Version 2.0   May 5, 1998.

WFPC2
DATA ANALYSIS
A TUTORIAL

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INTRODUCTION

This document is an introduction to basic data reduction and analysis for the Hubble Space Telescope Wide Field and Planetary Camera (WFPC2) instrument, written specifically for people unfamiliar with WFPC2 data. It has been written as a tutorial, and you are encouraged to retrieve the suggested datasets and try the examples in the document. However, before proceeding, you should have:

- some familiarity with IRAF,
- the current version of IRAF and STSDAS installed on your workstation,
- the current version of STARVIEW (the software interface to the HST archive) installed on your workstation,
- an account on the HST Data Archive at STScI.

More information about IRAF, STSDAS, and the HST Data Archive at STScI can be found at these websites:

- IRAF: *http://iraf.tuc.noao.edu/*
- STSDAS: *http://ra.stsci.edu/STSDAS.html*
- HST Data Archive: *http://archive.stsci.edu/starview.html*

Two useful documents to have in hand while going through the exercises in this tutorial are:

- The HST Data Handbook v3.0 (*http://www.stsci.edu/ftp/documents/html/data-handbook.html*)
- The WFPC2 Instrument Handbook v4.0 (*http://www.stsci.edu/ftp/instrument_news/WFPC2/Wfpc2_hand/wfpc2_handbook.html*)

Other useful documents for your WFPC2 library are:

- The 1997 HST Calibration Workshop with a New Generation of Instruments, September 22-24, 1997. *(http://www.stsci.edu/stsci/meetings/cal97/)*
- Calibrating Hubble Space Telescope: Post Servicing Mission, a Workshop held on May 15 - 17, 1995. (*http://www.stsci.edu/ftp/instrument_news/WFPC2/Wfpc2_serv/post_serv.html*)
- A Field Guide to WFPC2 Image Anomalies by J. Biretta, et al. (available at *http://www.stsci.edu/ftp/instrument_news/WFPC2/wfpc2_anomalies.html*)
- Performance and Calibration of WFPC2 on the Hubble Space Telescope by Jon Holtzman, et al. (*http://www.stsci.edu/ftp/instrument_news/WFPC2/wfpc2_doc.html#Othr*)
- The Photometric Performance and Calibration of WFPC2 by Jon Holtzman, et al. (*http://www.stsci.edu/ftp/instrument_news/WFPC2/wfpc2_doc.html#Othr*)
- Synphot Users Guide by Howard Bushouse (*http://ra.stsci.edu/documents/SyG/SG_1.html*)

A paper copy of these documents can be requested by sending e-mail to help@stsci.edu . There is also regularly-updated on-line WFPC2 information available at the WFPC2 Group at the STScI homepage

(*http://www.stsci.edu/ftp/instrument_news/WFPC2/wfpc2_top.html*).

On-line help files are also available in IRAF and STSDAS. The task *apropos* allows you to locate an IRAF or STSDAS task. For example, if you need to know how to access the task *crrej* in STSDAS, just type:

apropos crrej

apropos will return a list of tasks, along with a brief description and location in IRAF or STSDAS, with the string "crrej" in it.

sky - Sky processing by "crrej-like" algorithm. (stsdas.analysis.dither)
ocrreject - Generate a STIS CCD image (images and spectra) free of (stsdas.hst_calib.stis)
crrej - Combine images to make a cosmic ray free image. (stsdas.hst_calib.wfpc)
gsky - Compute sky with "crrej" mode algorithm (stlocal.testwfpc)

To run *crrej*, the packages *stsdas*, *hst_calib*, and *wfpc* must first be loaded.

If you need detailed information about a particular IRAF or STSDAS task, type *help <taskname>*.

For example.

help crrej

To write the *crrej* on-line help in a file, type

help crrej | type dev=text > crrej.help

This document is divided into four sections:

- **SECTION 1** contains instructions on how to retrieve files from the HST archive at STScI.
- **SECTION 2** covers image display, important header keywords, data quality checks, as well as useful IRAF and STSDAS tasks for data reduction and analysis (such as *metric*, *compass*, *imexam, wmosaic, warmpix, crrej*).
- **SECTION 3** has an overview of the calibration pipeline, and how to recalibrate WFPC2 data.
- **SECTION 4** is a guide to WFPC2 photometry

Future sections of this document will include other data analysis methods such as dithering.

Throughout this document, examples of tasks and procedures will use the following datasets:

u2g40o05t.c0h, u2g40o06t.c0h, u2g40o09t.c0h, and *u2g40o0at.c0h.*

For general questions about WFPC2 data reduction, please get in touch with your assigned contact scientist, or send e-mail to *help@stsci.edu*. For questions and comments about this document, please contact Shireen Gonzaga *(shireen@stsci.edu)* or Chris O'dea *(odea@stsci.edu)*.

1.0 DATA RETRIEVAL FROM THE HUBBLE SPACE TELESCOPE ARCHIVE

1.1 Data retrieval from the archive at STScI

HST data is archived at three sites: the Canadian Astronomy Data Center (CADC) , the Space Telescope European Coordinating Facility(ST-ECF), and the Space Telescope Science Institute (STScI). This document only covers the STScI archive, in particular, using the Starview archive interface. If you wish to retrieve data from one of the other two sites, please refer to instructions on their websites:

CADC: *http://cadcwww.dao.nrc.ca/hst/*
ST-ECF: *http://archive.eso.org/archive/hst/*

To retrieve data from the archive at STScI, you'll need an account. If you do not have one, please fill out the account request form located at *http://archive.stsci.edu/registration.html* .

Currently, some HST principal investigators receive their data on an EXABYTE tape. These files can be written to disk using the STSDAS task *strfits* (please refer to the HST Data Handbook for more information on this task). Principal investigators and their designated co-investigators can also retrieve the proprietary data for their proposals from the archive (they must, however, have this proprietary data sent directly to a machine at their home institution).

For a given dataset, the archive provides:

- raw data files (uncalibrated data),
- calibrated data files (processed using the best reference files available when the data was first received and calibrated in the WFPC2 pipeline),
- data quality files (information about the positions and characteristics of bad pixels),
- telescope pointing and jitter files (information about telescope guiding when observations were executing),
- list of the latest and best calibration reference files.

How do I retrieve files from the archive?

Archive data can be retrieved using the archive interface program *starview*. This software can be installed on your local Sparcstation, or DEC VAX, or Alpha machine, and is available at *http://archive.stsci.edu/dist_starview.html* .

To run *starview*, type ***xstarview*** to bring up the main menu screen. Outlined below is an example of how to retrieve the datasets *u2g40o05t, u2g40o06t, u2g40o09t,* and *u2g40o0at* as well as their associated reference files. Before you begin, make sure there is enough space on your machine to receive the retrieved data. (One calibrated dataset takes up about 15MB of space.)

- Create a directory for the data about to be retrieved.
- At the main *xstarview* menu, select **HST Instrument Searches**
- In the next window, select the WFPC2 **Instrument** button
- In the next window, enter the search constraints. In this case, the dataset name is known so simply enter *u2g40o05t* in the **dataset name** field, then select **Begin Search**.
- A screen containing the search results will appear. Since we need to retrieve this dataset, select the **Mark Dataset** button.
- At this point you could **Edit Search Constraints** to search for the other datasets *u2g40o06t, u2g40o09t,* and *u2g40o0at*. Mark them for retrieval as well.
- When you are ready to retrieve the data, select **Retrieve Marked Data**. A table will appear with a list of all data marked for retrieval.
- Hit the **Submit Request** button.
- Another screen will appear asking what kinds of files you want to retrieve. For this exercise, select **Calibrated**, **Uncalibrated**, **Data Quality, and Best Reference Files**. (If you are not recalibrating the data, just select the **Calibrated** and **Data Quality** buttons.)
- Select the **Submit Request** button again. A screen appears asking for your archive username and password, as well as the destination machine, location and password for the retrieved data. Enter this information, then hit the **Submit** button.
- Shortly after submitting your request, the archive system will send an e-mail acknowledgment of your retrieval request. They will also notify you by e-mail when the data has been retrieved. If you wish to check the status of your request, select **Retrieval Status** under **Commands** in the main *xstarview* menu. Or you can also check the archive request monitor page at *http://star1.stsci.edu/RequestMonitor.html*

Sometimes, it is necessary to recalibrate the data. That's because better reference files than those used in the original calibration of the data (as stored in the archive) may have since become available. *starview* can help you check if new reference files are available for your data:

- At the main xstarview menu, select **HST Instrument Searches**
- On the next window, select the WFPC2 **Reference** button**.**
- Enter the dataset for which reference files are needed in the **Dataset Name** category (for example, *u2g40o05t*). Then select **Begin Search**.
- A screen will appear listing the reference files. The **Used** column indicates reference files that were used in the pipeline calibration. The **Recommended** column reflects the latest and best reference files for the dataset. If files in these two columns differ, the data <u>may</u> need to be recalibrated (more on this later). Make a note of the reference file changes.

2.0 WORKING WITH WFPC2 IMAGES

Before using the tasks mentioned below, be sure to load the packages containing those tasks. If you use the tasks often, their package names can be entered in the IRAF start-up file (called *login.cl* or *loginuser.cl* found in your IRAF directory) so that the packages are automatically loaded whenever you fire-up IRAF. Some useful packages to load before proceeding are listed below (to load a task, just type the task name at the *cl* prompt, then hit <return>):

- *images*
  - *tv* (in *images* package)
- *stsdas*
  - *fitsio* (in *stsdas* package)
  - *hst_calib* (in *stsdas* package)
    - *wfpc* (in *hst_calib* package)
  - *toolbox* (in *stsdas* package)
    - *ttools* (in *toolbox* package)

If you are running IRAF on a Sparcstation, be sure to run it in an *xterm* window or some of the tasks mentioned in this chapter, such as *imexam*, will not work. (If you have problems, please consult your local IRAF expert or systems administrator.)

2.1 Converting images from FITS to GEIS format

Data retrieved from the archive are in *FITS* format, and must be converted to the *GEIS* format. *FITS (Flexible Image Transport System)* is a standard format for storing and exchanging astronomical information that is used world-wide. *GEIS* files *(Generic Edited Information Sets)* is the format used by STSDAS.

A GEIS file is similar to an IRAF format file in that it consists of two parts: a header file, and a data file. A GEIS data file, however, can accommodate several images within a single dataset. This is particularly useful for an instrument like the WFPC2 with four CCD chips that create four separate images for a given observation.

Note: future versions of IRAF will have a FITS kernel; this allows IRAF and STSDAS tasks to directly use FITS files, making conversion to GEIS unnecesary.

How do I Convert an Image from FITS to GEIS format?

Before doing this conversion, two important IRAF/STSDAS parameters must be set. This can be done whenever you work with WFPC2 images in STSDAS, or you can make it a default setting by editing your *login.cl* or *loginuser.cl* file located in your *iraf* directory.

set imtype = hhh

This tells IRAF/STSDAS that your image files are in the GEIS format.

set stdimage = imt800

This tells the image display software to display all 800x800 pixels of a single WFPC2 chip.

The conversion from FITS to GEIS is done using the STSDAS task *strfits*; Be sure to set the parameters ***xdimtog=yes*** and ***oldirafname=yes***. Here's an example of the *strfits* parameter file for converting FITS files on disk to GEIS files:

```
PACKAGE = fitsio
   TASK = strfits

fits_fil =          *.fits    FITS data source
file_lis =                    File list
iraf_fil =                    IRAF filename
(templat =           none)    template filename
(long_he =             no)    Print FITS header cards?
(short_h =            yes)    Print short header?
(datatyp =        default)    IRAF data type
(blank =               0.)    Blank value
(scale =              yes)    Scale the data?
(xdimtog =            yes)    Transform xdim FITS to multigroup?
(oldiraf =            yes)    Use old IRAF name in place of iraf_file?
(force =               no)    Force conversion from fits?
(offset =               0)    Tape file offset
(Version =    14-May-1995)    Strfits version
(mode =                ql)
```

2.2 Displaying WFPC2 Images

There are two commonly-used image display tools: *saoimage* and *ximtool*. *saoimage* can be started by typing ***saoimage*** on your workstation. For *ximtool*, type ***ximtool*** . Which one should you use? It's a matter of personal preference. Try both tools and pick the one that best serves your needs.

Open either *ximtool* or *saoimage*. Then start up IRAF and STSDAS. The IRAF task *display* will display the image on your image display tool. Remember that these are multi-group GEIS files, and most WFPC2 datasets have four groups. Each group represents an image from either the PC, WF2, WF3, or WF4. When displaying an image, a group must be specified.

In the example below, group 2 of image *u2g40o05t.c0h* is displayed.

display u2g40o05t.c0h[2] 1

Try playing with contrast and color tables in *saoimage* or *ximtool*. Also try editing the *display* parameters. You could set the lower and upper image display range, ***z1*** and ***z2***, to different values. (If you manually set ***z1*** and ***z2***, be sure to set the parameters ***zrange*** and ***zscale*** to **"no"**, or as illustrated in the example below, **"zr- zs-"**.)

Example:

display u2g40o05t.c0h[2] 1 zr- zs- z1=-5 z2=200

If you are viewing an object with low surface brightness, such as a galaxy, try changing the parameter ***ztrans*** from ***linear*** (the default value) to ***log***.

Example:

display u2g40o05t.c0h[2] 1 zr- zs- z1=-5 z2=200 ztrans=log

<u>Can I "blink" two or more images with the same pointing?</u>

For example, to compare *u2g40o05t.c0h* and *u2g40o06t.c0h*, display each image in separate image display buffers and "blink" them.

1. In **saoimage**, display the first image. Select ***scale***, then select the ***blink*** button. Click on the image with the left-most button to store it in the image buffer. Then, display the second image. Make sure that the ***scale*** button is highlighted, then place the cursor on the image and press the left-most button. This will allow you to view the previous image again, and you can blink back and forth between the two images by clicking that button. Similarly, a second image can be stored in the buffer by clicking on the middle mouse button. Therefore, it is possible to "blink" three images with **saoimage**.

2. In **ximtool**, display the first image in frame 1, and the second image in frame 2. Use the ***blink*** button in the menu to toggle between the two images. Up to four images can be blinked using **ximtool**. The frames can be specified in the *display* task, for example,

   display u2g40o05t.c0h[2] 3

   will display the image in **ximtool** frame #3.

2.3 Getting more information about the WFPC2 images

Information about the images are available from two sources:

- the phase2 proposal
- image header keywords

2.3.1 Looking at the original phase2 proposal

Phase 2 proposals can be viewed at:

http://presto.stsci.edu/public/propinfo.html

Enter the four-digit program ID (no leading zero in the number) in the **search** field. A screen containing program information will appear. Select the **formatted listing** button. Increase the size of the screen so the entire width of the display can be easily read.

2.3.2 Reading the Image Header File

In this section, we will take a close look at the calibrated data header file (with extension **.c0h**) for dataset *u2g40o05t*.

The header file is populated with *keywords* containing information about the observation. A keyword dictionary is located at:

http://archive.stsci.edu/keyword/

and also in the HST Data Handbook.

How do I Read a Header File?

There are several ways to look up information about an image in its header file. But first, try paging through the header file using an editor (like vi or emacs). You will see keywords common to all groups in a dataset, and pointers to group-dependent keywords stored in the group binary data file.

- The STSDAS task *iminfo* gives a summary of important parameters for a dataset.

  iminfo u2g40o05t.c0h

  results:

Rootname	**Instrument**	**Target Name**
U2G40O05T	**WFPC2**	**NGC5139**

Program = 2G4	**Obs Date = 15/02/95**
Observation set = 0O	**Proposal ID = 05663**
Observation = 05	**Exposure ID = 112.2000058**
Source = Tape Recorder	**Right ascension = 13:25:37.0**
File Type = SCI	**Declination = -47:35:38**
	Equinox = J2000

First filtername = F555W	**Number of groups = 4**
Second filtername =	**Data type = real**
Image type = EXT	**Exposure time (sec) = 16.**
Mode = FULL	**Dark time (sec) = 16.**
Serials = OFF	
Shutter = A	**Calibration steps done:**
Kelsall spot lamp = OFF	**MASK ATOD BLEV BIAS DARK FLAT**

- The STSDAS task *imheader* displays all header keywords in a group (this also includes the group-dependent keywords that are "hidden" in the binary group image file).

  imheader u2g40o05t.c0h[2] l+ | page

  The *l+* option tells *imheader* to display all keywords for group 2. Specifying *l-* will display only a few major keywords in the header file. *page* is an IRAF (also UNIX) command that will allow you to scroll through the information.

- If you know the keywords you wish to look up, try *hedit*. The example below illustrates how values for the keywords DETECTOR and BIASODD in the image *u2g40o05t.c0h[2]* are obtained.

  hedit u2g40o05t.c0h[2] DETECTOR,BIASODD .

  (The period after **BIASODD** is not a typo. It tells *hedit* not to change the keyword value.)

  The results:

  u2g40o05t.c0h[2],DETECTOR = 2
  u2g40o05t.c0h[2],BIASODD = 318.638

- In the example below, the task *hselect* echoes the name of the dataset and group, and looks up the keyword values DETECTOR, BIASODD, and BIASEVEN for group 3 (WF3 chip) of all images in the directory.

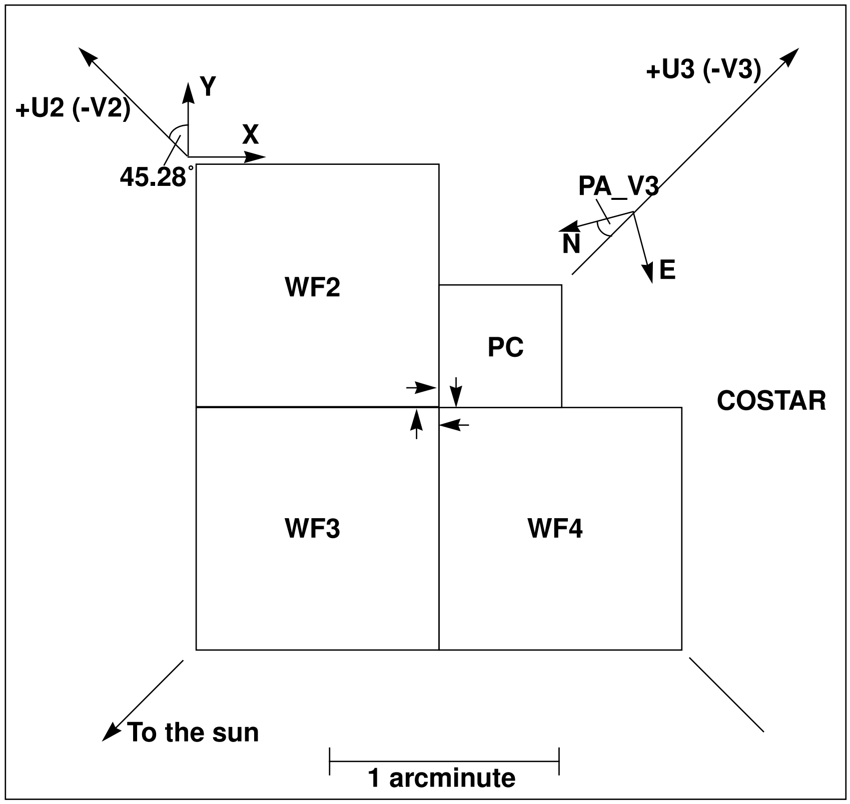
  hselect *.c0h[3] $I,DETECTOR,BIASODD,BIASEVEN yes

  The results:

u2g40o05t.c0h[3]	**3**	**304.7928**	**304.7473**
u2g40o06t.c0h[3]	**3**	**304.7491**	**304.749**
u2g40o09t.c0h[3]	**3**	**304.7918**	**304.7464**
u2g40o0at.c0h[3]	**3**	**304.835**	**304.7911**

2.3.3 Some Useful WFPC2 Header Keywords

DETECTOR	CCD chip used to obtain image; 1 for PC, 2 for WF2, 3 for WF3, and 4 for WF4. A group-dependent keyword.
DATE-OBS	Date of observation.
TIME-OBS	Time of observation in Universal Time
FILTNAM1	Spectral element used in observation.
FILTNAM2	Second spectral element (if any) used in observation
EXPTIME	Exposure time
FGSLOCK	Type of guiding, either FINE (for fine lock) or GYRO (for gyro control)
EXPFLAG	Indicates if the exposure was interrupted (for example, by loss of lock on guide stars)
PROPOSID	Phase 2 proposal ID
LINENUM	Visit and line number of exposure in phase 2 proposal
CRPIX1	*x* coordinate of reference pixel A group-dependent keyword.
CRPIX2	*y* coordinate of reference pixel. A group-dependent keyword.
CRVAL1	Right ascension of reference pixel (in degrees). A group-dependent keyword.
CRVAL2	Declination of reference pixel (in degrees). A group-dependent keyword.
ORIENTAT	The angle (in degrees) between the positive y-axis of a chip and celestial north. The value of an angle ranges from -180 degrees to 180 degrees, where a positive angle is measured clockwise, and a negative angle is measured counter-clockwise. A group-dependent keyword.
PA_V3:	The angle, in degrees, measured north to east, between celestial north and the positive V3 axis of the telescope. (The same value applies to all four chips because it is defined in the spacecraft frame of reference.) The diagram on page 17 illustrates the WFPC2 field-of-view, as well as the direction of the V1, V2, and V3 axis. For more information, please refer to the HST Data Handbook and the WFPC2 Instrument Handbook.



2.4 Useful WFPC2 Data Reduction and Analysis Tasks

This section contains examples of some handy IRAF and STSDAS tasks:

imexamine	Examine images using image display, graphics, and text (cl.images.tv)
compass	Draw north and east arrows (stsdas.graphics.sdisplay)
xy2rd	Translate a 2-D image pixel coordinate to right ascension and declination (stsdas.toolbox.imgtools)
metric	Translate WF/PC pixel coordinates to RA & Dec with geometric distortion (stsdas.hst_calib.wfpc)
wmosaic	Mosaic the four WF/PC frames into one image. (stsdas.hst_calib.wfpc)
crrej	Combine images to make a cosmic ray free image. (stsdas.hst_calib.wfpc)
imedit	Examine and edit pixels in images (cl.images.tv)
wfixup	Interpolate over bad columns in a WF/PC frame. (stsdas.hst_calib.wfpc)
synphot	Tasks for synthetic photometry and modelling instrument response. (stsdas.hst_calib)

2.4.1 *imexamine* - Examine images using image display, graphics, and text (cl.images.tv)

One handy use of this task is to examine the PSF structure of stars. Highlighted below are several particularly useful features:

- First, display the image using the *display* task
- Type **imexam**. A cursor will appear on the image. Place the cursor on a star and hit **s**. A three-dimensional plot of the star will appear.
- Place the cursor on a star and hit **r**. A radial plot of the star appears.
- Place the cursor on a star and hit **a**. No plot appears but x,y coordinates of the star's center, and other useful information appears on the screen.
- To exit from *imexam*, place the cursor on the image and type **q**.

The *imexam* task has many features; commands listed above will help you get started. More information can be found in the *imexam* on-line help file, accessed by typing

help imexam.

2.4.2 *compass* - Draw north and east arrows. (stsdas.graphics.sdisplay)

The *compass* task is used to draw arrows pointing to the north and east.

Example:
Create a copy of *u2g40o05t.c0h[2]* that has an arrow drawn in to show "north".

compass u2g40o05t.c0h[2] outimage.hhh 400 400

Example:
Overlay the compass arrows on an existing display.

display u2g40o05t.c0h[2] 1
compass u2g40o05t.c0h[2] "" 400 400 device=imd

Note: This task occasionally does not work (reason yet to be determined). When this happens, type **flpr** (flush process) a couple of times at the *cl* prompt, and try the task again. If that does not work, log out of IRAF, then log back in and try the task again.

2.4.3 *xy2rd* - Translate a 2-D image pixel coordinate to right ascension and declination (stsdas.toolbox.imgtools)

This task converts the x-y pixel position to right ascension and declination. xy2rd uses the group parameters CRVAL1, CRVAL2, CRPIX1, CRPIX2, and other coordinate-related keywords to extrapolate the RA and DEC values.

Example:

xy2rd u2g40o05t.c0h 400 400 hms=yes

output:

RA = 13:25:34.0829, Dec = -47:35:16.401

2.4.4 *metric* - Translate WF/PC pixel coordinates to RA & Dec with geometric distortion (stsdas.hst_calib.wfpc)

This task also translates x-y pixel values to right ascension and declination, but takes the extra step of applying geometric corrections and optional centroiding. The WF2 values for CRVAL1, CRVAL2, CRPIX1, CRPIX2, and other coordinate-related keywords are used as a reference point for measurements in all chips within a dataset. Therefore, if WF2 data is not present in the dataset (as is possible for single-chip readouts), this task will not work.

Example:

metric u2g40o05t.c0h 400 400 hms=yes centroid=no

Output:

```
# METRIC version: 2.1 (Jun 1995)
# input file: u2g40o05t.c0h
# centroid box size = 7 pixels
#x(raw)  y(raw) x(cent) y(cent) x(geom) y(geom) x(meta) y(meta)    RA         Dec
400.00  400.00  400.00  400.00  400.00  400.01  211.33 -134.95 13:25:34.1191 -47:35:16.303
```

2.4.5 *wmosaic* - Mosaic the four WF/PC frames into one image. (stsdas.hst_calib.wfpc)

The four groups in a WFPC2 science dataset can be quilted together to form a 1600x1600 pixel image using the task *wmosaic* located in **stsdas.hst_calib.wfpc**. (In order to display the entire image, be sure to type **set stdimage = imt1600**.)

Example:

wmosaic u2g40o05t.c0h u2g40o05t_m.hhh

2.4.6 *crrej* - Combine images to make a cosmic ray free image. (stsdas.hst_calib.wfpc)

WFPC2 images are undersampled, making it difficult to distinguish between faint stars and low energy cosmic rays, particularly for long exposures that accumulate many hits. One cosmic ray removal strategy is to take multiple exposures at the same pointing, combine the images, and reject high counts that occur in only one of the frames (indicating a cosmic ray).

Example:
Combine images *u2g40o05t.c0h* and *u2g40o06t.c0h* using *crrej*.

Before running this task, check the A-to-D gain for the images.

hedit u2g40o05t.c0h,u2g40o06t.c0h atodgain .

Results

u2g40o05t.c0h,ATODGAIN = 15.00000000000
u2g40o06t.c0h,ATODGAIN = 15.00000000000

Therefore, the A-to-D gain parameter should be set to 15, and the readnoise (5 electrons) parameter set to 0.33.

crrej “u2g40o05t.c0h,u2g40o06t.c0h” u2g40o05_6.c0h “u2g40o05t.c1h,u2g40o06t.c1h” “8,6,4” readnoise=0.33 atodgain=15

crrej parameters:

PACKAGE = wfpc
TASK = crrej

input = “u2g40o05t.c0h,u2g40o06t.c0h”	**Input images**
output = “u2g40o05_6.c0h”	**Output image name**
masks = “u2g40o05t.c1h,u2g40o06t.c1h”	**Input/output masks (optional)**
sigmas =“8,6,4”	**Rejections levels in each iteration**
(radius = 1.5)	**CR expansion radius in pixels**
(pfactor = 0.5)	**CR expansion discriminator reduction factor**
(initial = “min”)	**Initial value estimate scheme (min or med)**
(lower = -99.)	**Lower limit of usable data**
(upper = 4096.)	**Upper limit of usable data**
(sky = “none”)	**How to compute the sky**
(expname = “exptime”)	**Exposure time keyword name**
(readnoise = “0.33”)	**Read noise(s) (in DN) of the detector(s)**
(atodgain = “15”)	**Detector gain(s) in electrons/DN**
(scalenoise = “3,1”)	**Multiplicative term (in PERCENT) from noise mod**
(dq = “”)	**Data quality filter pset**

(skyname = "BACKGRND")	**Name of the group parameter to be updated with**
(crdqval = 128)	**Data quality value for pixels flagged as cosmic**
(fillval = 0.)	**Fill value for pixels having no good values in**
(verbose = yes)	**Print out verbose messages?**
(mode = "al")	

Note: the parameters *sigmas*, *pfactor*, *radius*, and *scalenoise* are suggested values for a first-try at *crrej*. These parameters depend on several factors, such as exposure time, the number of images combined, and scientific goals. Users are advised to try several different values, and choose the parameter values best suited for their data.

2.4.7 *imedit* - Examine and edit pixels in images (cl.images.tv)

Editing images can be done using an interactive task called *imedit*. There is extensive on-line help available in IRAF.

To get started, display the image using *saoimage* or *ximtool*, then fire up *imedit*.

Example:

imedit u2g40o05t.c0h[1] out_img.hhh

The first field specifies the input file, and the second field is the single-group output file.
To view a summary of *imedit* cursor commands, place the cursor on the image, then type **?**

Listed below are some image editing suggestions. There are many more commands available, so please consult the on-line help file for more information:

- To remove a feature and substitute it with the background value.
  - Place the cursor at the bottom left boundary of the feature area, then type **a**
  - Then, place the cursor at the top right of the area, and type **a** again

- To remove a feature but substitute it with a constant value.
  - Specify the value of the constant by placing the cursor on the image, then typing ***:v <value>*** where *<value>* is a numerical constant.
  - Then, use the cursor to mark the boundaries as outlined above, but hit **d** instead of **a**.

- The two cursor strokes mentioned above define rectangular areas to be edited. An aperture can also be specified.
  - First, set the radius with the command ***:radius <value>***
  - Position the cursor on the area to be edited.
  - For background value substitution, type **b** once.
    For constant value substitution, type **e** (be sure to set the constant value before doing this).

- To exit the task and save the image editing results, place the cursor on image and type **q.** If you don’t want to save the changes, type **Q**.

Note that the output file must be a single-group image. If you wish to edit all four groups of a dataset, do the following: edit and write the results of each group to a single-group image. Then combine them back into a 4-group image using the *imcopy* command (don’t use the task *gcopy*).

Example:
Run *imedit* on each group of the image *u2g40o05t.c0h*, and save the results to four single-group images.

imedit u2g40o05t.c0h[1] img_1.hhh
imedit u2g40o05t.c0h[2] img_2.hhh
imedit u2g40o05t.c0h[3] img_3.hhh
imedit u2g40o05t.c0h[4] img_4.hhh

Then, combine the four single group images back into a single four-group image.

imcopy img_1.hhh img_all.c0h[1/4]
imcopy img_2.hhh img_all.c0h[2]
imcopy img_3.hhh img_all.c0h[3]
imcopy img_4.hhh img_all.c0h[4]

This way, the group header information is preserved, and other WFPC2 tasks like *wmosaic* can be run on the resulting 4-group dataset.

2.4.8 *wfixup* - Interpolate over bad columns in a WF/PC frame (stsdas.hst_calib.wfpc)

This task performs cosmetic touch-ups to images. *wfixup* accepts an input image and its associated data quality file. It identifies pixels flagged as “bad” in the data quality file, and performs a simple linear interpolation over those bad pixels.

In the example below, *wfixup* is performed on all four groups of a WFPC2 image, using its associated data quality file, and the results written to an output file called *clean_img.hhh*. In this example, the task parameters have been set such that the longest allowable length of continuous bad pixels to be interpolated is ten; if the width of consecutive bad pixels is greater than this, the pixel values are not changed.

wfixup u2g40o05t.c0h u2g40o05t.c1h clean_img.hhh 10 indef

2.4.9 *synphot* - Tasks for synthetic photometry and modelling instrument response. (stsdas.hst_calib)

synphot is a software package that simulates photometric data and spectra for HST instruments. It is useful for such things as predicting count rates in any observing mode, plotting HST calibration target spectra, plotting sensitivity curves for various observing modes, as well as examining the photometric transformations between HST observing modes and conventional systems such as Johnson UBV.

Full details about the many different features of *synphot* are best obtained from the Synphot Users Manual, available on-line at
http://ra.stsci.edu/documents/SyG/SG_1.html .

More information about each *synphot* task can also be found in the on-line STSDAS help files.

Other WFPC2-related Synphot information can be found at
http://www.stsci.edu/ftp/instrument_news/WFPC2/wfpc2_doc.html

Atlases of HST standard star spectra, as well as observed and synthetic spectra from other atlases (such as Buser-Kurucz Atlas and Bruzual-Persson-Gunn-Stryker Atlas) can be downloaded from the institute web site.
http://www.stsci.edu/ftp/instrument_news/Observatory/cdbs/astronomical_catalogs_alt.html #calspec

For now, we illustrate a few *synphot* examples relevant for WFPC2 data.

Example 1:

Plot the F555W bandpass, normalized to a maximum value of 1 with wavelength range between 4000 to 8000 A. Then, overplot the Johnson V bandpass (using dotted lines) for comparison.

plband wfpc2,f555w left=4000 right=8000 norm+
plband v ltype=dashed left=3000 right=9000 app+ lt=dotted

To save this to a postscript file, first create a metacode file, then use the task *psikern* to convert it to a postscript file.

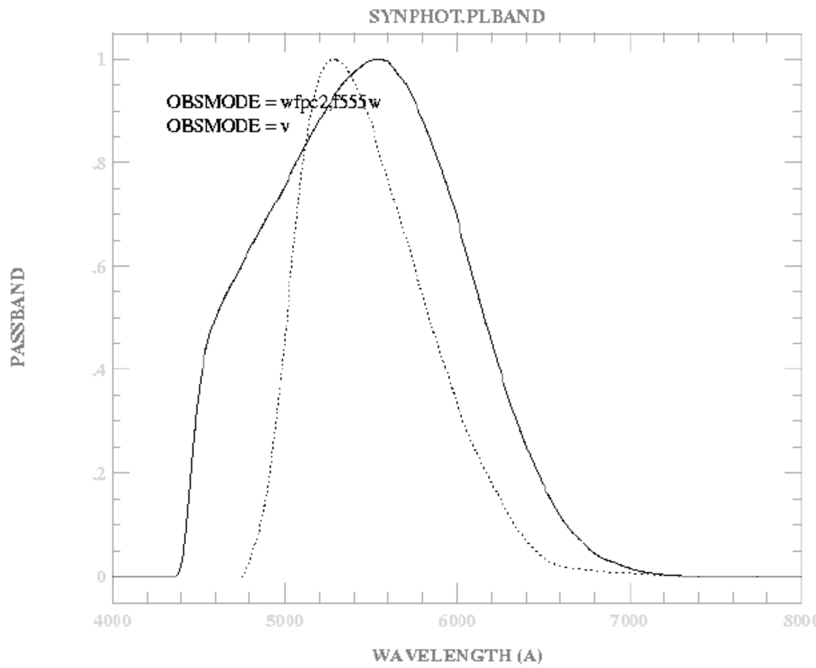
At the cl prompt, type
=gcur

Place the cursor on the plot, then type
:.write file.meta

Type **q** to return to the IRAF command mode.

Use the task *psikern* to convert the metacode file to a postscript file.

psikern file.meta dev=psi_def output=file.ps



Example 2:

Calculate the predicted count rate for the standard star GRW+70d5824, in the WFPC2 using the PC chip, gain 7, and F814W.

First, retrieve the table containing the spectrum for GRW+70d5824 from the location mentioned at the beginning of this section.

Then, type

calcphot wfpc2,1,a2d7,f814w spectrum="grw_70d5824_005.tab" form=counts

Results:

```
Mode = band(wfpc2,1,a2d7,f814w)
  Pivot      Equiv Gaussian
 Wavelength       FWHM
  7995.938       1521.478    band(wfpc2,1,a2d7,f814w)
Spectrum:  grw_70d5824_005.tab
   VZERO      (COUNTS s^-1 hstarea^-1)
     0.          2900.565
```

Example 3:

In this example, we plot some results from calcphot. We will determine the integrated counts in four WFPC2 filters, F439W, F555W, F675W, and F814W in the PC at gain 7, for star #111 in the Bruzual-Persson-Gunn-Stryker Atlas (bpgs_111) that has been normalized to a V magnitude of 16.

First, retrieve the table containing the spectra of star bpgs111.

Then, type

calcphot @modes.lis "rn(bpgs_111,band(v),16.0,vegamag)" counts out=bpgs111_results

where **modes.list** is a file containing a list of WFPC2 modes

```
wfpc2,1,f439w,a2d7
wfpc2,1,f555w,a2d7
wfpc2,1,f675w,a2d7
wfpc2,1,f814w,a2d7
```

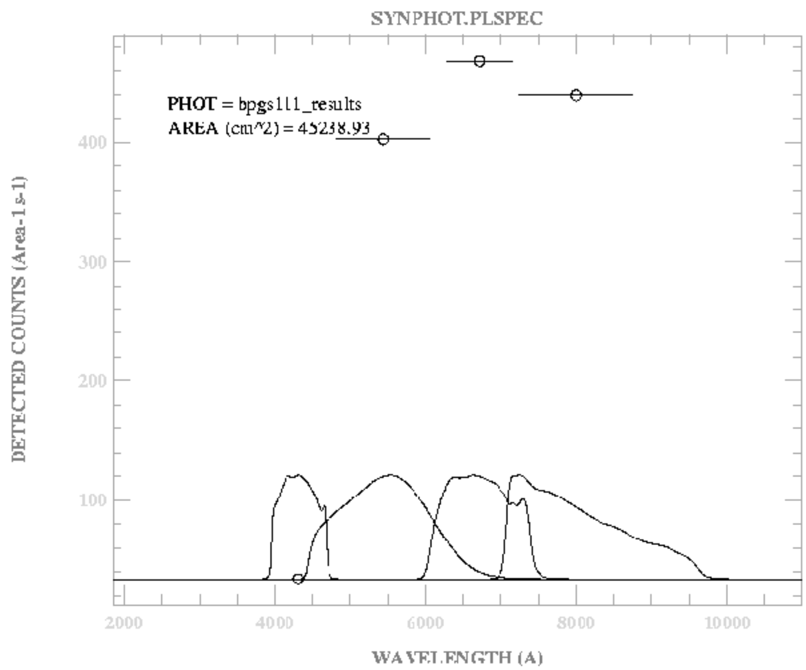
Results:

```
Mode = band(wfpc2,1,f439w,a2d7)
  Pivot      Equiv Gaussian
 Wavelength       FWHM
  4312.101       476.4123    band(wfpc2,1,f439w,a2d7)
Spectrum:  rn(bpgs_111,band(v),16.0,vegamag)
    VZERO     (COUNTS s^-1 hstarea^-1)
      0.         34.05189

Mode = band(wfpc2,1,f555w,a2d7)
  Pivot      Equiv Gaussian
 Wavelength       FWHM
  5442.934       1229.807    band(wfpc2,1,f555w,a2d7)
Spectrum:  rn(bpgs_111,band(v),16.0,vegamag)
    VZERO     (COUNTS s^-1 hstarea^-1)
      0.         402.5905

Mode = band(wfpc2,1,f675w,a2d7)
  Pivot      Equiv Gaussian
 Wavelength       FWHM
  6717.734       867.2407    band(wfpc2,1,f675w,a2d7)
Spectrum:  rn(bpgs_111,band(v),16.0,vegamag)
    VZERO     (COUNTS s^-1 hstarea^-1)
      0.         468.4575

Mode = band(wfpc2,1,f814w,a2d7)
  Pivot      Equiv Gaussian
 Wavelength       FWHM
  7995.949       1521.497    band(wfpc2,1,f814w,a2d7)
```

Spectrum: rn(bpgs_111,band(v),16.0,vegamag)
VZERO (COUNTS s^-1 hstarea^-1)
0. 439.4534

To plot the results (entire command on one line)

plspec "" "" counts pfile=bpgs111_results left=INDEF right=INDEF bottom=INDEF top=INDEF wavetab =""



2.5 Assessing Data Quality

Before proceeding with data analysis, it's always a good idea to check the quality of the WFPC2 images.

- Were the correct calibration steps performed? (More details about calibration can be found in section 3 of this document, or in the HST Data Handbook.) For example, if the observation is less than 10s long, be sure that the shutter shading correction was performed, and the dark correction was not performed:

  hedit u2g40o05t.c0h shadcorr,darkcorr .

  results:

u2g40o05t.c0h,SHADCORR = OMIT
u2g40o05t.c0h,DARKCORR = COMPLETE

- Check for bias jumps. This is recorded in the history section of the header file for each group. Just do a search on the word “jump”

  imhead u2g40o05t.c0h[2] l+ | match jump

  results:

  Nothing was found. If the calibrated file was retrieved from the archive and the date of file creation (keyword DATE) was before August 1996, bias jumps will not be recorded because the bias jump detection software had not yet been installed in the pipeline.

  hedit u2g40o05t.c0h[1] DATE .

  result:

  u2g40o05t.c0h[1],DATE = 15/02/95

  The following is an example of the same dataset that had been recently recalibrated with a version of *calwp2* that has the bias jump detection software. The following bias jump detections were recorded in the .c0h header file:

  imhead u2g40o05t.c0h[2] l+ | match jump

  result:

  HISTORY WF2: bias jump level ~0.119 DN.
  HISTORY WF3: bias jump level ~0.115 DN.
  HISTORY WF4: bias jump level ~0.164 DN.

- Check the image header file to see if the most recent calibration files were used. Compare the reference file names listed in the header file with those recommended in STARVIEW (as outlined in section 1), or by checking the reference files list on the WFPC2 website at
  http://www.stsci.edu/ftp/instrument_news/WFPC2/Wfpc2_memos/wfpc2_reffiles.html

  Example:
  List the names of the reference files used in the pipeline calibration of image *u2g40o05t.c0h*.

  hedit u2g40o05t.c0h maskfile,atodfile,biasfile,darkfile,flatfile,shadfile .

  results:

u2g40o05t.c0h,MASKFILE = uref$e2112084u.r0h
u2g40o05t.c0h,ATODFILE = uref$dbu1405fu.r1h
u2g40o05t.c0h,BIASFILE = uref$f1j1615qu.r2h
u2g40o05t.c0h,DARKFILE = uref$f220923ju.r3h
u2g40o05t.c0h,FLATFILE = uref$e380935cu.r4h
u2g40o05t.c0h,SHADFILE = uref$e371355eu.r5h

Check STARVIEW to see if newer reference files are available for this image.

	USED	RECOMMENDED	LEVEL OF CHANGE	PERFORMED
A-to-D Correction:	DBU1405FU.R1H	DBU1405FU.R1H	NO CHANGE	COMPLETE
Bias Correction:	F1J1615QU.R2H	FCB1503AU.R2H	UNKNOWN	COMPLETE
Dark Current Correction:	F220923JU.R3H	F2H1134SU.R3H	UNKNOWN	COMPLETE
Flat Field Correction:	E380935CU.R4H	G640925NU.R4H	UNKNOWN	COMPLETE
Static Pixel Mask:	E2112084U.R0H	F8213081U.R0H	UNKNOWN	COMPLETE
Shutter Shading File:	E371355EU.R5H	E371355EU.R5H	NO CHANGE	OMIT
Engineering File:	U2G40O05T.X0H			COMPLETE
Photometry Cal. Table:	UCAL:U2G40O05T.C3T			COMPLETE
Graph Table:	E8210190M.TMG	H5L1440CM.TMG		
Components Table:	EAI1341PM.TMC	H7I13018M.TMC		

In this example, STARVIEW indicates that the bias, flat, dark, and mask reference files have changed since the initial pipeline calibration. (Recalibration is covered in section 3.)

ii) Check Data Quality Files

For each observation, a set of ascii data quality files are created, with the extensions *.pdq*, and *.trl.* The *.trl* file, generated during pipeline calibration, contains a log of calibration steps. The *.pdq* file contains information about the actual and predicted observational parameters, and any obvious features that may have been noted by the post-observation processing staff. You should page through these files to look for anything that would indicate a problem with the data.

Each science image (extensions .c0h and .c0d) has an associated data quality file (.c1h and .c1d) that provides information about the quality of each pixel in a science image. Bad pixels in the science image are flagged in the data quality image; these flagged pixels are designated non-zero positive values indicating the nature of the pixel problem (listed below). The values in the pixels are additive; a value of 3 would indicate a combination of 1 and 2.

Value	Description
0	**Good pixels.**
1	**Reed-Solomon decoding error. Pixels in a data packet that were corrupted during data transmission.**
2	**Defect in one of the calibration reference files used in calibration or recalibration. Includes charge transfer traps.**
8	**A-to-D converter saturation. Signal that is greater than or equal to the maximum AtoD value (4096).**
16	**Pixel value was lost during readout or data transmission.**
256	**Pixels lying above a charge transfer trap that may be affected by the trap.**
512	**Unrepairable hot pixel.**
1024	**Repairable hot pixel.**

How do I determine if any bad pixels fall on critical parts of my science image?

Blink the science and data quality images images. First, display the science image, then display the data quality file, and “blink” them.

Hint: When displaying the data quality image, first run *wstatistics* on the file to determine the minimum and maximum values. Set the lower and upper display ranges (*z1* and *z2* parameters) to match those minimum/maximum values (and be sure to set *zrange* and *zscale* to “no”). This will produce a display clearly showing the bad pixels. When the data quality file is displayed, place the cursor on the bad pixel to read its value on the image display tool. Remember that these displayed values are not exact, but are close enough for you to determine what the pixel value should be.

3.0 CALIBRATION AND RECALIBRATION

Data from HST is received at the Data Distribution Facility at Goddard, then sent to the Institute where it's fed into the Routine Science Data Processing (RSDP) system, also called the **pipeline**.

Raw image data from the spacecraft have known instrumental signatures that need to be removed. In the pipeline, raw images are calibrated to take out these features, using the best reference files available at the time. The raw and calibrated data are then sent by tape or by FTP (File Transfer Protocol) to the Principal Investigator, and also stored in the HST data archive. A copy of the pipeline calibration software, called *calwp2,* is available in STSDAS and can be accessed by loading the *stsdas.hst_calib.wfpc* packages. (Note that the *wfpc* package has tasks for both the wfpc1 and wfpc2 instruments.)

Sometimes, it may be necessary to recalibrate your data, depending on the condition of your data or your scientific goals. Newer and better reference files, such as better darks or flat fields, may have become available since the original pipeline calibration.

Each individual calibration step can be executed by setting a "switch" in the raw data header file. This way, if a particular calibration step is unnecessary, it does not have to be performed when you recalibrate the data using *calwp2*.

3.1 Input and Output Files in the Calibration Process

(The file extensions are noted in parenthesis.)

The input data files are:

- Raw data (.d0h, .d0d).
- Data quality files for raw science data (.q0h, .q0d).
- Standard header packet containing observation parameters (.shh, .shd) [Although a part of the raw data set, it is not used by *calwp2*].
- Note: The extracted engineering files (.x0d, .x0h), and its associated data quality files (.q1h, .q1d) are part of the raw dataset. But they are used during calibration and are therefore listed in the next category.

The input calibration reference files are:

- Static mask file (.r0h, .r0d).
- A-to-D (analog-to-digital converter) correction file (.r1h, .r1d).
- Extracted engineering data (.x0h, .x0d), and its data quality file (.q1h, .q1d). [This is the chip overscan area. It's a component of the raw dataset retrieved from the archive.]
- Bias image reference file (.r2h, .r2d), and its data quality file (.b2h, .b2d).

- Dark image reference file (.r3h, .r3d), and its data quality file (.b3h, .b3d). [Only used for exposures over 10s.]
- Flat field file (.r4h, .r4d), and its data quality file (.b4h, .b4d).
- Shutter shading correction (.r5h, .r5d). [Only used for exposures under 10s.]
- HST Graphs Table (.tmg) and Components Table (.tmc), throughput tables used to determine photometric information for a dataset.

After running *calwp2*, output files are:

- Calibrated science data (.c0h, .c0d).
- Data quality file for calibrated science data (.c1h, .c1d).
- Histogram of good science data pixel values (.c2h, .c2d) [optional].
- Photometric throughput table for the dataset (.c3t).
- Ascii file containing group parameters and their values (.cgr).

3.2 The Calibration Steps

<u>What are the calibration steps?</u>

Each calibration step that is performed, either in the pipeline or *calwp2,* is listed below in the order it is done:

1. The **static mask reference file (.r0h, .r0d)** identifies charge transfer traps and other pixels affected by the traps. This information is entered in the calibrated image data quality file (.c1h, .c1d). The image data (.c0h, .c0d) itself is not changed.
   The header keyword switch is **MASKCORR**.
   The header keyword indicating the calibration filename is **MASKFILE**.

2. The **A-to-D reference file (.r1h, .r1d)** corrects each pixel value of the science data for analog-to-digital conversion errors.
   The header keyword switch is **ATODCORR**.
   The header keyword indicating the calibration filename is **ATODFILE**.

3. A mean bias level is subtracted from each pixel in the science image. This value, one for each chip, is derived from a subset of the overscan region for that chip. The overscan regions are stored in the **extracted engineering file (.x0h, .x0d)**. (Its **data quality file (.q1h, .q1d)** contains bad pixel information that is also flagged in the calibrated science data quality file (.c1h, .c1d).)
   The header keyword switch is **BLEVCORR**.
   The header keyword indicating the calibration filename is **BLEVFILE**.
   The header keyword indicating the calibration data quality filename is **BLEVDFIL**.

4. Position-dependent bias patterns are subtracted from the science data using the **bias pattern reference file**, also referred to as the **superbias file (.r2h, .r2d)**. Bad pixels in the bias pattern

reference file are recorded in its **data quality file (.b2h, .b2d)**, and are also flagged in the science data quality file (.c1h, .c1d) during calibration.
The header keyword switch is **BIASCORR**.
The header keyword indicating the calibration filename is **BIASFILE**.
The header keyword indicating the calibration data quality filename is **BIASDFIL**.

5. The **dark reference file (.r3h, .r3d)**, and its **data quality file (.b3h, .b3d)**, are generated about every week. Dark reference files are only needed for observations with DARKTIME values greater than 10s.
The header keyword switch is **DARKCORR**.
The header keyword indicating the calibration filename is **DARKFILE**.
The header keyword indicating the calibration data quality filename is **DARKDFIL**.

6. The science image is multiplied with a **flat field reference image (.r4h, .r4d)**. Information about bad pixels in the flat field reference image is found in its **data quality file (.b4h, .b4d)**, and flagged in the science image data quality file (.c1h, .c1d) during calibration.
The header keyword switch is **FLATCORR**.
The header keyword indicating the calibration filename is **FLATFILE**.
The header keyword indicating the calibration data quality filename is **FLATDFIL**.

7. For exposures less than 10 seconds, a **shutter shading correction file (.r5h, .r5d)** must be applied to the science data. This is necessary because the finite shutter velocity creates a "shading" effect in the image. This "shading" effect also depends on which of the two shutters is used (either shutter A or B).
The header keyword switch is **SHADCORR**.
The header keyword indicating the calibration filename is **SHADFILE**.

8. In order to populate photometry-related keywords in the calibrated science header files, set the keyword switch DOPHOTOM in the ".d0h" file to ***PERFORM***. During calibration, values for the following keywords will be obtained:
PHOTMODE
PHOTFLAM
PHOTPLAM
PHOTBW
PHOTZPT

This step uses two tables, a **graph table (.tmg)** and a **component table (.tmc)** containing telescope and instrument throughput information. These tables are often updated for all on-board HST instruments as new results from ongoing calibration activities become available. To find out the names of the latest WFPC2 throughput tables, see the WFPC2 Synphot memo at
http://www.stsci.edu/ftp/instrument_news/WFPC2/Wfpc2_phot/wfpc2_synphot.html

For example, as of January 21, 1998, the latest WFPC2 throughput tables were

h5g10115m.tmc
h5l1440cm.tmg

This calibration step will not change the data values, it will only populate the header photometry keywords. This is useful for people who plan to use a flux-based photometric system such as the AB or STMAG system. More information about different photometric systems can be found in section 4, and the WFPC2 section of the HST Data Handbook.

In addition, a throughput table (.c3t) will be created by *calwp2* using the *Synphot* program.

The header keyword switch is **DOPHOTOM**.
The header keywords indicating the calibration tables are **GRAPHTAB** for the graph table (.tmg), and **COMPTAB** for the components table (.tmc).

9. An optional calibration step is to generate a file containing histograms of raw data, A-to-D corrected data, and the final calibrated output data for each group. This file (.c2h, .c2d) will contain histograms of raw data in row 1, A-to-D corrected data in row 2, and the final calibrated data in row 3.
   The header keyword switch is **DOHISTOS**.

10. The image datatype is specified in the input image header file.
    The header keyword is **OUTDTYPE**, and can be set to either REAL, LONG or SHORT.

Note: During the calibration process, *calwp2* detects saturated pixels in the raw image file (.d0h, .d0d), and flags them in the calibrated data quality file (.c1h, .c1d). Therefore, the keyword switch **DOSATMAP**, which creates an image map of saturated pixels is unnecessary, and should be set to OMIT.

More information on the calibration steps can be obtained from the WFPC2 section in the HST Data Handbook (Volume 1, version 3, dated October 1997).

3.3 The Calibration Procedure

Recalibrating the dataset *u2g40o05t*

Using *xstarview*, check the **used** and **recommended** reference files for dataset *u2g40o05t.* (See section 1 for instructions)

Example: Calibration reference files needed for *u2g40o05t* from *xstarview*:

	USED	RECOMMENDED	CHANGE	PERFORMED
A-to-D Correction:	**DBU1405IU.R1H**	**DBU1405FU.R1H**	**NO CHANGE**	**COMPLETE**
Bias Correction:	**F1J1615QU.R2H**	**FCB1503AU.R2H**	**UNKNOWN**	**COMPLETE**
Dark Current Correction:	**F220923JU.R3H**	**F2H1134SU.R3H**	**UNKNOWN**	**COMPLETE**
Flat Field Correction:	**E380935CU.R4H**	**G640925NU.R4H**	**UNKNOWN**	**COMPLETE**
Static Pixel Mask:	**E2112084U.R0H**	**F8213081U.R0H**	**UNKNOWN**	**COMPLETE**

Shutter Shading File:	**E371355EU.R5H**	**E371355EU.R5H**	**NO CHANGE**	**OMIT**
Engineering File:	**U2G40O05T.X0H**			**COMPLETE**
Photometry Cal. Table:	**U2G40O05T.C3T**			**COMPLETE**
Graph Table:	**E8210190M.TMG**	**H5L1440CM.TMG**	**UNKNOWN**	
Components Table:	**EAI1341PM.TMC**	**F5211373M.TMC**	**UNKNOWN**	

For this dataset, some new reference files have become available since the data was originally calibrated: superbias file, dark correction file, flat field file, static pixel mask, as well as graph and component tables. Since there are several new reference files, it would be advisable to recalibrate this dataset before proceeding with data analysis. But this may not always be the case; please refer to the HST Data Handbook and WFPC2 Instrument Handbook to determine if your data needs to be recalibrated.

Each calibration step will be executed in *calwp2* if the input image header keyword "switch" is set to ***PERFORM***. The step will not be executed if the "switch" is set to ***OMIT***.

Below is an excerpt of a raw data header file (.d0h) showing the calibration keyword switches./
RSDP CONTROL KEYWORDS

		/ RSDP CONTROL KEYWORDS
MASKCORR=	**'PERFORM**	**'/Do mask correction: PERFORM, OMIT, COMPLETE**
ATODCORR=	**'PERFORM**	**'/Do A-to-D correction: PERFORM, OMIT, COMPLETE**
BLEVCORR=	**'PERFORM**	**'/Do bias level correction: PERFORM, OMIT, COMPLETE**
BIASCORR=	**'PERFORM**	**'/Do bias correction: PERFORM, OMIT, COMPLETE**
DARKCORR=	**'PERFORM**	**'/Do dark correction: PERFORM, OMIT, COMPLETE**
FLATCORR=	**'PERFORM**	**'/Do flat field correction: PERFORM, OMIT, COMPLETE**
SHADCORR=	**'OMIT**	**'/Do shaded shutter correction: PERFORM, OMIT, COMPLETE**
DOSATMAP=	**'OMIT**	**'/Output saturated pixel map: PERFORM, OMIT, COMPLETE**
DOPHOTOM=	**'PERFORM**	**'/Fill photometry keywords: PERFORM, OMIT, COMPLETE**
DOHISTOS=	**'OMIT**	**'/Make histograms: PERFORM, OMIT, COMPLETE**
OUTDTYPE=	**'REAL**	**'/Output image datatype: REAL, LONG, SHORT**

The following is an excerpt from the raw data header file, *u2g40o05t.d0h*, listing the calibration reference files (**uref**, **ucal**, and **mtab** are IRAF pointers to files--more on this later.):

		/ CALIBRATION REFERENCE FILES
MASKFILE=	**'uref$e2112084u.r0h**	**'/name of the input DQF of known bad pixels**
ATODFILE=	**'uref$dbu1405fu.r1h**	**'/name of the A-to-D conversion file**
BLEVFILE=	**'ucal$u2g40o05t.x0h**	**'/Engineering file with extended register data**
BLEVDFIL=	**'ucal$u2g40o05t.q1h**	**'/Engineering file DQF**
BIASFILE=	**'uref$f1j1615qu.r2h**	**'/name of the bias frame reference file**
BIASDFIL=	**'uref$f1j1615qu.b2h**	**'/name of the bias frame reference DQF**
DARKFILE=	**'uref$f220923ju.r3h**	**'/name of the dark reference file**
DARKDFIL=	**'uref$f220923ju.b3h**	**'/name of the dark reference DQF**
FLATFILE=	**'uref$e380935cu.r4h**	**'/name of the flat field reference file**
FLATDFIL=	**'uref$e380935cu.b4h**	**'/name of the flat field reference DQF**
SHADFILE=	**'uref$e371355eu.r5h**	**'/name of the reference file for shutter shading**
PHOTTAB =	**'**	**'/name of the photometry calibration table**

GRAPHTAB=	**'mtab$e8210190m.tmg**	**'/the HST graph table**
COMPTAB=	**'mtab$eai1341pm.tmc**	**'/the HST components table**

How do I set the new reference files and switches for recalibration?

Before running *calwp2*, the appropriate calibration files and calibration "switches" have to be set in the raw image header file (.d0h,). One way to do this is using the task *chcalpar* (found in the package *stsdas.hst_calib.ctools*).

chcalpar (CHange CALibration PARameters) is an easy way to edit GEIS header files. It is actually a task that calls other related tasks called "psets". When *chcalpar* is executed, it looks at the data to determine which instrument was used. Since our datasets are WFPC2 images, *chcalpar* will call the pset *ckwwfp2* to edit the raw image header file.

Example

chcalpar u2g40o05t.d0h

This command will call the WFPC2 pset *ckwwfp2* which will then list all the default header keyword switches and reference files for *u2g40o05t.d0h*.

(maskcor=	**perform)**	**>do mask correction?**
(atodcor=	**perform)**	**>Do A-to-D correction??**
(blevcor=	**perform)**	**>do bias level correction?**
(biascor=	**perform)**	**>do bias correction?**
(darkcor=	**perform)**	**>do dark correction?**
(flatcor=	**perform)**	**>do flat field correction?**
(shadcor=	**omit)**	**>Do shaded shutter correction?**
(dophoto=	**perform)**	**>fill photometry keywords?**
(dohisto=	**omit)**	**>Make histograms?**
(outdtyp=	**real)**	**>output image data type?**
(maskfil=	**uref$e2112084u.r0h)**	**>name of the input DQF of known bad pixels**
(atodfil=	**uref$dbu1405fu.r1h)**	**>name of the A-to-D conversion**
(blevfil=	**ucal$u2g40o05t.x0h)**	**>engineering file with extended register data**
(blevdfi=	**ucal$u2g40o05t.q1h)**	**>engineering file DQF**
(biasfil=	**uref$f1j1615qu.r2h)**	**>name of the bias frame reference file**
(biasdfi=	**uref$f1j1615qu.b2h)**	**>name of the bias frame reference DQF**
(darkfil=	**uref$f220923ju.r3h)**	**>name of the dark reference file**
(darkdfi=	**uref$f220923ju.b3h)**	**>name of the dark reference DQF**
(flatfil=	**uref$e380935cu.r4h)**	**>name of the flat field reference file**
(flatdfi=	**uref$e380935cu.b4h)**	**>name of the flat field reference DQF**
(shadfil=	**uref$e371355eu.r5h)**	**>name of the reference file for shaded shutter c**
(phottab=	**)**	**>name of the photometry calibration table**
(graphta=	**mtab$e8210190m.tmg)**	**>the HST graph table**
(comptab=	**mtab$eai1341pm.tmc)**	**>the HST components table**
(instrum=	**wfpc2)**	**Instrument represented by this pset**
(Version=	**14Feb94)**	**Date of Installation**
(mode=	**al)**	

- Edit the parameters to enter new reference filenames and switch settings, based on recommendations from starview, or from the WFPC2 reference file memo located at
  http://www.stsci.edu/ftp/instrument_news/WFPC2/Wfpc2_memos/wfpc2_reffiles.html
  When completed, type **:q** .

- The screen will reappear, but this time, the fields will be blank except for the new entries. Verify that the changes are correct and enter additional changes if necessary. When completed, type **:q** .

- A prompt will appear asking "**accept current parameters?**" with the options **no**, **yes**, and **abort**. If you wish to proceed in entering the new reference filenames and switches in the raw image header file (.d0h), type **yes** .

Please refer to the STSDAS on-line help files *calwp2*, *ckwwfp2*, and *chcalpar* for more details.

How do I run *calwp2*?

- Before running *calwp2*, be sure that pointers to the location of reference files are set up properly. **uref$, ucal$,** and **mtab$** are pointers to directories where reference files are stored. They are prefixes to the calibration filenames specified by the keywords in the image header. These pointers must be set before running *calwp2*.

  As an example, assume the raw data are located at **/data/whimbrel1/science/**, and *calwp2* will be run in that directory. And assume all reference files are located at **/data/whimbrel1/ref/** . In IRAF, set the pointers by typing

  set uref = /data/whimbrel1/ref/
  set ucal = /data/whimbrel1/science/
  set mtab = /data/whimbrel1/ref/

  You can verify that the pointers were set correctly by using the IRAF *show* command,

  show uref

  gives

  /data/whimbrel1/ref/

- After all this, running *calwp2* is easy. At the IRAF prompt, type

  calwp2 u2g40o05t u2g40o05t

  In this example, the calibrated science data will have the same rootname as the raw science data, with the c0h/.c0d extension.

3.4 A Closer Look at the Calibration Process

What happens to the pixels at each stage of the calibration process?

The best way to understand the calibration process is to manually perform each step in the calibration pipeline, tracing a couple of pixels from the beginning to the end of the process. To do this, pick two unsaturated pixels in your raw science image, (x1,y1) and (x2,y2), and make a note of their raw data values, and location in their chip.

1. Perform the mask correction

What are the new science data pixel values?

Background: The static pixel mask reference file contains a map of permanently bad pixels. Currently, only two types of bad pixels are flagged: charge transfer traps (assigned the value 2) and pixels above charge transfer traps that are affected by the traps (assigned the value 256). This mask file is copied to the calibrated data quality file (.c1h, .c1d).

Hint: The mask correction only updates the data quality file (.c1h, .c1d) with information about bad pixels. The science data is not changed. But be sure to check (x1,y1) and (x2,y2) to make sure they are not affected by the traps.

2. Perform the A-to-D correction

What are the new science data pixel values?

Background: Each CCD pixel absorbs energy from photons of light that impinge upon it, releasing electrons within the semiconductor. The accumulated electrons from a particular pixel are trapped in a specific location corresponding to that pixel. The analog-to-digital converter (ADC) is a device that converts the CCD pixel voltage signal (from trapped electrons) to Data Numbers (DNs) that can be stored in computer memory. For the WFPC2, the ADC has a range of 12 bits--4096 possible values ranging from 0 to 4095. In order to effectively "scale" the accumulated signal for storage, users can specify a **gain** of 7 electrons/DN or 14 electrons/DN. The choice of gain setting depends on the scientific objectives of the observations. (For more information, see the WFPC-2 Instrument Handbook (version 4.0), page 65-66, and for a general overview of CCDs, please refer to **Electronic and Computer-aided Astronomy: From Eyes to Electronic Sensors**, by Ian McLean.)

The A-to-D converter has a known problem; certain DN values are reported more (or less) frequently than a perfect device. The A-to-D converter therefore produces small errors when converting from electrons to DN values. Although the "true" DN values can never be recovered, the errors are systematic and a statistical correction can be applied. (The largest correction for WFPC2 is 0.1%.)

In theory, the A-to-D correction is a function of temperature. The A-to-D conversion reference file is a matrix of values for each chip; the first row contains possible temperature values for Bay 3. The second and subsequent rows, with each row corresponding to a particular temperature, contain A-to-D conversion corrections for each DN value between 0 to 4095.

The example below illustrates the structure of an A-to-D converter correction file with conversion values for five different temperatures. The first row has 5 temperature values, t1 to t5. The second row has the DN corrections corresponding to temperature t1--there are 4096 columns, with the first column containing the correction value for a raw DN value of 0, and 4096th column containing the correction for the raw DN value of 4095. The third row has the corrections for temperature t2, the 4th row for temperature t3, etc..

	(col 1)	**(col 2)**	**(col 3)**	**(col 4)**	**(col 5)**	**. . . . .(col 4096)**
(row 1)	----	*t1*	*t2*	*t3*	*t4*	*t5*
(row 2)	0_t1	1_t1	2_t1	3_t1	4_t1	. . . . .4095_t1
(row 3)	0_t2	1_t2	2_t2	3_t2	4_t2	. . . . .4095_t2
(row 4)	0_t3	1_t3	2_t3	3_t3	4_t3	. . . . .4095_t3
(row 5)	0_t4	1_t4	2_t4	3_t4	4_t4	. . . . .4095_t4
(row 6)	0_t5	1_t5	2_t5	3_t5	4_t5	. . . . .4095_t5

The A-to-D reference file was created from data taken during WFPC2 Thermal Vacumn tests before launch. On-orbit checks have determined that the conversion values have remained constant. Therefore, only the conversion values for a single temperature setting is necessary. Current reference files have the dimension 4096x2. Row 1 has one temperature entry, at [2,1], and all other values in row 1 are set to -1 (null value). Row two is the lookup table for this temperature, and has 4096 columns.

Example:
Determine the A-to-D correction for a DN value of 317 for the WF2 chip.

This correction can be found in group 2 of the A-to-D reference file, at location [317+1,2]. The task *listpix* can be used to obtain the correct DN value to be substituted in the calibrated data files (.c0h, .c0d).

listpix dbu1405fu.r1h[2][318,2]

Result:

1. 316.8434

During the A-to-D correction step in the calibration, all DN values of 317 in group 2 of the raw image data are changed to 316.8434.

3. Perform the bias level correction

What are the global bias values for even (BIASEVEN) and odd (BIASODD) columns?
What are the science data pixel values (x1,y1) and (x2,y2) after subtracting its global bias value?

Background: A pedestal of about 300 DN is introduced into the signal chain to prevent the occurence of negative numbers. A mean value for this bias level can be obtained in the CCD overscan region stored in the engineering files (.x0d, .x0h) that accompany each WFPC2 dataset. (The overscan area is obtained as the CCD electronics continues to read-out even though there is no longer any physical correspondence to the chip.)

The mean bias value is slightly different for even and odd columns. During calibration, mean bias values are determined for the even and odd columns of the science image, derived using a subsection of the overscan region. These values are stored in the science image header keywords BIASEVEN and BIASODD, respectively. The mean bias levels are then subtracted from the science image; the BIASEVEN value from even columns of the science image, and the BIASODD value from the odd columns of the science image.

The mean bias levels are calculated from a subsection of the overscan image (.x0h,.x0d) at [9:14,10:790]. Columns 9, 11, and 13 in the overscan region are used to obtain the BIASEVEN value. Columns 10, 12, and 14 are used to derive a value for BIASODD. (This nomenclature, where odd columns in the engineering file are used to determine the mean bias level of even columns in the science image, and vice versa, is due to an offset between the overscan region and the image.)

Hints:

- Determine if (x1,y1) and (x2,y2) in the science image fall on even or odd columns.
- Determine the mean bias level for even and odd columns (BIASEVEN and BIASODD) for each chip, using the overscan region of that chip in the engineering file (.x0d, .x0h). Use a task like *imstat* to get mean values of the appropriate sections in the overscan image.
- Subtract the bias level (either BIASEVEN or BIASODD) from the value of the science data pixel, depending on whether the image pixel falls in an even or odd column.

4. Perform a bias correction

What are the pixel values in the bias correction file?
What are the new science data pixel values?

Background: After subtracting the global bias values from the image, there still remains small scale bias values that vary from pixel-to-pixel. These are removed by subtracting a bias correction reference image (.r2h, .r2d) from the science image. This bias reference file, or “superbias”, is generated annually using 120 individual bias frames that were corrected for A-to-D conversion errors and had their global bias levels subtracted.

Hint: Look up the pixel values in the bias correction file (.r2h, .r2d) at positions (x1,y1) and (x2,y2). Subtract that bias correction value from the science data pixels.

5. Perform a dark correction

What are the pixel values in the dark file?
What are the new science data pixel values?

Background: Thermally-induced dark currents, as well as a faint "glow" caused by cosmic rays striking the corrector plates, make dark corrections necessary for exposures greater than 10s. This correction is done by subtracting a dark reference image from the science image.

The dark reference image has two components: one is a "superdark" generated from 120 individual dark images. The second is hot pixel information derived from five darks taken during the week of the science observations. Therefore, a new dark reference file is generated every week using the same superdark, but containing weekly-updated hot pixel information. Dark reference files used in standard processing are therefore always out-of-date by a week or two. Depending on the data analysis goals, a user may wish to recalibrate the data with an up-to-date dark reference file, or run the *warmpix* task to identify hot pixels. Please refer to the HST Data Handbook for more information.

Each dark reference image is normalized to a 1s exposure time. Therefore, when it is applied to the science data, the dark file is first scaled to the science image by multiplying it with the DARKTIME keyword value in the raw science data header file (.d0h). (DARKTIME is defined as the total time from the start of an exposure to the beginning of readout. The pipeline approximates this "darktime" by setting it equal to the exposure time.)

Hint: Look up the pixel values of (x1,y1) and (x2,y2) in the dark reference file. Remember that the dark file has been normalized to 1 second. Therefore, to correct for exposure time, look up the keyword DARKTIME in the raw image header file. Multiply the dark file pixel value by the DARKTIME value. Then, subtract the correctly-scaled dark value from the science data pixel value.

6. Flat field the image

What are the pixel values in the flat field image?
What are the new science data pixel values?

Background: The photometric response in the science image varies over the field-of-view. There are several reasons for this effect. Each CCD pixel has its own unique quantum efficiency. Each chip has a slightly different electronic gain. Large-scale vignetting of the field is caused by the telescope and WFPC2 mirrors, their support structures, and WFPC2 filters. Optical distortions are introduced by field flatteners in front of each chip, causing the sky area per pixel at a chip corner to be about 5% smaller than at the chip center. A manufacturing defect affecting every 34th row in the CCDs also reduces sky coverage per pixel. Even dust particles on the pyramid, CCD window,and detectors cause artifacts. Most electronic effects were characterized during pre-launch thermal vacumn testing, while large-scale optical effects were determined from on-orbit earth flats. The flat field file corrects for these sensitivity variations in the science image.

Hint: Look up the pixel values for (x1,y1) and (x2,y2) in the flat field file. Multiply the science pixel values with their corresponding flat field pixel values. (Note: The flat fields have been inverted to be consistent with other multiplicative reference files used in the pipeline calibration.)

7. Shutter Shading Correction

Was a shutter shading correction necessary for this dataset?

Background: The WFPC2 has two shutter blades. When an exposure begins, one shutter blade is moved off the light path. The exposure ends when the second shutter blade moves to block the light path. Although the blades move rapidly, their finite motion can cause exposure time variations over the field-of-view for total exposure times of 1s or less. The calibration software automatically applies a shutter shading correction to images with total exposure times less than 10s. The two shutters have slightly different speeds; therefore, there are two different correction files depending on which blade was moved out of the way at the beginning of the exposure.

Hint: Exposure times less than 10 seconds require a shutter shading correction. Below is an example of applying this correction using the IRAF task *imcalc*:

imcalc sci_image, shutter out_image “im1 * (1 + (im2 / <exposure time>))”

As a final check, compare the (x1,y1) and (x2,y2) values from the step-by-step calibration with the pixel values in the previously-calibrated images. Do they agree to 3 decimal places? If “no”, you may want to check your steps for errors.

3.5 Using the *warmpix* Task

This task is located in *stsdas.hst_calib.wfpc*.

If the only new "recommended" reference file for a dataset, as suggested by Starview or the WFPC2 reference file memo, is the dark reference file, a user may wish to forego recalibration, and simply fix the hot pixels in the image. This is only applicable to images taken after July 1996. (Images prior to that were not calibrated with dark reference files made from superdarks.) Not all images require warm pixel correction; it depends very much on the observer’s scientific goals. To determine if running *warmpix* is necessary for your dataset, please refer to a detailed discussion in the HST Data Handbook (v3.0) pages 26-17 to 26-19.

Warm pixels are CCD pixels that have an elevated dark current. Some warm pixels are permanent, but most are transient, likely created by the on-orbit bombardment by heavy cosmic ray nuclei. As a result, the distribution of warm pixels in the CCDs changes over time. Most warm pixels are removed during monthly decontaminations, when the CCD's operating temperature is raised to 22°C for about 6 hours to remove contaminants that degrade UV throughput. WFPC2 images are processed in the calibration pipeline within hours of reaching the ground. The dark calibration files used are generally out-of-date and cannot accurately correct for warm pixels.

The *warmpix* task allows a user to determine the location of warm pixels, and in some cases, perform a correction. It takes the following input files: calibrated science image, calibrated science image data quality file, dark and flat field reference files, and a list of hot pixels. The dark and flat field reference files must be the same as those used to calibrate the image, and may be retrieved from the archive. The hot pixel table (generated monthly by the WFPC2 group) identifies and tracks all hot pixels that occurred within a 4-week time period (between decontaminations), and can be downloaded from

http://www.stsci.edu/ftp/instrument_news/WFPC2/wfpc2_warmpix.html

In the example below, *warmpix* is run on dataset *u2g40o05t* :

- First, find the date of the observation, and the names of the dark and flat reference files used to calibrate the dataset.

  hedit u2g40o05t.c0h date-obs,darkfile,flatfile .

  Result:

  u2g40o05t.c0h,DATE-OBS = 15/02/95
  u2g40o05t.c0h,DARKFILE = uref$f2h1134su.r3h
  u2g40o05t.c0h,FLATFILE = uref$g640925nu.r4h

<u>Note:</u> This image was taken prior to July 1996. It's better to recalibrate it with a superdark instead of running *warmpix* on it. However, for the purpose of illustrating the steps in this task, we will assume otherwise.

- Retrieve the dark and flat reference files (the ones originally used to calibrate the image, as shown above) from the archive. Place them in a subdirectory, then set the *uref* pointers (as described in section 3.3) to that subdirectory (Assume, for this example, that the reference files are placed in /data/whimbrel1/ref/).

  set uref = /data/whimbrel1/ref/

- Download the hot pixel table corresponding to the observation date from the hot pixel web site. For this dataset, the hot pixel table that corresponds to the observation date is *decon_950212_950311.tab*. Place it in the directory containing the science data and its data quality images. Remember that the table has to be first uncompressed.

!mv decon_950212_950311.tab decon_950212_950311.tab.Z
!uncompress decon_950212_950311.tab.Z

- Run the *warmpix* task.
  Listed below are the parameters for the *warmpix* task:

PACKAGE = wfpc
TASK = warmpix

input = u2g40o05t.c0h	**input image(s)**
masks = u2g40o05t.c1h	**input mask(s)**
tables = decon_950212_950311.tab	**input warm pixel table(s)**
rej_thre = 0.1	**rejection threshold (DN/sec)**
fix_thre = 0.003	**fixing threshold (DN/sec)**
var_thre = 0.003	**variance threshold (DN/sec)**
(fix_dqv = 1024)	**Data quality value for fixed pixels**
(rej_val = INDEF)	**Pixel value for rejected pixels**
(runagai = no)	**Rerun this task on images which ran this task be**
(verbose = yes)	**print out verbose message?**
(mode = al)	

To run the task, type:

warmpix u2g40o05t.c0h u2g40o05t.c1h decon_950212_950311.tab 0.1 0.003 0.003

Note: it is not necessary to specify the dark and flat field reference files in the *warmpix* parameters because *warmpix* gets their names from the image header file keywords DARKFILE and FLATFILE.

4.0 Photometry: Converting DNs to a Magnitude

This section illustrates the use of aperture photometry to obtain the V and I magnitudes of two stars in the PC, and two stars in WF3. Other methods, such as PSF-fitting photometry, surface photometry, and narrow-band photometry, are not covered in this document. For more details on these methods, please refer to the following sources of information:

1. PSF-fitting Photometry:
   Please refer to the WFPC2 PSF page, in particular, to papers by Surdej et al., and Remy et al., at
   http://www.stsci.edu/ftp/instrument_news/WFPC2/wfpc2_psf_page.html

2. Narrow-band Photometry:
   FAQ located at
   http://www.stsci.edu/ftp/instrument_news/WFPC2/Wfpc2_faq/wfpc2_nrw_phot_faq.html

3. Surface Photometry:
   STSDAS has a software package for surface photometry called isophote (stsdas.analysis.isophote). Please refer to the on-line help files for more information on this method.

Many useful papers on WFPC2 photometry can also be found in the WFPC2 Clearinghouse at
http://www.stsci.edu/ftp/instrument_news/WFPC2/Wfpc2_clear/wfpc2_clrhs.html

Some general background information on photometry:

- There are five filters in the WFPC2 that are similar (but not identical) to the Johnson U, B, V filters, and the Cousins R, I filters. These are, respectively, **F336W, F439W, F555W, F675W,** and **F814W**.

- The **ST magnitude** is the Space Telescope magnitude system, based on a spectrum with constant flux per unit wavelength. This is different from the conventional photometric (Vegamag) systems that use the spectrum of Vega to define a magnitude zeropoint.

- Additional information about WFPC2 photometry can be obtained from the WFPC2 home page, the HST Data Handbook, and from the two papers by Holtzman et al. mentioned at the beginning of this document.

Obtaining Magnitudes of Stars in WFPC2 Images

The example below outlines a step-by-step procedure for measuring the magnitudes of four stars, two in the PC and two in WF3, using F555W and F814W images retrieved from the archive in section 1, and recalibrated in section 3.

Filter	Images (CR-SPLIT Pairs)	Star ID	(x,y) Chip Position	ID from Harris, (AJ 105, p 1196)
F555W	u2g40o05t.c0h[1], u2g40o06t.c0h[1]	1	315,191	1461
F555W	u2g40o05t.c0h[1], u2g40o06t.c0h[1]	2	314,662	1714
F555W	u2g40o05t.c0h[3], u2g40o06t.c0h[3]	3	327,222	4111
F555W	u2g40o05t.c0h[3], u2g40o06t.c0h[3]	4	380,576	917
F814W	u2g40o09t.c0h[1], u2g40o0at.c0h[1]	1	315,191	1461
F814W	u2g40o09t.c0h[1], u2g40o0at.c0h[1]	2	314,662	1714
F814W	u2g40o09t.c0h[3], u2g40o0at.c0h[3]	3	327,222	4111
F814W	u2g40o09t.c0h[3], u2g40o0at.c0h[3]	4	380,576	917

4.1 Combine The Image Pairs

Determine if the image pairs for each filter are registered. This can be crudely done by blinking the images, or measuring the position of several stars (using *imexam*) in each image to verify if their positions are identical. In general, consecutive observations with the same pointing using the same guide stars will not show any offsets. But if the exposure is long, and one of the Fine Guidance Sensors loses track of its guide star, a small drift in the telescope roll is possible, resulting in a slightly trailed image. Such problems are always documented in the data quality reports (.pdq files) that accompany each dataset, retrievable from the archive. Also, principal investigators of observations affected by pointing anomalies are contacted via e-mail by the institute.

Note: the best way to measure offsets between images is to use the *crosscor* task in *stsdas.analysis.fourier*. This method is also used for determining offsets between dithered images, and a version of this task can be found in the *dither* package, *stsdas.analysis.dither*. For more information about dithering, please see the HST Data Handbook and WFPC2 website.

If the images have the same pointing (and they should for these datasets), use *crrej* to combine the images (as described in section 2.4.6):

Combine u2g40o05t.c0h & u2g40o06t.c0h to create u2g40o05_6.c0h (F555W observations)
Combine u2g40o09t.c0h & u2g40o0at.c0h to create u2g40o09_a.c0h (F814W observations)

The resulting image will have the total exposure time of the two input images

4.2 Look-up Some Useful Image Header Keywords

For groups 1 and 3 of each image, obtain the following keyword values from the header file using hedit or hselect: FILTNAM1, EXPTIME, and ATODGAIN.

Example:

hsel *.c0h[1] $I,FILTNAM1,EXPTIME,ATODGAIN yes

results:

u2g40o05_6.c0h[1]	**F555W**	**32.**	**15.00000000000**
u2g40o05t.c0h[1]	**F555W**	**16.00000000000**	**15.00000000000**
u2g40o06t.c0h[1]	**F555W**	**16.00000000000**	**15.00000000000**
u2g40o09_a.c0h[1]	**F814W**	**28.**	**15.00000000000**
u2g40o09t.c0h[1]	**F814W**	**14.00000000000**	**15.00000000000**
u2g40o0at.c0h[1]	**F814W**	**14.00000000000**	**15.00000000000**

hsel *.c0h[3] $I,FILTNAM1,EXPTIME,ATODGAIN yes

results:

u2g40o05_6.c0h[3]	**F555W**	**32.**	**15.00000000000**
u2g40o05t.c0h[3]	**F555W**	**16.00000000000**	**15.00000000000**
u2g40o06t.c0h[3]	**F555W**	**16.00000000000**	**15.00000000000**
u2g40o09_a.c0h[3]	**F814W**	**28.**	**15.00000000000**
u2g40o09t.c0h[3]	**F814W**	**14.00000000000**	**15.00000000000**
u2g40o0at.c0h[3]	**F814W**	**14.00000000000**	**15.00000000000**

4.3 Measure the Counts for Each Star

We will make our measurements of the four stars using the task *phot* in *noao.digiphot.apphot*.

Note: if you wish to measure a lot of stars in the image, the task *daofind*, in the same package, can be used to identify the stars and make a coordinate list to be used as input to the *phot* task. See the WFPC2 Instrument Science Report 95-04 for an example of running *daofind*.

4.3.1 Create a Coordinate List for the Stars

For each chip, create a file containing the coordinates of the stars.

Examples:

For the PC, the file "coor_grp1" contains:
315 191
314 662

For the WF3, the file "coor_grp3" contains:
327 222
380 576

4.3.2 Set the Parameters for the *phot* Task

Listed below is an example of parameters for *phot*. Some of the parameters are non-default values. Here, we use the coordinate input file "coor_grp1" (**coords=coor_grp1**), run the task non-interactively (**interactive=no**), and choose not to verify critical parameters while running the task (**verify=no**).

PACKAGE = apphot
TASK = phot

image = "image.c0h"	**Input image**
skyfile = " "	**Sky file**
(coords = "coor_grp1")	**Coordinate list**
(output = "default")	**Results file**
(plotfile = " ")	**File of plot metacode**
(datapars = " ")	**Data dependent parameters**
(centerpars = " ")	**Centering parameters**
(fitskypars = " ")	**Sky fitting parameters**
(photpars = " ")	**Photometry parameters**
(interactive = no)	**Mode of use**
(radplots = no)	**Plot the radial profiles in interactive mode**
(verify = no)	**Verify critical parameters in non-interactive m**
(update = no)	**Update critical parameters in non-interactive m**
(verbose = no)	**Print messages in non-interactive mode**
(graphics = "stdgraph")	**Graphics device**
(display = "stdimage")	**Display device**
(icommands = " ")	**Image cursor: [x y wcs] key [cmd]**
(gcommands = " ")	**Graphics cursor: [x y wcs] key [cmd]**
(mode = "ql")	

Other "sub-tasks" are called by *phot*, called psets (parameter sets):

datapars - Edit the data dependent parameters (*noao.digiphot.apphot*)
centerpars - Edit the centering parameters (*noao.digiphot.appho*t)
fitskypars - Edit the sky fitting parameters (*noao.digiphot.apphot*)
photpars - Edit the photometry parameters (*noao.digiphot.apphot*)

- Listed below are the parameters for *datapars*. Non-default parameters are set for specifying a gain of 14 (**epadu=14**), and the filter keyword (**filter=filtnam1**).

PACKAGE = apphot
TASK = datapars

(scale = 1.)	**Image scale in units per pixel**
(fwhmpsf = 2.5)	**FWHM of the PSF in scale units**
(emission = yes)	**Features are positive ?**
(sigma = INDEF)	**Standard deviation of background in counts**
(datamin = INDEF)	**Minimum good data value**

(datamax = INDEF)	**Maximum good data value**
(noise = “poisson”)	**Noise model**
(ccdread = “ ”)	**CCD readout noise image header keyword**
(gain = “ ”)	**CCD gain image header keyword**
(readnoise = 0.)	**CCD readout noise in electrons**
(epadu = 14.)	**Gain in electrons per count**
(exposure = “exptime”)	**Exposure time image header keyword**
(airmass = “ ”)	**Airmass image header keyword**
(filter = “filtnam1”)	**Filter image header keyword**
(obstime = “ ”)	**Time of observation image header keyword**
(itime = 1.)	**Exposure time**
(xairmass = INDEF)	**Airmass**
(ifilter = “INDEF”)	**Filter**
(otime = “INDEF”)	**Time of observation**
(mode = “ql”)	

- Listed below are the parameters for *centerpars*. Here, we use the centroiding algorithm for determining the star’s positions by setting **calgorithm=centroid**.

PACKAGE = apphot
TASK = centerpars

(calgorithm = “centroid”)	**Centering algorithm**
(cbox = 5.)	**Centering box width in scale units**
(cthreshold = 0.)	**Centering threshold in sigma above background**
(minsnratio = 1.)	**Minimum signal-to-noise ratio for centering alg**
(cmaxiter = 10)	**Maximum number of iterations for centering algo**
(maxshift = 1.)	**Maximum center shift in scale units**
(clean = no)	**Symmetry clean before centering ?**
(rclean = 1.)	**Cleaning radius in scale units**
(rclip = 2.)	**Clipping radius in scale units**
(kclean = 3.)	**Rejection limit in sigma**
(mkcenter = no)	**Mark the computed center on display ?**
(mode = “ql”)	

- Parameters for *fitskypars* are listed below. In this example, the sky annulus is set for stars in the PC image, where the annulus radius and width are set to 32 pixels (1.57") and 11 pixels (0.54") respectively. (Suggested values for the WF chips are 15 and 5 pixels respectively.)

  Note: in the case of crowded fields, these annulus values obviously will not work. The user will have to select a tighter annulus for sky measurements, depending on the magnitude of the star.

PACKAGE = apphot
TASK = fitskypars

(salgorithm = “centroid”)	**Sky fitting algorithm**
(annulus = 32.)	**Inner radius of sky annulus in scale units**
(dannulus = 11.)	**Width of sky annulus in scale units**

(skyvalue = 0.)	**User sky value**
(smaxiter = 10)	**Maximum number of sky fitting iterations**
(sloclip = 0.)	**Lower clipping factor in percent**
(shiclip = 0.)	**Upper clipping factor in percent**
(snreject = 50)	**Maximum number of sky fitting rejection iterati**
(sloreject = 3.)	**Lower K-sigma rejection limit in sky sigma**
(shireject = 3.)	**Upper K-sigma rejection limit in sky sigma**
(khist = 3.)	**Half width of histogram in sky sigma**
(binsize = 0.1)	**Binsize of histogram in sky sigma**
(smooth = no)	**Boxcar smooth the histogram**
(rgrow = 0.)	**Region growing radius in scale units**
(mksky = no)	**Mark sky annuli on the display**
(mode = "ql")	

- Aperture sizes are specified in the task *photpars*. For this photometry example, an aperture size of 0.5" is used--11 pixels for PC and 5 pixels for WF images. These aperture sizes are reasonable for bright stars in uncrowded regions. However, for faint stars in crowded regions, values like an aperture radius of 2 pixels, and a sky annulus area between the radius of 5 to 10 pixels (*fitskypars* parameters: **annulus=5** and **dannulus=5**) are typically used. Note that this will affect the aperture correction, as explained in section 4.4.3.

  One of the parameters in *photpars* is **zmag**, the zeropoint of the magnitude scale. The currently best-known values for the zeropoint can be obtained from the HST Data Handbook (Version 3, Oct. '97), table 28.1, on page 28.7. (Be sure to check the WFPC2 webpage for updates.) The zeropoint values (in the Vegamag photometric system--more on this later) in the table assume a gain 7 setting. A note on how to convert these values to gain 15 is documented in table 28.1 in the Data Handbook.

  Listed below are the zeropoint for each filter-chip combination of the images in our example. Column 3 contains the gain 7 zeropoints from table 28.1. Column 4 has the zeropoint values corrected for gain 15 (the gain 7 zeropoint plus the correction factor from gain 7 to gain 15, where -0.745 and -0.756 are the corrections for the PC and WF3 respectively. See the bottom of table 28.1 for corrections for other chips.)

Dataset & Group	**Filter**	**Gain 7 Zeropoint**	**Gain 15 Zeropoint**
u2g40o05t.c0h[1]	**F555W**	**22.545**	**22.545 + (-0.745) = 21.800**
u2g40o06t.c0h[1]	**F555W**	**22.545**	**22.545 + (-0.745) = 21.800**
u2g40o09t.c0h[1]	**F814W**	**21.639**	**21.639 + (-0.745) = 20.894**
u2g40o0at.c0h[1]	**F814W**	**21.639**	**21.639 + (-0.745) = 20.894**
u2g40o05t.c0h[3]	**F555W**	**22.561**	**22.561 + (-0.756) = 21.805**
u2g40o06t.c0h[3]	**F555W**	**22.561**	**22.561 + (-0.756) = 21.805**
u2g40o09t.c0h[3]	**F814W**	**21.659**	**21.659 + (-0.756) = 20.903**
u2g40o0at.c0h[3]	**F814W**	**21.659**	**21.659 + (-0.756) = 20.903**

Example of the parameters in the *photpars* package (for F555W in PC):

PACKAGE = apphot
TASK = photpars

(weighting = "constant")	**Photometric weighting scheme for wphot**
(apertures = "11")	**List of aperture radii in scale units**
(zmag = 21.800.)	**Zero point of magnitude scale**
(mkapert = no)	**Draw apertures on the display**
(mode = "ql")	

4.3.3 Run the *phot* Task

To run *phot* for each of the four combined images, type (one line for each *phot* command):

phot u2g40o05_6.c0h[1] "" coords=coor_grp1 output=u2g40o05_6_g1.mag.1 readnoise=7.1 epadu=14 exposure=exptime zmag=21.800 calgorithm=centroid cbox=5 salgorithm=mean annulus=32 dannulus=11 aperture=11

phot u2g40o09_a.c0h[1] "" coords=coor_grp1 output=u2g40o09_a_g1.mag.1 readnoise=7.1 epadu=14 exposure=exptime zmag=20.894 calgorithm=centroid cbox=5 salgorithm=mean annulus=32 dannulus=11 aperture=11

phot u2g40o05_6.c0h[3] "" coords=coor_grp3 output=u2g40o05_6_g3.mag.1 readnoise=7.1 epadu=14 exposure=exptime zmag=21.805 calgorithm=centroid cbox=5 salgorithm=mean annulus=15 dannulus=5 aperture=5

phot u2g40o09_a.c0h[3] "" coords=coor_grp3 output=u2g40o09_a_g3.mag.1 readnoise=7.1 epadu=14 exposure=exptime zmag=20.903 calgorithm=centroid cbox=5 salgorithm=mean annulus=15 dannulus=5 aperture=5

The readnoise for each chip is 5 electrons. However, *crrej* added two images together, and therefore, the readnoise for the combined image is $\sqrt{5^2+5^2}$. The gain, however, remains at 14 because the images were added, and the exposure times updated. (If another image combining task had been used to obtain the average of the two images, the gain should be set to 28, if it is not done automatically.)

4.3.4 Inspect the *phot* Output

The output files (ending in **.mag.1**) contain a record of the *phot* parameters and the count measurements. Selected fields from these output files can be extracted to a more readable form with the task *txdump*.

Example:

txdump *.mag.1 "image,id,ifilter,rapert,flux,mag,merr,sum,msky,area,itime" yes

where:

image = image name and group
id = star identification number, in order of appearance in the coordinate file
ifilter = filter
rapert = radius of the aperture
flux = total number of counts excluding sky in the aperture
mag = magnitude measured within apertures
merr = error in magnitude
sum = total counts including sky
msky = sky value in counts per pixel
area = total pixel area of aperture
itime = exposure time

results:

u2g40o05_6.c0h[1]	**1**	**F555W**	**11.00**	**4564.775**	**16.414**	**0.006**	**4587.63**	**0.06009388**	**380.3212**	**32.**
u2g40o05_6.c0h[1]	**2**	**F555W**	**11.00**	**3554.886**	**16.686**	**0.007**	**3575.996**	**0.05551124**	**380.2668**	**32.**
u2g40o05_6.c0h[3]	**1**	**F555W**	**5.00**	**7811.104**	**15.836**	**0.003**	**7849.037**	**0.4812799**	**78.81808**	**32.**
u2g40o05_6.c0h[3]	**2**	**F555W**	**5.00**	**3477.515**	**16.715**	**0.006**	**3499.221**	**0.2753735**	**78.82498**	**32.**
u2g40o09_a.c0h[1]	**1**	**F814W**	**11.00**	**4350.715**	**15.415**	**0.006**	**4388.517**	**0.09934025**	**380.5276**	**28.**
u2g40o09_a.c0h[1]	**2**	**F814W**	**11.00**	**3402.475**	**15.682**	**0.007**	**3396.398**	**-0.01597657**	**380.3856**	**28.**
u2g40o09_a.c0h[3]	**1**	**F814W**	**5.00**	**3289.936**	**15.728**	**0.006**	**3309.517**	**0.2483964**	**78.82965**	**28.**
u2g40o09_a.c0h[3]	**2**	**F814W**	**5.00**	**3377.46**	**15.699**	**0.006**	**3398.775**	**0.269974**	**78.95436**	**28.**

The results above provide the total flux and magnitude of the stars. For example, star #1 (Harris star #1461) in the PC/F555W filter has a total (sky-subtracted) count of 4564.775 and magnitude of 16.414.

4.4 Corrections to the Measured Counts

Four kinds of corrections should be considered before proceeding. Some of these corrections may be small, and you may elect to ignore them for your purposes:

1) Correction for geometric distortion
2) Charge Transfer Efficiency (CTE) Correction
3) Aperture correction
4) Contamination correction (only significant for UV observations)

4.4.1 Geometric Distortion

The WFPC2 camera optics introduce a geometric distortion of the field that affects astrometry and photometry. The distortion is removed during calibration by the flat field files. However, this causes a change in the pixel scale with the biggest effect at the edges of the chip.

This geometrical distortion correction does not affect surface photometry, but for point source photometry, a correction needs to be applied as a function of the position of the object in the field. (For more information, please refer to the paper by Holtzman et. al., Performance and Calibration of WFPC2 on the Hubble Space Telescope, especially figure 16.)

A geometric correction image was generated by the WFPC2 IDT, called f1k155bu.r9h, that can be retrieved from the archive or the photometry section in the WFPC2 home page at
http://www.stsci.edu/ftp/instrument_news/WFPC2/Wfpc2_memos/wfpc2_reffiles.html#Pixel

Note: There is a wavelength dependence in the distortion in the UV. Details regarding corrections for UV data can be found in the paper "Geometry of the WFPC2 Focal Plane" by Trauger et. al. in Calibrating Hubble Space Telescope: Post Servicing Mission, a Workshop held on May 15 - 17, 1995.

For these data, the geometric corrections for the four stars are:

star 1:
listpix f1k1552bu.r9h[1][315,191]
1. 0.9914891

star 2:
listpix f1k1552bu.r9h[1][314,662]
1. 0.9874064

star 3:
listpix f1k1552bu.r9h[3][327,222]
1. 0.9950892

star 4:
listpix f1k1552bu.r9h[3][380,576]
1. 0.9954213

Total counts corrected for geometric distortion are:

Corrected Counts = (Measured Counts) * (Geometric Correction Factor)

Star ID	Filter	Chip	Counts	Geom. distort. Factor	Corrected Counts
1	F555W	PC	4564.775	0.9914891	4525.924656
2	F555W	PC	3554.886	0.9874064	3510.117188
3	F555W	WF3	7811.104	0.9950892	7772.745230
4	F555W	WF3	3477.515	0.9954213	3461.592502
1	F814W	PC	4350.715	0.9914891	4313.686500
2	F814W	PC	3402.475	0.9874064	3359.625591
3	F814W	WF3	3289.936	0.9950892	3273.779782
4	F814W	WF3	3377.46	0.9954213	3361.995624

4.4.2 Charge Transfer Efficiency (CTE) Correction

The WFPC2 was found, shortly after launch, to have a significant charge transfer efficiency (CTE) problem; objects appeared about 10% fainter at the top of the chip (at y=800), when compared to the bottom of the chip (at y=0).

The operating temperature of the CCDs was reduced from -76^{o}C to -88^{o}C on April 23 '94. After this cool-down, the difference due to CTE was reduced to about 4%. CTE effects in warmer temperature data are not well characterized.

CTE has been well-characterized for data taken at the standard -88^{o}C operating temperature. A recent Instrument Science Report (ISR 97-08, New Results on Charge Transfer Efficiency and Constraints on Flat-Field Accuracy by Whitmore and Heyer) shows that CTE actually depends on four parameters: target brightness, background, as well as *x* and *y* position on the chip. Equations for determining CTE corrections in WF2, WF3, and WF4 measurements, at 2 and 5 aperture radii, are documented in ISR WFPC2 97-08. CTE in the PC has not been as well-characterized; however, when working on PC data , the same CTE correction equations used for the WF frames should be applied to the PC data.

The equation for correcting for CTE:

$$\text{Counts}_{\text{corr}} = [1 + (\text{Y\_CTE}/100) * (\text{Y}/800) + (\text{X\_CTE}/100) * (\text{X}/800)] * \text{Counts}_{\text{obs}} \quad (1)$$

where, for aperture = 5 pixels,

$$\text{Y\_CTE} = 10^{(0.6930 - 0.2675 * \log_{10}(\text{BKG}_{\text{blank}}))} \quad (2)$$

$$\text{X-CTE} = 7.040 - 1.63 * \log_{10}(\text{Counts}_{\text{obs}}) \quad (3)$$

There are several things to keep in mind when determining the CTE in your images:

- When applying the CTE corrections to combined images, each of the combined images must have the same or closely similar exposure time. Determining the CTE correction for a combined image created from images with unequal exposure times (for example, one long exposure and one short exposure) cannot be easily done.

- The CTE equations were derived for cases where the combined image was an average of two or more images of equal exposure times. But some image combining tasks, like *crrej*, add the images. In such instances, measured values in the equations, such as $\text{BKG}_{\text{blank}}$ in CTE equation (2), and $\text{Counts}_{\text{obs}}$ in CTE equation (3), should be averaged--divided by the number of images used to create the add-combined image. Equation (1) remains unaffected.

- The equations in ISR 97-08 are most appropriate for data taken around June 1996, since the equations were derived based on data taken during that time. There is some evidence that CTE loss is increasing with time (effect currently being studied by B. Whitmore and S. Casertano at STScI). For more infomation, please refer to the memo "Time Dependence of the Charge Transfer Efficiency" on the WFPC2 webpage at

http://www.stsci.edu/ftp/instrument_news/WFPC2/wfpc2_doc.html#Stat

As more information becomes available, updates will be posted on the WFPC2 website and WFPC2 Space Telescope Analysis Newsletter.

- The CTE correction equations were derived from data taken at gain=7 (7 electrons per DN). For data taken at an A-to-D gain of 14, the counts in CTE equations (2) and (3), for the x- and y-CTE components respectively, need to be multiplied by 2.

- The equations are slightly different for 2 pixel aperture radii measurements. Please refer to ISR WFPC2 97-08 for details.

- The zeropoints in table 28.1 in the HST Data Handbook assumed a CTE correction of 2%. The new CTE formula in ISR 97-08 suggests it could be much higher. Work is currently in progress to determine better CTE corrections for zeropoints.

- For short exposure images, the background counts may not be suitable for plugging into the CTE equation due to its low signal-to-noise ratio. One alternative is to use background values from long exposure images using an identical observing mode, then scaled to match the exposure time of the images. (One option is to use a table of background values available in ISR 98-01, but be sure to normalize the background to the proper exposure time before using it.)

Example:

Steps for determining the CTE affecting Star #3 in F555W at WF3, position (327,222):

1. Determine the mean background near the center of the WF3 for the F555W image, using the task *imstat*.

   imstat u2g40o05_6.c0h[3][420:459,360:399]

   Results:

```
#                                IMAGE NPIX  MEAN   STDDEV  MIN     MAX
u2g40o05_6.c0h[3][420:459,360:399]1600  0.0804   0.8512   -2.989  2.794
```

2. Using the CTE formulae, determine the CTE-corrected counts for star #3 (counts measured with an aperture size of 5 pixels). The image in this example was taken at gain 14. Therefore, the BKG_{blank} value in equation (2), and $Counts_{obs}$ in equation (3) have to be multiplied by 2. The combined image in this example was created from two images, added together using the

task *crrej*. Therefore, the BKG_{blank} value in equation (2), and $Counts_{obs}$ in equation (3) have to be divided by 2.

$$\text{Y-CTE (star \#3)} = 10^{(0.6930 - 0.2675 * \log_{10}(BKG_{blank} * 2 \ / 2))}$$
$$= 10^{(0.6930 - 0.2675 * \log_{10}(0.0804 * 2 \ / 2))} = 9.67930$$

$$\text{X-CTE (star \#3)} = 7.040 - 1.63 * \log_{10}(7772.745230 * 2 / 2)) = 0.69836$$

$$Counts_{corr} = [1 + (Y\_CTE/100) * (Y/800) + (X\_CTE/100) * (X/800)] * Counts_{obs}$$
$$= [1 + (9.6793/100) * (222/800) + (0.6984/100) * (327/800)] * 7772.745230$$
$$= 8003.70944$$

CTE-corrected counts for all stars in our example:

Star ID	Filter	Chip	Bkgnd Counts	Counts From (4.4.1)	x	y	X-CTE	Y-CTE	CTE-Corr Counts
1	F555W	PC	0.06667	4525.924656	315	191	0.08120	10.17650	4655.15618
2	F555W	PC	0.06667	3510.117188	314	662	0.26113	10.17650	3823.08097
3	F555W	WF3	0.0804	7772.745230	327	222	0.69836	9.67930	8003.70944
4	F555W	WF3	0.0804	3461.592502	380	576	0.27098	9.67930	3723.73244
1	F814W	PC	0.1303	4313.686500	315	191	0.11520	8.50653	4420.23639
2	F814W	PC	0.1303	3359.625591	314	662	0.29215	8.50653	3613.15369
3	F814W	WF3	0.09127	3273.779782	327	222	0.31047	9.35647	3376.31706
4	F814W	WF3	0.09127	3361.995624	380	576	0.29165	9.35647	3609.10885

Hint: a quick way to tabulate these numbers is to create an IRAF table of input values, using the task *tcreate*. Then, use the task *tcalc* to calculate the values.

4.4.3 Aperture Correction

For 0.5” aperture measurements, a correction to an infinite aperture has been defined as subtracting 0.1 magnitude from the measured magnitude, or multiplying the measured flux by 1.09648. (See the HST Data Handbook, chapter 28 for more information). This correction must be applied when using the Synphot or HST Data Handbook zeropoints, not when using the zeropoints published by Holtzman et al.

Star ID	Filter	Chip	Counts from (4.4.2)	Aper. corr. Factor	Corrected Counts
1	f555w	PC	4655.15618	1.09648	5104.28565
2	f555w	PC	3823.08097	1.09648	4191.93182
3	f555w	WF3	8003.70944	1.09648	8775.90733
4	f555w	WF3	3723.73244	1.09648	4082.99815
1	f814w	PC	4420.23639	1.09648	4846.70080
2	f814w	PC	3613.15369	1.09648	3961.75076
3	f814w	WF3	3376.31706	1.09648	3702.06413
4	f814w	WF3	3609.10885	1.09648	3957.31567

4.4.4 Contamination Correction

Contaminants accumulate on the CCD windows over time, producing a time-dependent loss of throughput. While contamination has very little effect in the visible and near-IR wavelengths, it does impact UV observations by up to 30% over 30 days. Therefore, every four weeks, the WFPC2 is warmed to about +22˚C for 6 hours to remove the buildup of contaminants.

A table of contamination rates can be found in the HST Data Handbook (chapter 28), and in the WFPC2 Instrument Handbook. Dates of the decontamination events are recorded in the WFPC2 home page at
http://www.stsci.edu/ftp/instrument_news/WFPC2/Wfpc2_memos/wfpc2_history.html#Dec

The throughput decline seen in the F555W is very small: 1.4% over 30 days in the PC, and 1.6% over 30 days in WF3. For F814W observations, the values are so small that no correction is necessary.

In this example, the F555W data was taken on February 15, 1995 (Modified Julian Date 49763.411).

hsel u2g40o05_6.c0h $I,date-obs,expend yes

results:

u2g40o05_6.c0h 15/02/95 49763.41149220

The last decontamination event before that date was on 12 Feb ‘95 (Modified Julian Date 49760.0792). This information was obtained from the WFPC2 WWW mentioned above. Therefore, **the observations were taken 3.33 days after a decontamination**.

Listed below are the contamination-corrected counts for the four stars:
(F555W/PC: 1.4% over 30-days, F555W/WF3: 1.6% over 30-days, negligible for F814W):

Star_ID	Filter	Chip	Contamination Correction Using Counts From (4.4.3)	Corrected Counts
1	F555W	PC	5104.28565 / (1 - (3.33/30 * 0.014))	5112.23005
2	F555W	PC	4191.93182 / (1 - (3.33/30 * 0.014))	4198.45622
3	F555W	WF3	8775.90733 / (1 - (3.33/30 * 0.016))	8791.52107
4	F555W	WF3	4082.99815 / (1 - (3.33/30 * 0.016))	4090.26246
1	F814W	PC	4846.70080	4846.70080 (no change)
2	F814W	PC	3961.75076	3961.75076 (no change)
3	F814W	WF3	3702.06413	3702.06413 (no change)
4	F814W	WF3	3957.31567	3957.31567 (no change)

4.5 Converting Counts to the Vegamag Photometric System

The magnitude is defined as

$$\mathbf{m= -2.5log_{10}(DN/exptime) + zeropoint}$$

where the zeropoint of an instrument, by definition, is the magnitude of an object that produces one count (or one DN) per second.

The zeropoint can be determined using four ways:

1. From your own ground-based photometry of the stars (if available).
2. Use the zeropoints published by Jon Holtzman (The Photometric Performance and Calibration of WFPC2, PASP 1995).
3. Use the zeropoints published in the HST Data Handbook.
4. Use the value from the image header keyword PHOTFLAM.

Before proceeding, it is useful to clarify several photometric systems:

- The zeropoints published in Holtzman et. al are defined as the *WFPC2 Flight Photometric System*. This system was established to match the Johnson-Cousins UBVRI system such that the magnitudes of Vega in the standard U, B, V, R, and I filters are the same as the magnitudes in the closest equivalent WFPC2 filters (F336W, F439W, F555W, F675W, and F814W respectively). Holtzman et al. also provide transformation coefficients to convert the WFPC2 Flight Photometric System to standard UBVRI magnitudes, but warn that the transformations can be highly uncertain. The use of photometric transformations is generally not recommended.

- Another set of zeropoints was published by Whitmore and Heyer in Instrument Science Report 96-04, and recently updated in the November 1997 HST Data Handbook. These zeropoints are in the *Vegamag System*. The Vegamag system is defined such that Vega has a magnitude of zero for all WFPC2 filters. In this system, the magnitude of Vega in the U, B, V, R, and I passbands is also zero.
  (Note: the examples in this document use the Vegamag System.)

  The magnitude of Vega in the two systems are summarized in the table below:

System used by Holtzman et. al. '95:		**Synphot Vegamag System:**	
U(Johnson-Cousins)=0.02	**F336W(WFPC2 Flight)=0.02**	**U(Vegamag)=0**	**F336W(Vegamag)=0**
B(Johnson-Cousins)=0.02	**F439W(WFPC2 Flight)=0.02**	**B(Vegamag)=0**	**F439W(Vegamag)=0**
V(Johnson-Cousins)=0.03	**F555W(WFPC2 Flight)=0.03**	**V(Vegamag)=0**	**F555W(Vegamag)=0**
R(Johnson-Cousins)=0.039	**F675W(WFPC2 Flight)=0.039**	**R(Vegamag)=0**	**F675W(Vegamag)=0**
I (Johnson-Cousins)=0.035	**F814W(WFPC2 Flight)=0.035**	**I (Vegamag)=0**	**F814W(Vegamag)=0**

- The PHOTFLAM keyword value gives the *flux of a source with constant flux per unit wavelength (in ergs s^{-1} cm^{-2} A^{-1})* that produces a count rate of 1 DN per second. This keyword is useful for converting the counts directly to a flux density, or to a flux-based system such as the AB system or the STMAG system. Please refer to the section on WFPC2 Data Analysis in the HST Data Handbook for more details.

Example:

Convert the counts to magnitudes in the Vegamag system, using the zeropoints in the HST Data Handbook:

$m = -2.5\log_{10}(DN/exptime) + zeropoint$

Star_ID	Filter	Chip	Counts	Exptime	Zeropoint	Magnitude
1	F555W	PC	5112.23005	32	21.800	16.291
2	F555W	PC	4198.45622	32	21.800	16.505
3	F555W	WF3	8791.52107	32	21.805	15.708
4	F555W	WF3	4090.26246	32	21.805	16.538
1	F814W	PC	4846.70080	28	20.894	15.298
2	F814W	PC	3961.75076	28	20.894	15.517
3	F814W	WF3	3702.06413	28	20.903	15.591
4	F814W	WF3	3957.31567	28	20.903	15.518

At this point, it is possible to derive (V-I) colors for the four stars:

star ID	$V_{vegamag}$	$I_{vegamag}$	(V - I)
star1	16.291	15.298	0.993
star2	16.505	15.517	0.988
star3	15.708	15.591	0.117
star4	16.538	15.518	1.020

To convert the magnitudes derived thus far to another filter system, a small transformation needs to be made. This transformation is essentially zero for an A0V star, and depends on the spectrum of the star, hence it is often called the "color term". It is quite small for some filters, such as from F555W to V. The color term can be computed using the Space Telescope Science Data Analysis System synthetic photometry software package (*SYNPHOT).*

Note: Although it is possible to define a "photometric transformation" to convert these photometry results to one of the standard systems, we generally do not recommend it. These transformations have limited precision; they depend on color range, metallicity, and surface gravity of the stars. Errors of 0.2 magnitudes or more can occur, depending on the filter used and on how much the spectral energy distribution of the measured objects differs from that of the objects on which the transformation is defined. Therefore, we recommend that the WFPC2 photometric results be referred to a system based on its own filters.

To run Synphot in STSDAS, load *stsdas*, *hst_calib*, and *synphot*.

One of the key ingredients in our use of *synphot* is a reference stellar spectra that best matches the object in our images. There are several on-line catalogs of stellar spectral atlases available--both observed and modeled data. Please refer to the WFPC2 web page (section on Synphot) for details on how to obtain these spectra.

Example:

Determine the Cousins I magnitude for stars 1 & 2 observed with F814W in the PC.

The stars in this image are in NGC 5139 (Omega Cen), a galactic globular cluster. For calculating the offset between the two bandpasses, the spectrum of a K0 III star was adopted for stars 1, 2 and 4. (These stars have a similar V-I value, whereas star 3 is clearly different). For the example below, the spectrum of HD136366 (called bpgs_111) from the Bruzual-Persson-Gunn-Stryker Spectral Atlas is used.

Copy the spectra table to a working directory or set up a pointer to it. Then,

a) Use Synphot to determine the magnitude of HD136366 in the Vegamag system for the Cousins I passband
b) Use Synphot to determine the magnitude of HD136366 in the Vegamag system for the PC and F814W filter passband.
c) Obtain the correction in magnitudes between the Cousins I passband and the F814W filter passband by subtracting (b) from (a):
   Cousins I correction = ($HD136366_I$ magnitude) - ($HD136366_{F814W}$ magnitude)
d) Add this correction to the previously-obtained F814W magnitudes to get the Cousins I magnitudes in the Vegamag system.

Steps (a), (b), and (c):

a) Calculate the Cousins I magnitude for HD136366 (bpgs_111) in the Vegamag system.

   calcphot "band(cousins,i)" bpgs_111 vegamag ---------- (a)

   Result:

```
Mode = band(cousins,i)
  Pivot      Equiv Gaussian
 Wavelength       FWHM
  7891.108      898.7716   band(cousins,i)
Spectrum:  bpgs_111
   VZERO          VEGAMAG     Mode: band(cousins,i)
     0.          -0.98776
```

b) Calculate the PC/F814W magnitude for HD136366 (bpgs_111), in the Vegamag system, specifying the instrument, chip, and filter.

calcphot "band(wfpc2,1,f814w)" bpgs_111 vegamag ---------- (b)

Result:

```
Mode = band(wfpc2,1,f814w)
  Pivot      Equiv Gaussian
 Wavelength       FWHM
  7995.946       1521.506   band(wfpc2,1,f814w)
Spectrum:  bpgs_111
   VZERO          VEGAMAG     Mode: band(wfpc2,1,f814w)
     0.         -0.99594
```

c) Cousins I Correction for the PC is obtained by subtracting (b) from (a):

-0.98776 - (-0.99594) = 0.00818

Note: it may be useful to run steps (a), (b), and (c) on different K0III reference spectra, and obtain an average correction to be applied to step (d).

d) Determine the Cousins I magnitude in the Vegamag photometric system for the two stars measured in PC/F814W:

$$\mathbf{m_{PC\_I} = -2.5log10(DN_I/exptime) + zeropoint_I + Cousins\ I\ correction}$$
$$\mathbf{= m_{PC\_F814W} + Cousins\ I\ correction}$$

$\mathbf{m_{I\_star1} = 15.298 + 0.008 = 15.306}$
$\mathbf{m_{I\_star2} = 15.517 + 0.008 = 15.525}$

ACKNOWLEDGEMENTS

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We would like to thank the following people for their contributions:

Eddie Bergeron
Ivo Busko
Harry Ferguson
J.C. Hsu
Keith Noll
Krista Rudloff

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