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Binned flat fields for the WFC3/UVIS Channel

E. Sabbi & S. Baggett

December 20, 2012

ABSTRACT

We summarize the procedure necessary for creating calibration pipeline flat-fields for 2×2 and 3×3 on-chip binned WFC3/UVIS data from the full-frame unbinned flat-fields.

Introduction

A flat-field correction, i.e. calibrating out the detector pixel-to-pixel response variations, is a standard step in the reduction of image data. The present generation of flat-fields for Wide Field Camera 3 (WFC3) UVIS full-frame, unbinned, four-amp readouts (VCD20*_PFL.FITS) has been constructed from high signal-to-noise ground flat-fields and refined with on-orbit measurements. The ground data were acquired during the final thermal vacuum campaign (TV3) by simulating the sky illumination of the UVIS CCDs using the optical stimulus CASTLE (Sabbi et al. 2009). Subsequent photometric analyses of on-orbit images of stellar clusters were used to determine corrections for low and medium-frequency structures (Mack at al. 2012, in preparation). The result are unbinned flat-fields with uncertainties less than 1 % across the field of view (http://www.stsci.edu/hst/wfc3/analysis/uvis_flats).

The unbinned readout has been the overwhelming mode of choice for WFC3/UVIS since its installation in May 2009: as of this writing, about 99% of external UVIS images in the archive are unbinned. However, there are circumstances in which on-chip binning can be desirable, such as for achieving greater sensitivity when observing very faint targets, or for acquiring full-frame images as rapidly as possible. The pixel-to-pixel corrections in the flat-field do not depend upon the binning mode and thus in practice, data for flat-field construction are acquired in unbinned format only. However, unbinned calibration flat-fields can not be applied as-is to binned data, i.e., the calibration pipeline will not "bin up" unbinned flat-fields for use on binned data. Instead, the flat-fields for use with binned data must conform to binned image size requirements. In this TIR we describe how to derive binned calibration flats from the unbinned calibration flats already available in the CDBS archive (/grp/hst/cdbs/iref/).

Available binned modes in UVIS

The default observing mode for WFC3/UVIS is a full-frame four-amplifier readout resulting in a 4206×4140 pixel image. Figure 1 shows the structure of the raw image, including overscan areas, before it is processed through the calibration pipeline CALWF3 (Rajan et al. 2010). The image consists of two halves (one for each chip of the UVIS detector), where each chip contains 4096×2051 pixels for imaging. Adjacent to the science pixels are overscan regions: the first and the last 25 columns are the physical overscan, while the 60 innermost columns (30 for each amplifier) are virtual overscan. In each chip, the 19 rows farthest from the amplifiers provide the parallel virtual overscan.

Two binned formats are available on UVIS, 2×2 and 3×3. The binning itself is performed on-chip during readout. For example, for 2×2 binning, one row is shifted into the serial register and held while the second row is shifted into the register, then pairs of pixels from the combined row are read out. Because of the odd number of pixels in the unbinned physical and virtual parallel overscan, the data binned in this manner will have some pixels which are a mix of imaging and overscan pixels. In particular, for each chip in the 2×2 binned raw image there are:

- 9 rows of virtual overscan;
- 1 row of combined imaging and virtual parallel overscan;
- 1025 rows for imaging;
- 12 columns of physical overscan for each of the two amps in a chip;
- 1 column of combined imaging and physical overscan for each of the two amps in a chip;

Fig. 1.— *Structure of the UVIS 4206 × 4140 raw images. Pixels for imaging are in light yellow, phsical overscan is in dark yellow, and virtual overscan in light blue.*

- 1023 columns for imaging for each of the two amps in a chip;
- 1 combined imaging and virtual overscan column for each of the two amps in a chip;
- 14 columns of virtual overscan for each of the two amps in a chip.

And for each chip in the 3 × 3 binned image there are

- 6 rows of virtual overscan;
- 1 row of combined imaging and virtual parallel overscan;
- 683 rows for imaging;
- 8 columns of physical overscan for each of the two amps in a chip;
- 1 column of combined imaging and physical overscan for each of the two amps in a chip;
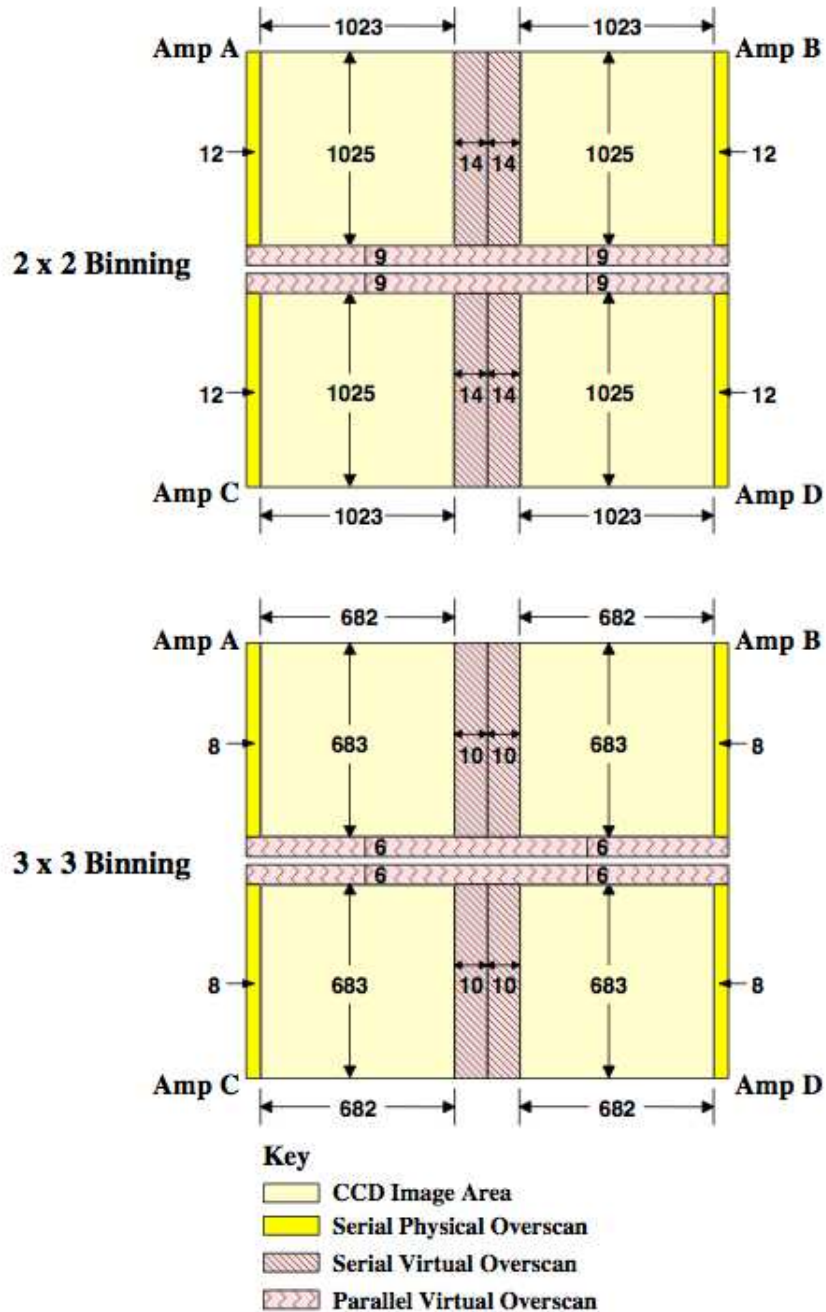- 682 columns for imaging for each of the two amps in a chip;
- 10 columns of virtual overscan for each of the two amps in a chip.

The structure of the binned raw images is shown in Figure 2. More details about the overscan region layouts for all the available readout modes can be found in Bushouse (2003).

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Fig. 2.— *Structure of the 2 × 2 (upper panel) and 3 (lower panel) UVIS raw images. Pixels for imaging are light yellow, physical overscan is dark yellow, and virtual overscan in pink.*

Binned Flat-Fields

Flat-fields for all filters in the UVIS channel, in the default full-frame unbinned mode, were generated from data acquired on the ground during the TV3 campaign (Sabbi et al.

2008). These flats were produced from WFC3/UVIS images taken with the CASTLE optical stimulus, an apparatus designed to emulate the the Hubble optics. Photometric analyses performed during the first months on-orbit using images of the rich stellar cluster ωCentauri showed residuals of up to 5% (Sabbi 2009). Two major sources of the errors were identified:

1. A large window ghost is superposed on the ground-based flat-fields, generated by light reflecting off the tilted focal plane of UVIS, the detector windows and the CCDs (Stiavelli 2001; McCullough 2011).

2. Differences between the illumination of the CASTLE simulator and the real Hubble optics introduced low-frequency structures (Mack et al. 2012, in preparation).

Both artifacts have been corrected in the most recent version of the full-frame unbinned calibration flat-fields (VCD20*_PFL.FITS), and now the uncertainties in the photometry of UVIS data due to the flat-fields are less than $\sim 1\%$.

Since (by design) no binned flat-fields are taken, binned flats for use in the calibration pipeline must be derived from the full-frame unbinned flat-fields. The current binned flats (W8T18*_PFL.FITS) were produced by averaging the appropriate 2x2 or 3x3 regions of the unbinned flat and placing the results in the proper locations within the binned flat. The full details of the PyRAF procedure are described in the remainder of this section.

In the full-frame unbinned flat-fields used by the calibration pipeline, both the physical and virtual overscan are trimmed. The first step is to copy the unbinned flats into a larger (4206×2070) file to mimic the presence of the overscan. For example, we used the following PyRAF commands:

```
mkimage big.fits option="make" value=1.0 ndim=2 dims"4206 2070"
imcopy (filename//"[4,noinherit][1:2048,1:2051]", "big.fits[0][26:2073,20:2070]", verb+) ⟹ Amp A
imcopy (filename//"[4,noinherit][2049:4096,1:2051]", "big.fits[0][2134:4181,20:2070]",verb+) ⟹ Amp B
imcopy (filename//"[1,noinherit][1:2048,1:2051]", "big.fits[0][26:2073,1:2051]", verb+) ⟹ Amp C
imcopy (filename//"[1,noinherit][2049:4096,1:2051]", "big.fits[0][2134:4181,1:2051]", verb+) ⟹ Amp D
```

Note that because of the odd numbers of imaging pixels, and, even more importantly, because of the columns where the information from both the imaging and virtual overscan is mixed during the binning process, each quadrant must be treated independently when binned flats are made. Once the full-size image exists, we average the value of the pixels using a 2×2 and a 3×3 block-average:

```
blkavg ("big.fits","bbig.fits",b1=2,b2=2,option="average") ⟹ 2 × 2
blkavg ("big.fits","bbig.fits",b1=3,b2=3,option="average") ⟹ 3 × 3
```

The resulting files now contain 2103×1035 pixels and 1402×690 pixels per chip in the 2×2 and 3×3 flats, respectively, i.e. the binned imaging pixels plus overscan. As mentioned above, the flat-fields (binned or unbinned) for use in the calibration pipline do not include the overscans. For this reason the 2×2 binned flats are trimmed according to the trim sections documented in the overscan file (q911321oi_osc.fits). That is, the first 13 columns and 9 rows from Amp A and the first 9 rows and last 13 columns are trimmed from Amp B, while from Amp C we trimmed the first 13 columns and the last 9 rows, and the last 9 rows and the last 13 columns from Amp D. Similarly, in the 3×3 binned flats in each chip we trimmed the first and the last 9 columns as well as the 6 rows facing the gap between the two CCDs.

To preserve the architecture of the UVIS fits file and the structure of the header, we use one of the earlier 2×2 and 3×3 dummy flat-fields from the /grp/hst/cdbs/iref/ directory as a template, and perform the trimming by copying only the desired image sections from the temporary full-size block-averaged file into the binned flat template. That is, for 2×2 and 3×3, the necessary copy statements are:

imcopy ("bbig.fits[0][14:1037,10:1035]", "template.2x2.fits[4][1:1024,1:1026]", verb+) $\implies$ Amp A
imcopy ("bbig.fits[0][1067:2090,10:1035]", "template.2x2.fits[4][1025:2048,1:1026]",verb+) $\implies$ Amp B
imcopy ("bbig.fits[0][14:1037,1:1026]", "template.2x2.fits[1][1:1024,1:1026]", verb+) $\implies$ Amp C
imcopy ("bbig.fits[0][1067:2090,1:1026]", "template.2x2.fits[1][1025:2048,1:1026]", verb+) $\implies$ Amp D

imcopy ("bbig.fits[0][10:691,7:690]", "template.3x3.fits[4][1:682,1:684]", verb+) $\implies$ Amp A
imcopy ("bbig.fits[0][712:1393,7:690]", "template.3x3.fits[4][683:1364,1:684]",verb+) $\implies$ Amp B
imcopy ("bbig.fits[0][10:691,1:684]", "template.3x3.fits[1][1:682,1:684]", verb+) $\implies$ Amp C
imcopy ("bbig.fits[0][712:1393,1:684]", "template.3x3.fits[1][683:1364,1:684]", verb+) $\implies$ Amp D

Note that the final binned mode calibration flatfields fulfill the size requirements of the pipeline: 2048×1026 and 1364×684 pixels per chip, for 2×2 and 3×3 modes, respectively.

To populate the error extensions ([2] and [5]), the errors are propagated in quadrature from the unbinned flat i.e., the square root of the sum of the squares of pixel values found in the corresponding extension of the default flats divided by 4 or 9, for the 2×2 and 3×3 binned flats, respectively.

blkavg ("big.fits","bbig.fits",b1=2,b2=2,option="sum") $\implies$ 2×2
imcalc ("bbig.fits[0]","bbig.fits",equals="0.25*sqrt(im1)",pixtype="double",nullval=0.,verb+)
blkavg ("big.fits","bbig.fits",b1=3,b2=3,option="sum") $\implies$ 3×3
imcalc ("bbig.fits[0]", "bbig.fits", "0.1111111*sqrt(im1)",verb+)

In the data-quality extensions ([3] and [6]) of the 2×2 flats, the pixels are set to 0 (i.e., marked as good), with the exception of columns 1024 and 1025 in both extensions, and rows 1026 in extension [3] and 1 in extension [6] which are set to 512 (i.e., marked as bad in the flat). In the 3×3 flats, row 684 in extension [3] and row 1 in extension [6] are set to 512, all other pixels remain 0. Finally, before delivery to the Calibration Database System (CDBS) for use in the calibration pipeline, each new binned flat had the necessary CDBS-related header keywords populated (e.g. FILTER, PEDIGREE, USEAFTER) and a short description was added to the header of the file. The resulting full-frame binned flats were tested through CALWF3 and then delivered to CDBS. Image names of the binned flats are (W8T18*_PFL.FITS).

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