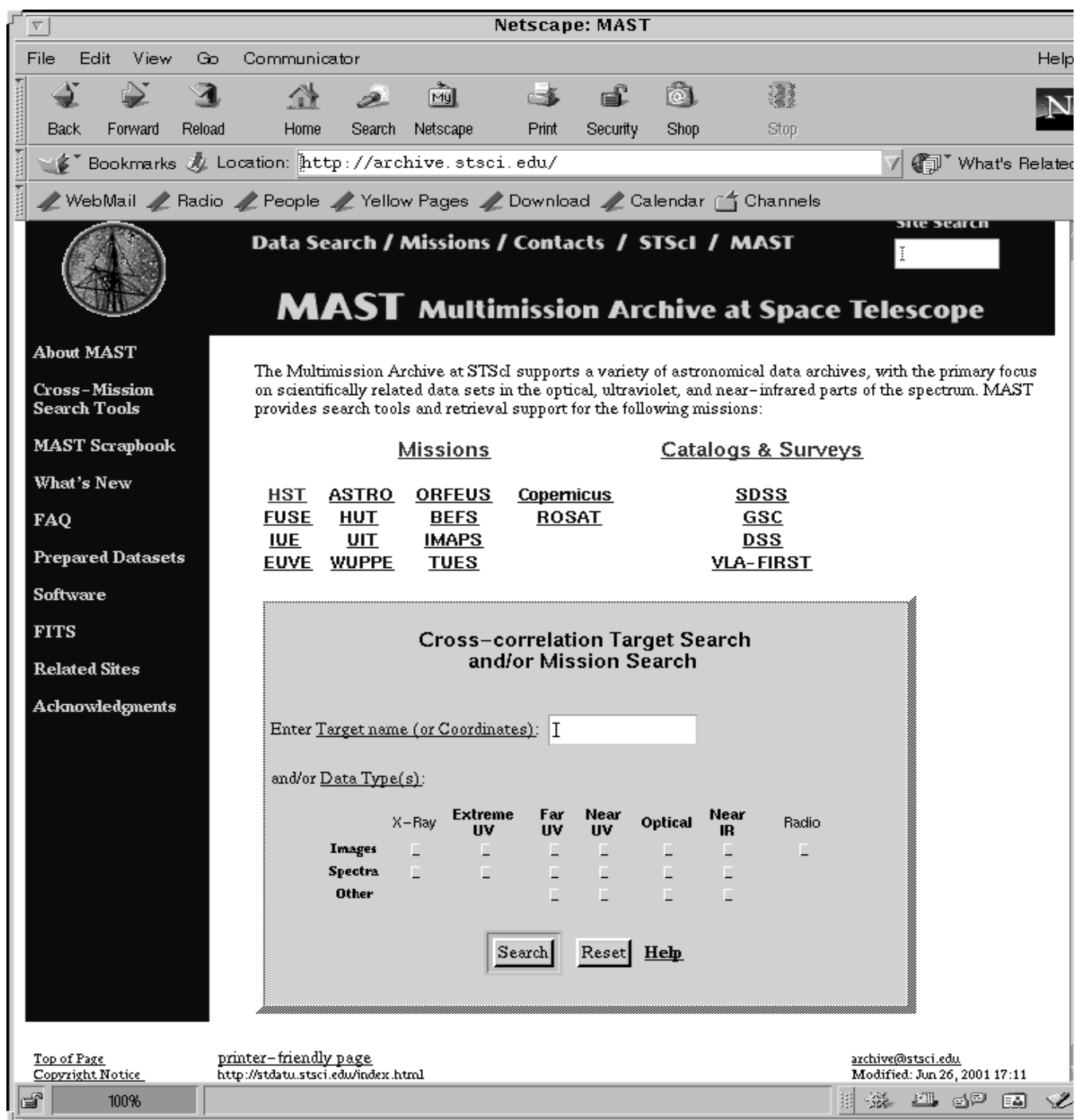
Figure 1.7: HST Archive Web search Form

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.

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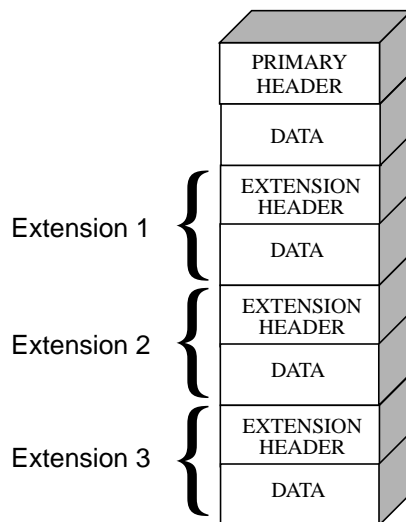
The three-letter identifier (e.g., d0h) that follows the rootname of an HST data file (see appendix B for more on HST file names) has often been called an "extension" in the past. However, because of the potential for confusion with FITS extensions, this handbook will refer to these three-letter identifiers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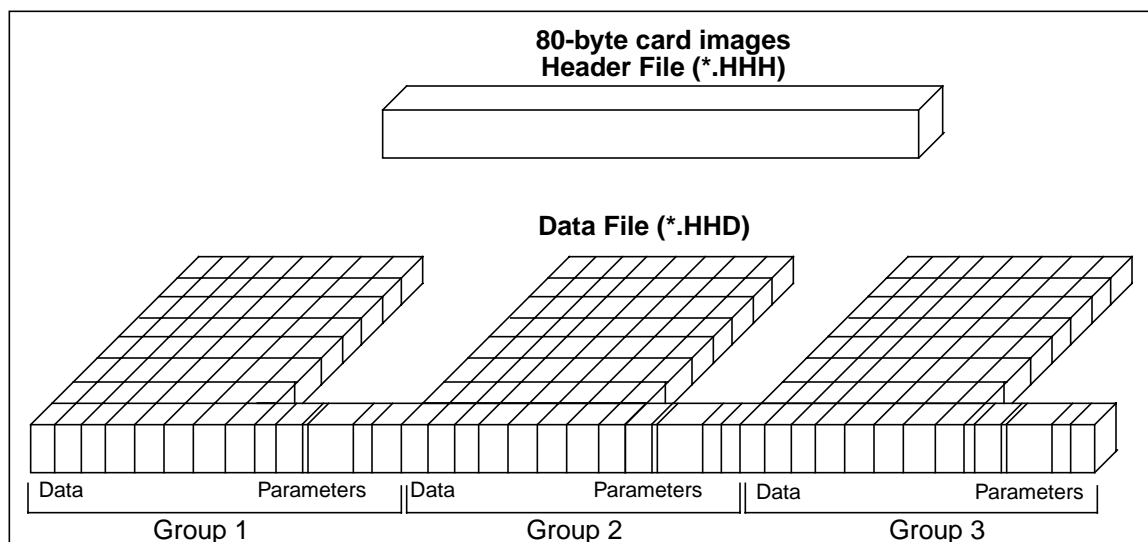
2.3.1 Converting FITS to GEIS

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.

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

■ - Implicitly Loaded
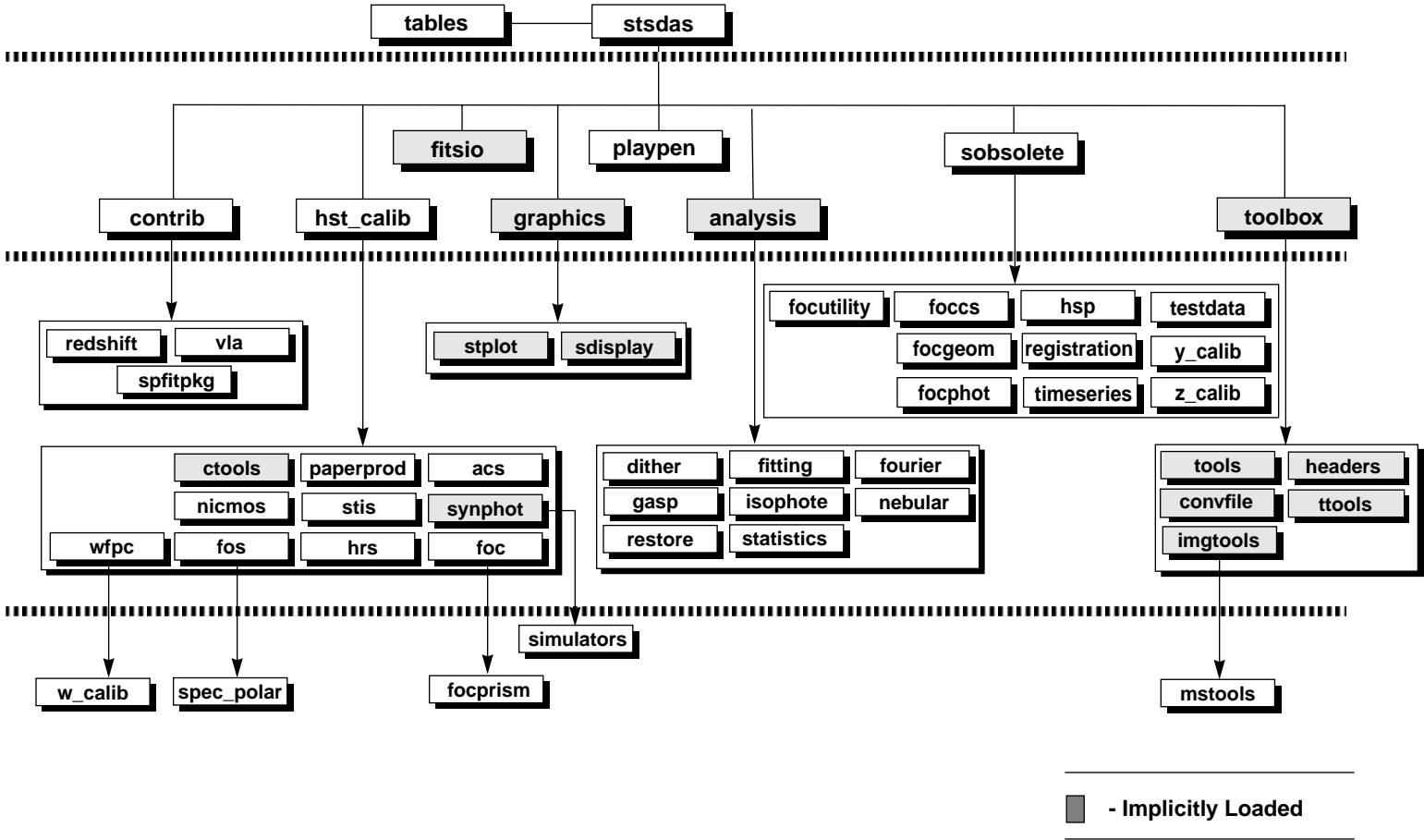
- **stsdas.toolbox.imgtools.mstools**: This package contains tools for working with FITS image extensions, in particular STIS and NIC-MOS image sets (imsets).

- **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

Run display task from IRAF window

z1 and z2 are image intensity range

Image appears in SAOimage window

To print hardcopy:

1 Click "etc"

2 Click "print"
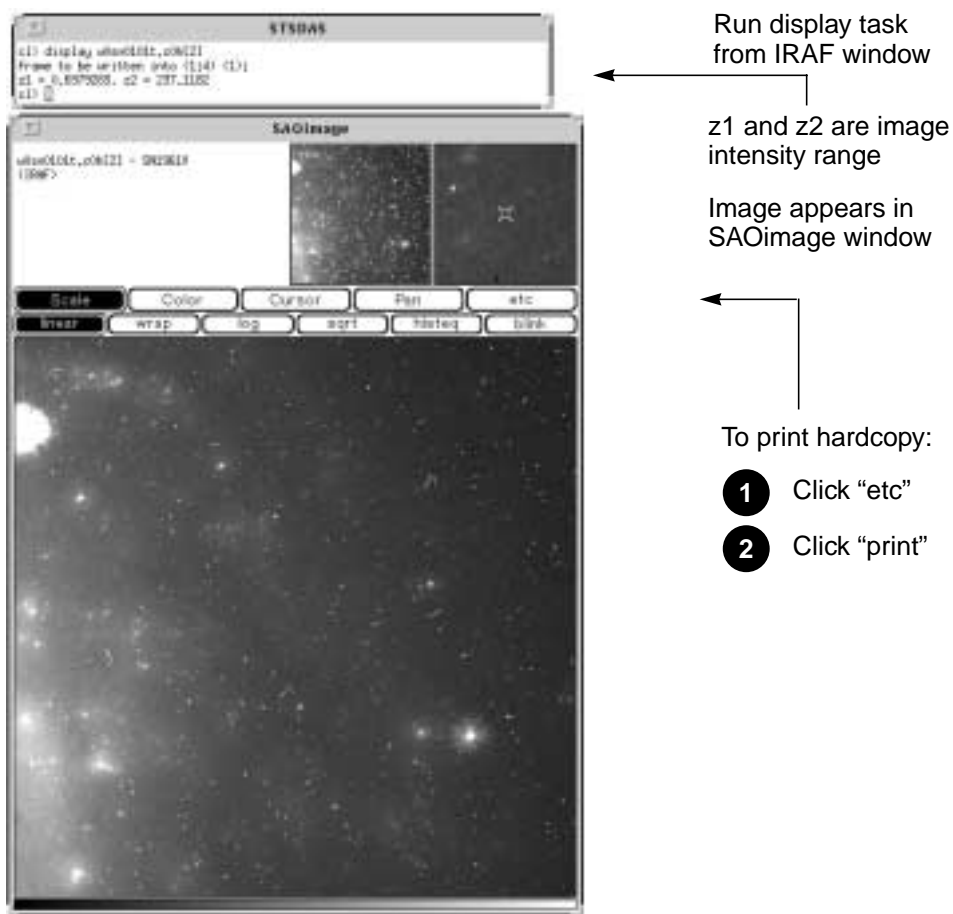
Modifying the Display

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
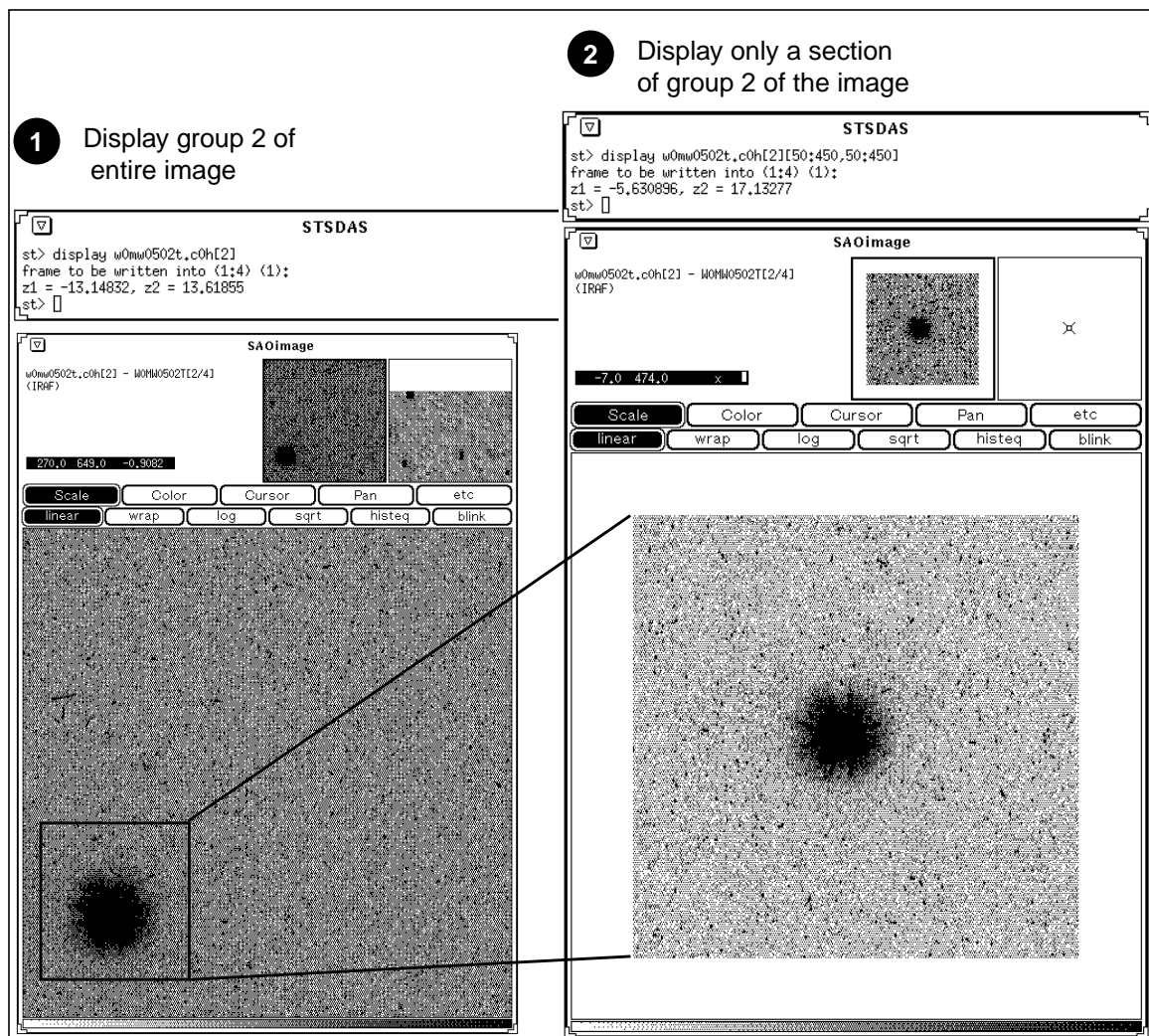
3.3 Analyzing HST Images

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


```
                              STSDAS
pl> ?
       calcomp     gkidir      imdkern    phistogram  sgidecode   surface
       contour     gkiextract  implot     pradprof    sgikern     velvect
       crtpict     gkimosaic   nsppkern   prow        showcap
       gdevices    graph       pcol       prows       stdgraph
       gkidecode   hafton      pcols      pvector     stdplot
pl> dir w*
w0mw0502t.c0d    w0mw0502t.c0h    w0mw0502t.d0h
pl> implot w0mw0502t.c0h 200
```

Plot line 200 of a
WF/PC-1 image

To Print This Plot:

1 Press `=`

2 Type **`::gflush`**
       to flush the
       buffer

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	$\sqrt{\sigma1^2 + \sigma2^2}$	OR	T1+T2	S1+S2
SUB	file	op1-op2	$\sqrt{\sigma1^2 + \sigma2^2}$	OR	T1	S1
MULT	file	op1*op2	$(op1 \times op2)\sqrt{(\sigma1/op1)^2 + (\sigma2/op2)^2}$	OR	T1	S1
DIV	file	op1/op2	$(op1/op2)\sqrt{(\sigma1/op1)^2 + (\sigma2/op2)^2}$	OR	T1	S1
ADD	constant	op1+op2	$\sqrt{\sigma1^2 + \sigma2^2}$	...	...	...
SUB	constant	op1-op2	$\sqrt{\sigma1^2 + \sigma2^2}$	...	...	...
MULT	constant	op1*op2	$(op1 \times op2)\sqrt{(\sigma1/op1)^2 + (\sigma2/op2)^2}$	...	T1*op2	...
DIV	constant	op1/op2	$(op1/op2)\sqrt{(\sigma1/op1)^2 + (\sigma2/op2)^2}$	...	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 ($\sigma1$ and $\sigma2$) are added in quadrature. If the constant is given with an error ($\sigma2$), 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:

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

and:

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

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$_\lambda$.

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.
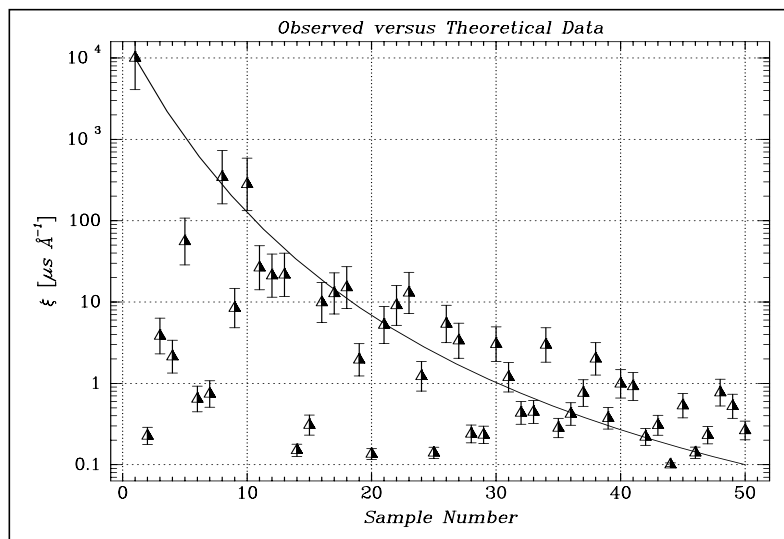
3.5 Analyzing HST Spectra

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 $\boxed{\text{S}}$ 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 $\boxed{\text{B}}$ keystroke.

- Use the $\boxed{\text{R}}$ 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 $\boxed{\text{P}}$.

- Press $\boxed{\text{F}}$ 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`.
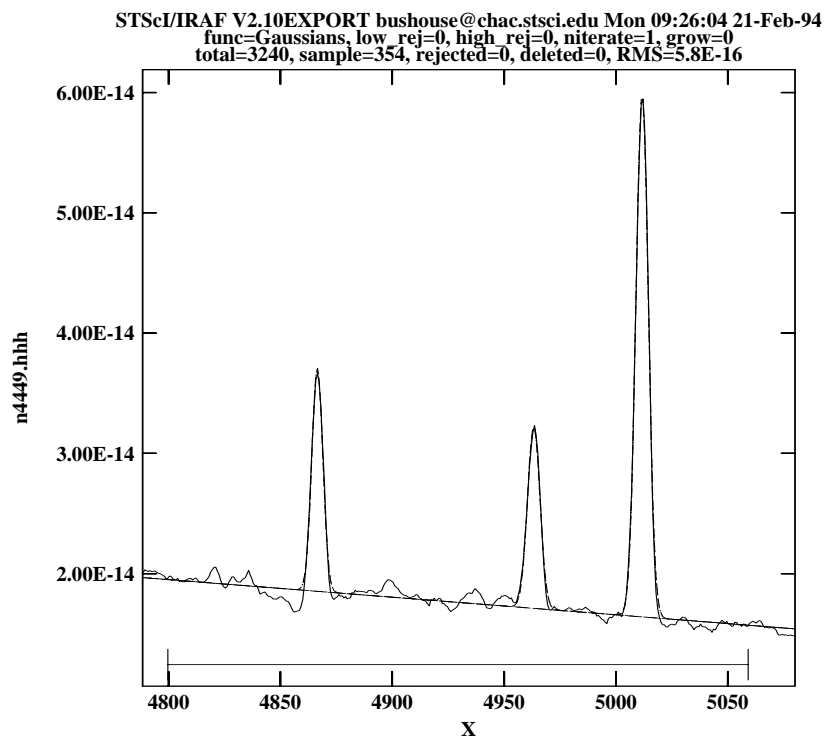
Figure 3.6: Fitting Hβ and [OIII] Emission Features in NGC 4449

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.

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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.

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 →

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 **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.
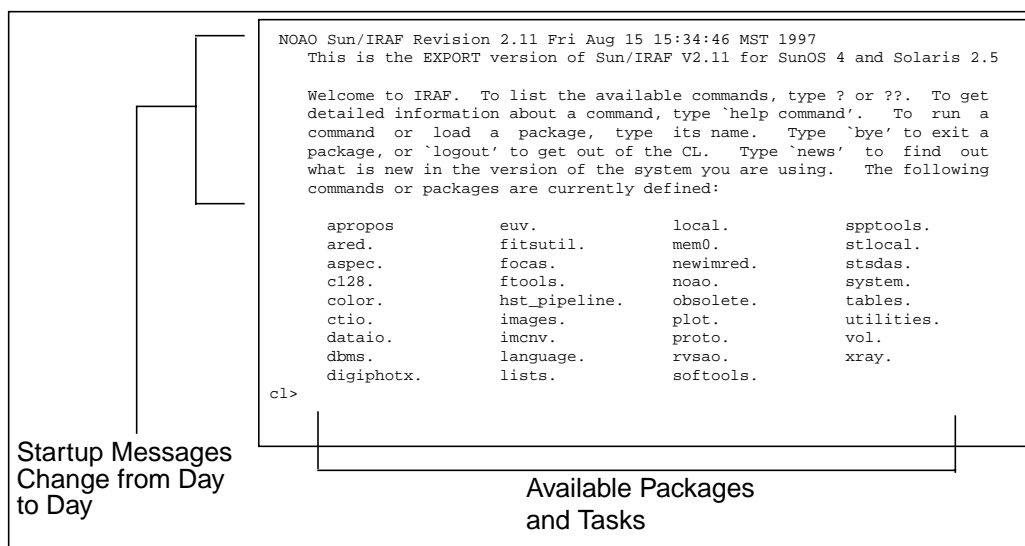
A.1.2 Starting and Stopping an IRAF Session

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

```
NOAO Sun/IRAF Revision 2.11 Fri Aug 15 15:34:46 MST 1997
    This is the EXPORT version of Sun/IRAF V2.11 for SunOS 4 and Solaris 2.5

    Welcome to IRAF.  To list the available commands, type ? or ??.  To get
    detailed information about a command, type `help command'.  To  run  a
    command  or  load  a  package,  type  its name.   Type  `bye' to exit a
    package, or `logout' to get out of the CL.   Type `news'  to  find  out
    what is new in the version of the system you are using.   The following
    commands or packages are currently defined:

    apropos          euv.             local.           spptools.
    ared.            fitsutil.        mem0.            stlocal.
    aspec.           focas.           newimred.        stsdas.
    c128.            ftools.          noao.            system.
    color.           hst_pipeline.    obsolete.        tables.
    ctio.            images.          plot.            utilities.
    dataio.          imcnv.           proto.           vol.
    dbms.            language.        rvsao.           xray.
    digiphotx.       lists.           softools.
cl>
```

Startup Messages
Change from Day
to Day

Available Packages
and Tasks

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
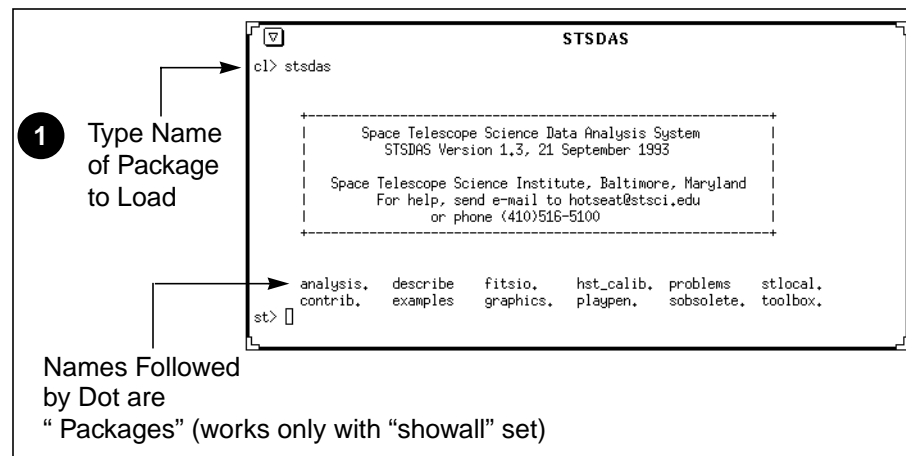
Some helpful commands for managing packages are:

- `?` - 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 direc-tory.

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

Available Commands ——————— [Space] Display Next Page
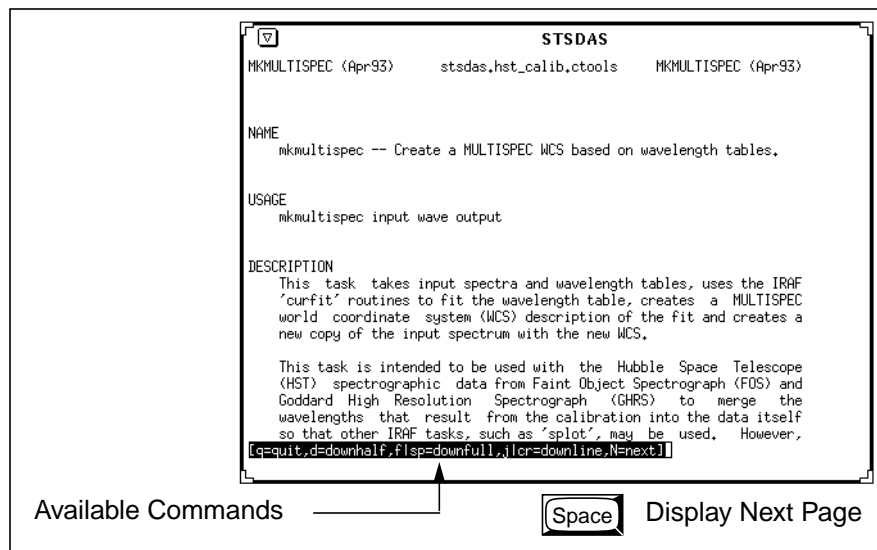
Two STSDAS tasks that display only certain sections of the help file are also available:

- **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

Look for Tasks Dealing with World Coordinates

Package
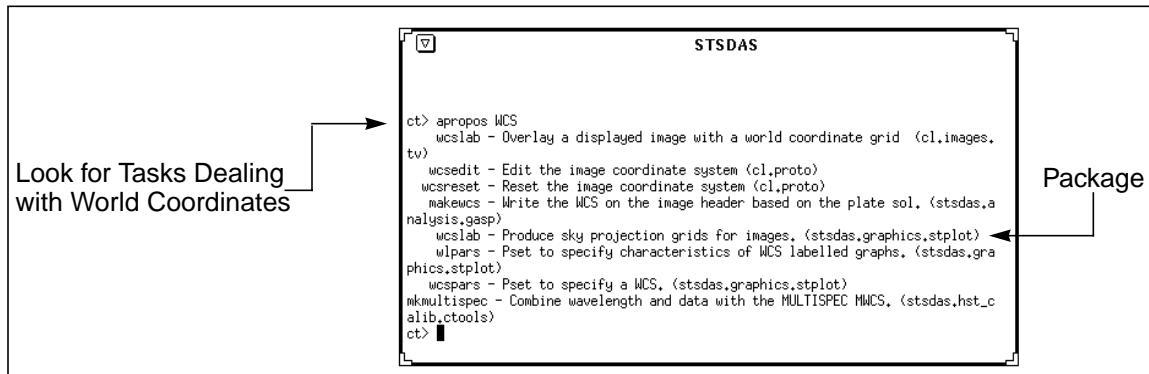
A.2.4 Setting Parameters

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

1 Type *lpar* Followed by Name of Task

Parameters and Current Settings
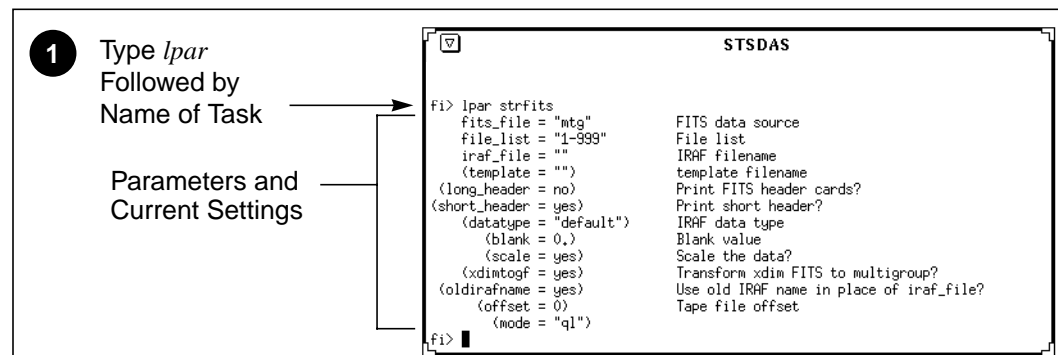
Setting parameters with eparam

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 `/soft-ware/ 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                                                    Just in case...
cl> cd /node/partition/stdata/synphot
cl> set crrefer = "/node/partition/stsdata/synphot/"
cl> task $unpack = unpack.cl
cl> tables
ta> fitsio                              The "$" is used because the task
fi> unpack                              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 -
```
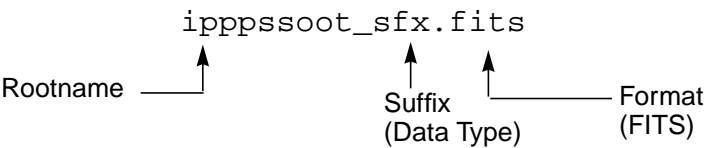
HST File Names

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:

```
ipppssoot_sfx.fits
```

Rootname ——— Suffix (Data Type)   Format (FITS)

- **Rootname**: The first part of the file name (`ipppssoot`) is the *root-name* 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

```
┌─────────────────────── < NICMOS Association Results > ───────────────────────┐
│ File   Searches   Constraint   View   Retrieve   Customize   Options   Comments        Help │
│                                                                                             │
│  Association ID:  N3S211010              Proposal ID:  862                                   │
│                                                                                             │
│        Pattern:  NONE               PI (last name):  WAYNE BAGGETT                           │
│                                                                                             │
│    Member Name:  N3S211010              Target Name:  TARGET1                                │
│                                                                                             │
│    Member Type:  PROD-TARG               Start Time:  03/29/97 06:16:52                      │
│                                                                                             │
│                                                                                             │
│  RA (RA  ,2000):  17 59 09.185        Dec (Dec ,2000):  -61 35 02.000                        │
│                                                                                             │
│                                                                                             │
│    Camera:  2               Orient:  50.364          Aperture:  NIC2                         │
│                                                                                             │
│   Exp Len:  27.424          Numpos:  0                  Nread:  4                            │
│                                                                                             │
│    Filter:  F110W           Offset:                    Nsamp:  1                             │
│                                                                                             │
│      Mode:  ACCUM       Dither Size:  0.000           Readout:  FAST                         │
│                                                                                             │
│  Samp Seq:              Chop Size:  0.000                                                    │
│  ──────────────────────────────────  EXPOSURES  ──────────────────────────────              │
│                                                                                             │
│  Dataset Name:  N3S21106R           Position #:                  PAM Focus:  4.223           │
│                                                                                             │
│    Exp. Start:                        Exp. Flag:                                             │
│                                                                                             │
│                                                                                             │
│  RA (RA  ,2000):  18 00 00.000     Dec (Dec ,2000):  -61 30 00.000                           │
└─────────────────────────────────────────────────────────────────────────────────────────┘
┌─────────────────────────────────────────────────────────────────────────────────────────┐
│   Step Forward          Step Back          Mark Dataset         Retrieve Marked Data        │
│                                                                                             │
│   Scan Forward          Scan Back          Unmark Data          Write Result to File        │
│                                                                                             │
│   Edit Search Constraints                  Mark All             View Result as Table        │
│                                                                                             │
│   Record  1    of  1    (in progress)      Unmark All           Strategy      Preview       │
│                                                                                             │
│                                                                                Overlay      │
│                                                                                             │
│                                     Exit Screen ^Z                                          │
│                                                                                             │
└─────────────────────────────────────────────────────────────────────────────────────────┘
 MESSAGE: More records available. Use record controls to view search results
```

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/ftp/instrument_news/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.cmi` Table, 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
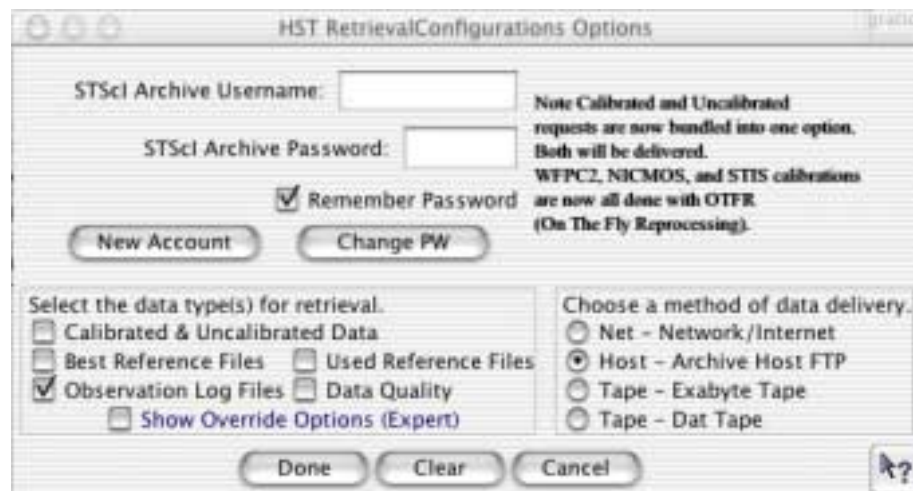
C.3 Using Observation Logs

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

NOAO/IRAF V2.11EXPORT lallo@squonk.stsci.edu Thu 13:55:32 18-Sep-97
squonk.stsci.edu!/data/squonk1/day118/jitterdata/x3y60102j_jit.fits
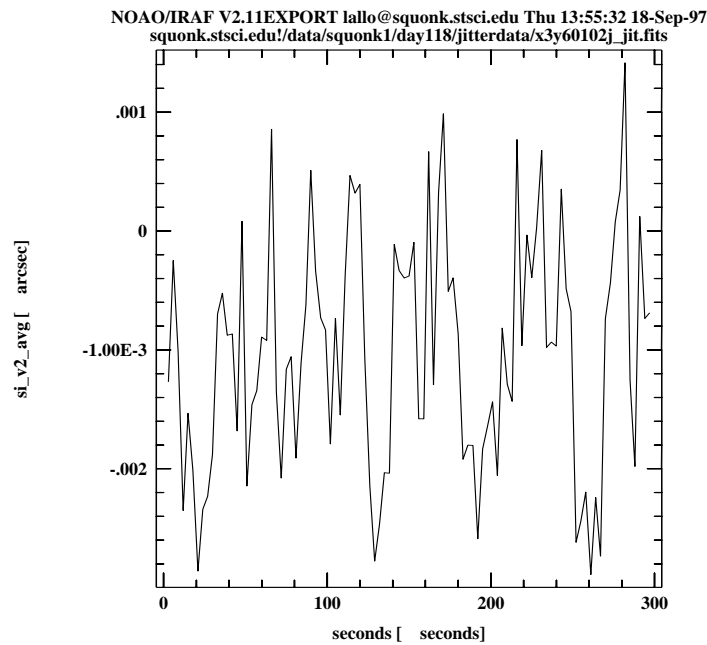
To get an idea of pointing stability, you can create a *jitter ball* by plotting jitter along the V2 axis vs. jitter along the V3 axis (see figure C.5):

```
st> sgraph "x3660102j_jit.fits si_v2_avg si_v3_avg"
```

Figure C.5:Plotting V2 vs. V3 Jitter

NOAO/IRAF V2.11EXPORT lallo@squonk.stsci.edu Thu 13:52:50 18-Sep-97
squonk.stsci.edu!/data/squonk1/day118/jitterdata/x3y60102j_jit.fits
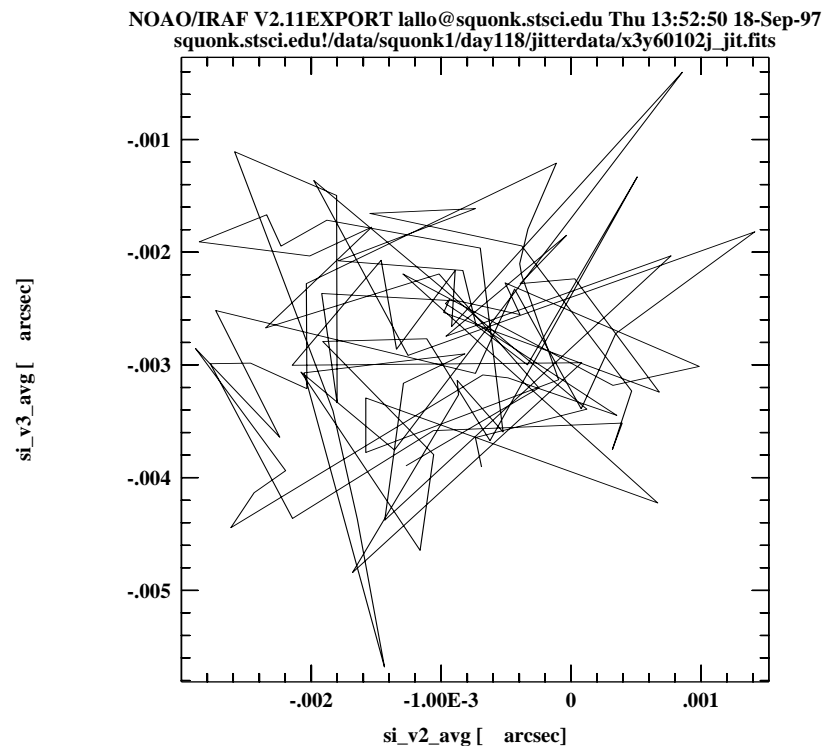
The **tstatistics** task can be used to find the mean value of the `si_v3_avg` column—the amount of jitter (in arcseconds) in the direction of the V3. This value can be used to model jitter in a PSF. In this example, the mean jitter is ~3 mas, which is typical for post-servicing mission data:

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/ftp/instrument_news/ Observatory/obslog/OL_1.html

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