WFC3 Image Calibration and Reduction Software

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**Abstract.** Standard WFC3 image processing consists of the calwf3 task, which removes instrumental signatures from the images, and multidrizzle, which corrects images for geometric distortion and combines dithered sets of exposures. In addition, the aXe software package is used off-line to perform spectral extraction and calibration of WFC3 grism data. We present an overview of the standard WFC3 pipeline processing and calibration, including the status of calwf3 and multidrizzle. Reasons for reprocessing data outside the pipeline environment are also discussed.

1. **WFC3 Pipeline Overview**

The pipeline data reduction and calibration system at STScI uses several steps to process WFC3 exposures when they arrive on the ground. A brief outline of those steps is listed here.

- **Generic Conversion.** Raw telemetry data from all the HST instruments goes through this process, which reformats the data into FITS files containing the raw detector readouts and a host of information about the exposure and the instrument stored in header keywords. In addition, this process also queries the STScI Calibration Data Base System (CDBS) to determine the appropriate calibration reference files (biases, darks, flats, etc.) to be used later when calibrating the data. The names of the selected reference files are stored in header keywords in the raw FITS files.

- **calwf3.** The calwf3 task is run for each raw or set of associated raw images to remove instrumental signatures. This includes the usual types calibrations, such as bias and dark subtraction, non-linearity correction, and flat fielding. For IR exposures it also includes up-the-ramp fitting to produce a final image from the multiple non-destructive reads of the IR detector. UVIS channel exposures obtained with the CR-SPLIT option are also combined by calwf3, but the resulting combined and CR-cleaned image is now essentially made obsolete by subsequent multidrizzle processing.

- **multidrizzle.** The multidrizzle task drizzles calibrated images to remove geometric distortion, combine dithered exposures, and remove cosmic-ray (CR) hits. For dithered exposures the resulting combined image is also cleaned of bad pixels and other cosmetic defects.

- **Archiving.** The raw telemetry files are stored in the Multimission Archive at STScI (MAST) and metadata gleaned from the calibrated images is stored in the archive catalog.

- **OTFR.** Image retrieval requests submitted to the MAST archive use the On-The-Fly-Reprocessing (OTFR) system to completely reprocess the data before delivering it to the requestor. This process starts from the raw telemetry data stored in the archive and re applies all generic conversion, calwf3, and multidrizzle processing using the latest software and calibration reference files.
• **aXe.** aXe is an off-line software package that is used exclusively for extracting and calibrating spectra from grism exposures. aXe processing is *not* applied within the pipeline. See Kümmerl et al. (2009), Kümmerl et al. (2010), and Kunthacker et al. (2010) for more information about aXe and its application to WFC3 grism images.

2. **Using MAST For Reprocessing**

Because WFC3 is still a relatively new science instrument on HST, the detailed instrumental calibrations are still evolving as we continue to learn more about the behavior of the instrument and continue to refine the calibration data. The simplest way for GO’s to have the latest calibrations applied to their data is to put in a retrieval request to MAST, which will result in a complete reprocessing of the data before being delivered, as mentioned in the previous section. This is also usually the best and only way to have the latest versions of the processing software applied to the data, because the software used in the STScI pipeline is updated more frequently than what is made available publically in the IRAF/STSDAS package.

WFC3 users are encouraged to check the “Late Breaking News” section of the WFC3 web site (http://www.stsci.edu/hst/wfc3) for information about new calibration reference files and updates to the calwf3 and multidrizzle software. Specific information about software updates can be found via the “Pipeline” link. The WFC3 team also periodically publishes WFC3 Space Telescope Analysis Newsletters (STANs), which contain information about calibration and software issues.

Users can determine which version of calwf3 was applied to their data by checking the value of the “CALVER” keyword in the header of their FITS files. Similarly, the “HISTORY” keywords contain a record of which version of multidrizzle, and associated sub-tasks, was used to produce the images.

3. **Recent CALWF3 Updates**

As discussed in section 1, calwf3 is the software task that applies instrumental calibrations to all WFC3 images. At the time of this writing, the latest version of calwf3 is v2.1, which was released to the public in June 2010 in the STSDAS package release v3.12. See the “Pipeline” link on the WFC3 web site for detailed information about all of the changes contained in this and previous versions.

Some of the more important changes that have occurred in the last few months include the following. First, a mistake in the way the IR flat fielding and gain conversion (FLATCORR step) were being applied resulted in DC offsets between the four amplifier quadrants in calibrated IR images. This problem was fixed in calwf3 v1.8. Secondly, the IR up-the-ramp fitting and CR rejection process (CRCORR step) was incorrectly computing the estimated uncertainties for the fits to each pixel, which resulted in severely underestimated ERR array values in the output IR _flt.fits files. This problem was fixed in calwf3 v2.0.

Finally, an updated version of the IR cosmic-ray rejection parameters table (CRRE-JTAB) was delivered in June 2010, which changed the behavior of the IR up-the-ramp fitting process (CRCORR step). Previously, when the CRCORR process encountered a pixel that was flagged as bad in all of the readouts for the exposure, it would not fit the pixel ramp data and instead simply enter a value of zero for that pixel in the output _flt.fits image. This happens for pixels that have a “static” problem condition, such as a dead, hot, or photometrically unstable pixel, in which case all the readouts for that pixel are flagged as bad. This differs from pixels for which only some of the readouts are bad, such as those that saturate part way through the exposure or contain a CR hit in one or more readouts.
Figure 1: A small section of a calibrated IR image showing the effects of the change to the CRREJTAB. The images are displayed with inverse contrast. The image on the left has bad pixels zeroed out, while the image on the right does not.

The updated version of the CRREJTAB that was put into use in June 2010 changes this behavior so that the CRCORR process still tries to fit the ramp data for pixels with all readouts flagged, coming up with a “best effort” value for the slope of the ramp. Such pixels are therefore no longer zeroed out in the calibrated image. All of the data quality (DQ) flags associated with those pixels are recorded in the DQ array of the output _flt.fits file, so users should be careful to check the DQ values to decide which pixels are safe to use in their analysis.

An example of the effects of this change is shown in Figure 1. The left panel of this figure shows a portion of a calibrated IR image that was produced before the change and therefore has bad pixels zeroed out. The right panel shows the same image produced with the new processing, which no longer zeroes out the bad pixels. Notice that a few pixels still have anomalous values, which are pixels that simply have very erratic behavior.

4. Recent MultiDrizzle Updates

WFC3 pipeline processing did not include the use of multidrizzle until early February 2010, when initial WFC3 geometric distortion solutions became available and the software itself had been verified to be working properly for WFC3 images. A few issues have been discovered and fixed since that time.

First, after having gained some experience with the application of multidrizzle to WFC3 IR images, an updated version of the IR multidrizzle parameters table (MDRIZTAB) was delivered in April 2010. This reference table sets the various multidrizzle processing parameters for use in the STScI pipeline. There were several changes to the table. The values of the “driz_sep_bits” and “final_bits” parameters were modified so that IR image pixels flagged with DQ=512, which indicates that the pixel is affected by an IR “blob” (see Pirzkal, Viana & Rajan 2010 and Pirzkal 2010) are considered to be good, while pixels with all other DQ values are considered bad and hence rejected. The CR detection threshold was increased to reduce the number of false detections and detected CRs are no longer flagged in the DQ arrays of the input _flt.fits images. Finally, sky subtraction was turned on for all exposures using wide- and medium-band filters and the IR grisms.
The second important change involved an update to both the WFC3 generic conversion process and multidrizzle, both of which occurred in April 2010. The generic conversion process was updated to compute the velocity aberration factor for all WFC3 exposures, as is done for other HST instruments. This value is stored in the “VAFATOR” header keyword of WFC3 FITS files and specifies the overall image scale factor that should be applied to correct for the expansion or contraction that results from the orbital motion of HST. Multidrizzle was also updated to make use of this keyword value when processing WFC3 images and include the appropriate scale factor when removing geometrical distortions from the images. Users who require precise relative astrometry or image registration should make sure to use reprocessed data products that have this correction applied.

5. Rerunning CALWF3 and Multidrizzle

Occasionally it may be necessary for a user to rerun calwf3 or multidrizzle on their data to achieve the optimum results for their science program. Rerunning calwf3 may be done, for example, when you want to apply an alpha release of a new calibration file that is available for download from the WFC3 web site, but not yet installed for use in the OTFR system. You might also want to use a custom version of a particular reference file, such as a modified bad pixel table to flag features unique to your data, or use different CR or bad pixel rejection parameters in the IR ramp fitting via the CRREJTAB table.

The procedure to do this is relatively straightforward. Once you have downloaded WFC3 reference files from the web and possibly made modifications to them, you simply need to edit the values of the header keywords in your raw data files that contain the names of these reference files, and then run calwf3 on the raw files. Details of this procedure can be found in the WFC3 Data Handbook, which is available at the WFC3 web site.

Multidrizzle processing must be closely tailored to different types of imaging situations, which cannot be done easily in the pipeline environment. The multidrizzle processing parameters that are used in the pipeline are therefore a “one size fits all” compromise. This makes it very important for users to rerun multidrizzle themselves on their data in order to achieve the best results. Typical parameters that may need optimizing include the final output image pixel size and corresponding “pixfrac” setting, and different values of the “driz_sep_bits” and “final_bits” parameters to accept and reject different families of flagged pixels. Perhaps most important is the use of user-supplied alignment information, which adjusts the alignment of the individual images being combined. This image alignment information can often be generated through the use of the “tweakshfits” task available in PyRAF. See the Multidrizzle Handbook for detailed information, the WFC3-specific multidrizzle information on the WFC3 web site, and Mutchler (2010).

Table 1 lists the WFC3 data quality (DQ) values that are used to flag various problem conditions with pixels in UVIS and IR images. Note that there are some unique conditions for the two imaging channels. When rerunning multidrizzle on your data it is important to consider which types of flagged pixels may be included in the combined image and which should be rejected. For example, permanently dead or bad pixels (dq=4) and saturated pixels (dq=256) should probably always be rejected. Some other types of flagged IR pixels, however, may be OK to include for some types of data. If you are mainly interested in bright sources in the images, then it’s probably OK to include pixels flagged as deviant in the IR zero read (dq=8) and possibly even photometrically unstable (dq=32), because the errors associated with these conditions are likely to be negligible compared to the source signal. For faint sources, on the other hand, these types of problem pixels should be rejected.

The choice of which types of flagged pixels to reject also depends on the dither pattern used for the exposures. If the dither steps are large enough to step over large features like the IR “blobs”, then you may reject pixels flagged with dq=512. The regions of rejected pixels will be filled in with good data from adjacent images. If the dither steps are smaller...
Table 1: WFC3 Data Quality Flags

<table>
<thead>
<tr>
<th>DQ Value</th>
<th>UVIS channel</th>
<th>IR channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reed-Solomon decoding error (on HST)</td>
<td>Reed-Solomon decoding error</td>
</tr>
<tr>
<td>2</td>
<td>Missing data packet (during downlink)</td>
<td>Missing data packet</td>
</tr>
<tr>
<td>4</td>
<td>Dead/Bad pixel</td>
<td>Dead/Bad pixel</td>
</tr>
<tr>
<td>8</td>
<td>(currently unassigned)</td>
<td>Deviant zero-read bias value</td>
</tr>
<tr>
<td>16</td>
<td>Hot pixel</td>
<td>Hot pixel</td>
</tr>
<tr>
<td>32</td>
<td>CTE tail (not yet implemented)</td>
<td>Photometrically unstable</td>
</tr>
<tr>
<td>64</td>
<td>Warm pixel</td>
<td>(currently unassigned)</td>
</tr>
<tr>
<td>128</td>
<td>Bad bias value in overscan</td>
<td>Bad reference pixel</td>
</tr>
<tr>
<td>256</td>
<td>Full-well saturation</td>
<td>Full-well saturation</td>
</tr>
<tr>
<td>512</td>
<td>Bad flat field value</td>
<td>Bad flat field value (blobs)</td>
</tr>
<tr>
<td>1024</td>
<td>Charge trap (not yet implemented)</td>
<td>(currently unassigned)</td>
</tr>
<tr>
<td>2048</td>
<td>A-to-D converter saturation limit</td>
<td>Detectable signal in zero read</td>
</tr>
<tr>
<td>4096</td>
<td>CR hit detected by multidrizzle</td>
<td>CR hit detected by multidrizzle</td>
</tr>
<tr>
<td>8192</td>
<td>CR hit detected by calwf3/wf3rej</td>
<td>CR hit detected by calwf3/crcorr</td>
</tr>
<tr>
<td>16384</td>
<td>Ghost/Crosstalk (not yet in use)</td>
<td>Ghost/Crosstalk (not yet in use)</td>
</tr>
</tbody>
</table>

than the blob size, however, then those regions can not be filled in and therefore should be rejected. Figure 2 shows an example of filling in the IR blobs via large dither steps. The left panel in the figure shows an individual calibrated image (.flt file) from the set of exposures, in which you can see the effect of one of the blobs. The resulting drizzled image (right panel) has the region of the blob filled in with good data from adjacent exposures.

References

Kümmel, M., Kuntschner, H., Walsh, J. R., Bushouse, H. & Straughn, A. 2010, this volume
Kuntschner, H., Kümmel, M., Walsh, J. R. & Bushouse, H. 2010, this volume
Mutchler, M. 2010, this volume
Pirzkal, N., Viana, A. & Rajan, A. 2010, WFC3 ISR 2010-06
Pirzkal, N. 2010, this volume
Figure 2: On the left is a section of a single IR image showing a region of decreased signal due to an IR “blob”. The image on the right is the result of multidrizzling a set of these images that used dither pattern steps larger than the size of the blobs, thus filling in the region of the blob with good data from other images.