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WFC3 Pixel Area Maps

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Abstract

We present the pixel area maps (PAMs) for the WFC3/UVIS and WFC3/IR detectors, and discuss the normalization of these images. HST processed _flt images suffer from geometric distortion and therefore have pixel areas that vary on the sky. The counts (electrons) measured for a source on these images depends on the position of the source on the detector, an effect that is implicitly corrected when these images are multidrizzled into _drz files. The _flt images can be multiplied by the PAMs to yield correct and uniform counts for a given source irrespective of its location on the image. To ensure consistency between the count rate measured for sources in _drz images and near the center of _flt images, we set the normalization of the PAMs to unity at a reference pixel near the center of the UVIS mosaic and IR detector, and set the SCALE in the IDCTAB equal to the square root of the area of this reference pixel. The implications of this choice for photometric measurements are discussed.

1. The New WFC3 Instrument on HST

The Wide Field Camera 3 (WFC3) is a fourth generation instrument on the Hubble Space Telescope (HST), installed during Servicing Mission 4 in May 2009. The instrument occupies the same position as the WFPC2 camera in the axial bay, and is therefore close to the optical axis of the telescope. WFC3 offers high resolution imaging over a very broad wavelength range, extending from the UV at 200 nm to the near IR at 1700 nm. The instrument contains a total of 77 narrow, medium, and wide band filters for imaging and three grisms for low resolution spectroscopy. The UV/Optical camera contains two CCDs that subtend an angular field of view of 162 $\times$ 162 arcseconds, with a pixel scale of 0.04 arcseconds. The IR camera consists of a single detector with a field of view of 136 $\times$ 123 arcseconds and a pixel scale of 0.13 arcseconds.

Like other HST instruments, the WFC3/UVIS CCDs and WFC3/IR detector both have geometric distortions that cause the effective area of pixels to vary across the field. Therefore, photometry of a source on a WFC3 image that has not been geometrically corrected (e.g., the _flt images processed by the HST CALWF3 pipeline) will vary depending on the position of the source on the detector. In this ISR, we present a simple means to correct this effect for WFC3 through a pixel area map (PAM). Although PAMs have been previously derived and described for other HST instruments (e.g., the ACS web page), we note that a different set of priorities has been established for WFC3 photometry. We have attempted to keep the derived photometry on _flt images as close as possible to both the native photometry (see Section 3) and the _drz (drizzled) image photometry, rather than to use a convenient but artificial pixel scale in the creation of the instrument astrometric tables. These PAMs are described in detail below.

2. Geometric Distortion in WFC3 Images

The WFC3/UVIS CCDs and WFC3/IR detector contain pixels that vary in their area on the sky as a result of the geometric distortion. As a consequence of this, more light will fall on a larger pixel relative to a smaller pixel, leading to an overall gradient in an image of a smooth background. However, the flatfielding process in the HST CALWF3 pipeline are designed to produce images that have a flat background (e.g., sky), thereby suppressing counts (hereafter taken to be in units of electrons) in larger pixels relative to smaller pixels. Hence, the measured total brightness of sources on _flt images will vary depending on the position of the object, and the areas of the pixels at that location.

To achieve uniform photometry over the detector, most users will measure counts on distortion free images. Kozhurina-Platais et al. (2009a; 2009b) have recently measured the geometric distortion of both the WFC3/UVIS CCDs and the IR detector. These measurements utilize Servicing Mission Orbital Verification 4 (SMOV4) preliminary observations of the nearby globular star cluster 47 Tuc and the Large Magellanic Cloud (LMC), measured in a single filter. The positions of stars in these stellar systems are compared to distortion free standard astrometric catalogues to yield a mapping from the distorted positions to the true positions (Anderson 2006; J. Anderson 2009, private communication). Over the entire astrometric catalog, the global accuracy of the positions of stars is 1 milliarcsecond. The preliminary polynomial fit to achieve this calibration for WFC3 has residuals of 3 millarcseconds in the UVIS channel and 10 milliarcseconds in the IR channel. The overall accuracy will improve with subsequent Cycle 17 calibration programs. As with all HST instruments, the geometric distortion solution is represented in the reference table, IDCTAB, described extensively in Hack & Cox (2001).

The geometric distortion can be corrected in WFC3 images using multidrizzle (Fruchter & Hook 2002; Koekemoer et al. 2002). The output of this program is a _drz image, which has a flat sky and contains pixels that are uniform in area (i.e., through proper corrections of the distortion and related pixel area variations). Therefore, photometry of any source in a _drz image will yield the same count rate (electons per second) irrespective of the position of the source on the image.

3. Photometry in _flt and _drz Images

Considering the uniform nature of _drz images (e.g., all pixels have the same area on the sky), HST instrument teams have historically calibrated their photometry for these images. Photometry measured on an _flt image therefore requires a field-dependent correction factor to: 1.) achieve uniformity in the measured count rate (e.g., measured counts scaled to an exposure time of 1 second) of an object across the field, 2.) match the output drizzled count rate. This correction is reflected as an image and is called the PAM, and comes from the derivatives of the geometric distortion polynomial. The size of the PAM image is the same as the _flt image and each pixel value is set to the normalized area of that pixel. By multiplying the _flt images by the PAM, users will recover the same count rate on _flt images and _drz images (e.g., _drz flux = (_flt flux) × (PAM), where the _flt image has been coverted to counts per second of exposure time).

An important value that is fed into multidrizzle through the IDCTAB is the SCALE parameter. Depending on the particular use of the program, this parameter can serve either one or two purposes. First, within multidrizzle, SCALE always specifies the default pixel scale for the input _flt images, before any output pixel scale is specified. In cases where users have not specified their own preferred *output* pixel scale, the parameter also serves the function of defining the default output pixel scale that images will be drizzled to. So, for example, if users prefer four times as many pixels in their multidrizzled output images relative to the input images, the required pixel scale to achieve this should be manually set within the program and that value will override the value of SCALE. Multidrizzle will then resample the pixel grid and also automatically adjust the count rate in each pixel by a factor of four to preserve photometry (i.e., each new pixel contains four times less flux than before, but there are four times as many pixels covering any given source).

For several previous HST instruments, the SCALE in the IDCTAB has *not* been set to the native pixel scale of the camera, but rather to a convenient number. This has ensured that the default *output* pixel scale of _drz images, where users have not specified their own pixel scale, is a slightly more convenient "round" number. The consequence of this approach is that measured photometry of the same source on a _drz and _flt image can differ strongly at all positions on the image. In effect, multidrizzle is forced to scale the count rate in all pixels by a systematic amount before applying the distortion solution. Based on this choice of SCALE, the calculated PAM from the geometric distortion has been renormalized by a factor that compensates for the two different pixel scales. It is the ratio of the true mean native pixel scale to the SCALE chosen in the IDCTAB that sets this normalization.

As an example of this convention, the ACS/HRC has a mean native pixel scale of ∼0.028 arcseconds but the SCALE in the IDCTAB has been set to a desired default output pixel scale of 0.025 arcseconds (i.e., a "round" number). A star (e.g., point source) centered on the HRC detector will therefore exhibit a difference in total integrated aperture count rate of 12% in the _flt and _drz image (note, extended source photometry would not be affected). The calculated photometric zero point, that is the magnitude of a star-like object that produces 1 count per second in a given aperture, is only accurate on the _drz images and is discrepant from the measured value on the _flt image by 12%. To correct this offset, users can multiply the _flt images by the PAM, which has values of ∼1.105 – 1.145, or they can adjust the count rate after performing photometry on the _flt image. Similarly, for ACS/SBC, the correction required through the PAM to achieve consistency in photometry between the _flt and _drz images is ∼60%, despite the actual areas of pixels over the detector varying by one tenth of this amount.

Whereas the presence of a geometric distortion and therefore a small *relative* difference in the photometry of a point source depending on its spatial location on an image may be well appreciated by HST users, an arbitrary normalization of the count rate measured on HST pipeline processed _flt images may not be well known. Specifically, a user analyzing _flt images with their native pixel scales may not know that the photometric zero points applicable to their data require large corrections that are much higher than the intrinsic variations that would be produced by the geometric distortion in their _flt images.

4. The WFC3 Pixel Area Maps (PAMs)

For the WFC3/UVIS and IR detectors, we adopt a slightly different practice for calibrating the photometry than described above for previous instruments. In this section, we 1.) outline our criteria for the creation of the PAMs, 2.) present and analyze the PAMs, and 3.) discuss the implications for photometric measurements on _flt and _drz images with this convention.

In creating the WFC3 PAMs, we first choose two reference pixels, one near the center of the UVIS field and one near the center of the IR detector. These values, chosen for convenience, are located at (x,y) = (2072, 2046) on the UVIS2 CCD (i.e., bottom chip) of the UVIS camera (each of the two CCDs have 4096 × 2051 pixels), and at (x,y) = (557, 557) on the IR camera (1014 × 1014 pixels), both in the image system (i.e., excluding the overscan pixels). The values were intentionally offset from the exact centers given the chip gap on the UVIS camera and the intersection of the four quads on the IR detector. The location of these reference pixels also currently corresponds to the reference locations of the UVIS-CENTER and IR apertures, respectively. Second, rather than arbitrarily choosing the SCALE parameter in the IDCTAB to a "round" number, we set the parameter to the square root of the area of the reference pixel. For the UVIS detector, this is formally 0.039621 arcseconds and for the IR detector it is 0.128243 arcseconds. Finally, we set the normalization of the PAMs to be unity at the reference pixels listed above.

The resulting PAMs for these choices are presented graphically in Figures 1 and 2. For the UVIS two chip mosaic, the normalized area of the pixels is ∼1 along a diagonal stretching from the top-right (e.g., Amp B on UVIS1) to the bottom-left (e.g., Amp C on UVIS2) of the detectors. The maximum and minimum variations in the pixels are towards the opposite corners of the image, with an amplitude of 7.2%. For the IR detector, the normalized area of the pixels is ∼1 along a horizontal row near the center (i.e., near the reference pixel), is minimal towards the bottom, and

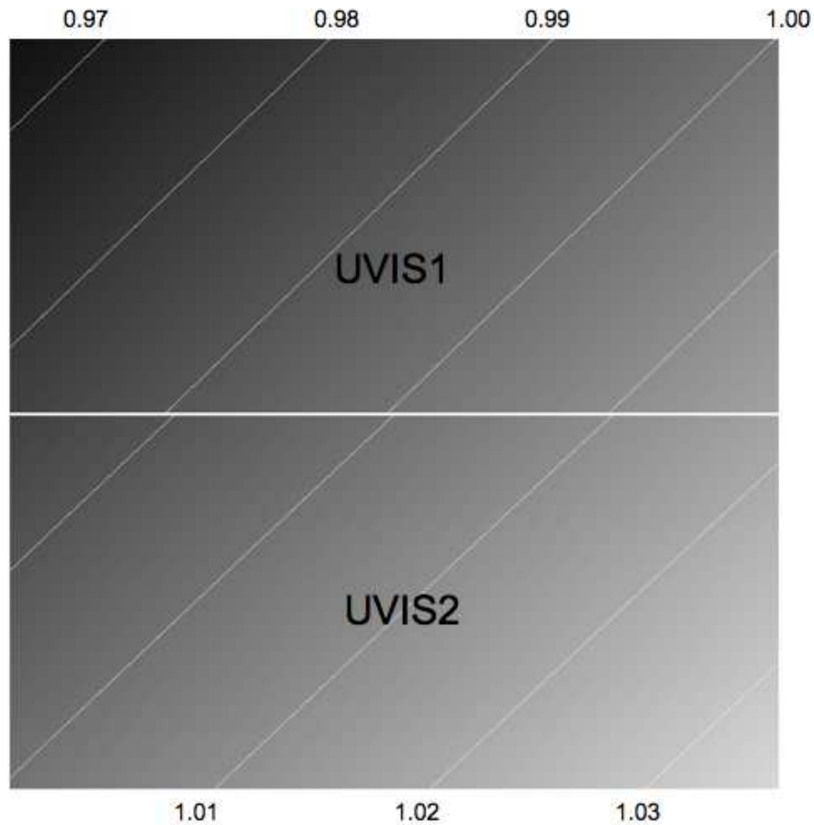

Fig. 1.— *The WFC3/UVIS pixel area map (PAM), renormalized as described in Section 4. The normalized area of the pixels is smallest in the top-left corner (e.g., Amp A on UVIS1) and largest on the bottom-right corner (e.g., Amp D on UVIS2), and roughly 1.0 along the opposite diagonal. The exact normalization to unity is set to pixel (x,y) = (2072, 2046) on UVIS2 and the SCALE in the IDCTAB has been set to the square root of the area of this reference pixel, 0.039621 arcseconds. Given this choice, a star roughly centered on the UVIS field will measure the same count rate on the _flt and _drz images, even without a PAM correction.*

is maximum near the top. The maximum variation in the area of the pixels over the entire detector is 8.6%.

With the convention described above, the PAM now serves the simple purpose of providing a relative correction to the count rate of a point source that is not located near the center of the detector (e.g., at the reference pixel), without any other large arbitrary scaling. For example, for a source in the top-left corner of the UVIS two chip mosaic, the PAM is 0.967 and so a star located near this location will have a count rate that has been adjusted upward by 3.3% due to the flat-fielding, relative to that measured at the reference pixel. By multiplying the _flt image by the PAM and performing photometry on the resulting image (or by simply multiplying the measured count rate by the value of the PAM at the given location), the count rate of this object will be the same at the corner and at the reference pixel. Further, this convention ensures that the photometry measured for any source that is near the center of the _flt image will naturally agree

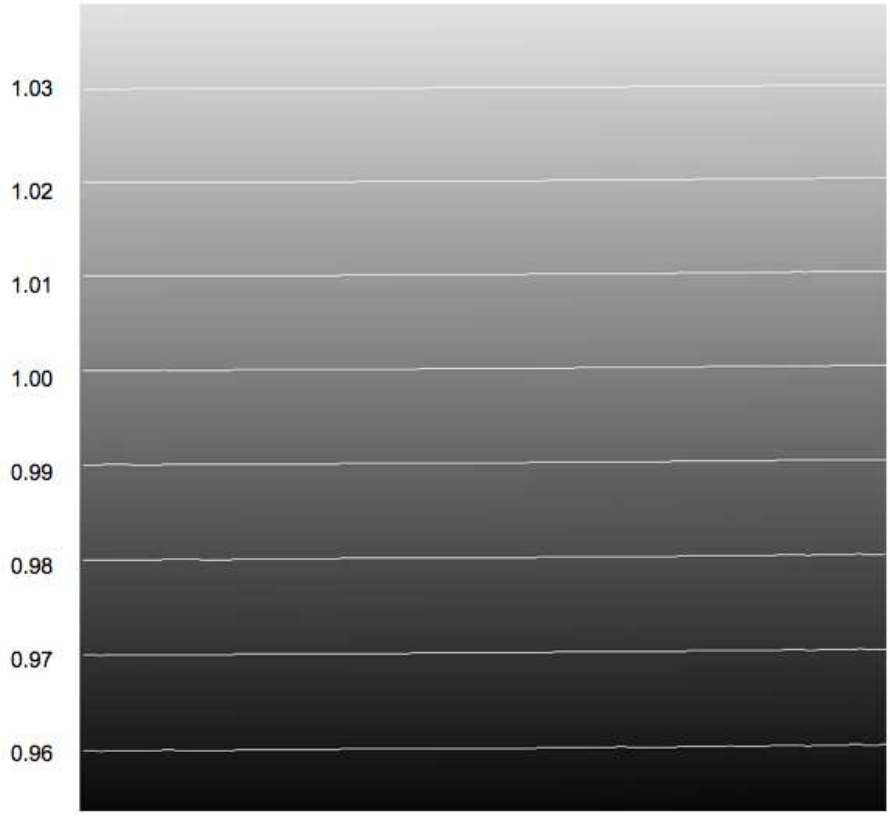

Fig. 2.— *The WFC3/IR pixel area map (PAM), renormalized as described in Section 4. The normalized area of the pixels is smallest at the bottom of the detector and largest at the top, and is roughly 1.0 along a horizontal band near the center. The exact pixel set to unity on the IR detector is at (x,y) = (557, 557), and the IDCTAB SCALE has been set to the square root of the area of this pixel, 0.128243 arcseconds. With this convention, the count rate measured for a star roughly centered on the IR detector will be the same on an _flt and _drz image, even in the absence of a PAM correction. The PAM simply serves to make a relative correction for stars that are not centered on the detector.*

with the photometry on a _drz image. Formally, these two will be exactly equal for an object on the reference pixel where the photometric zero points have been defined (see Kalirai et al. 2009a; 2009b), but in practice the PAM changes slowly over regions that are a few 100's of pixels across. For example, on the IR detector, over a box size of ±100 pixels from the reference pixel near the center of the detector, the photometry change will be less than 1%.

Finally, as the geometric distortion solutions for the detectors are improved over time, very small changes in the area of the reference pixels will occur. If the same reference pixel is retained in the future, this implies a change in the ratio of the _flt counts and the PAM corrected counts over time. The ratio of the PAM corrected counts to the _drz counts will, however, remain constant.

5. Conclusions

Photometry on WFC3/UVIS and IR _flt images suffers from geometric distortion and therefore varies across the field of view. We have presented the pixel area maps of the two UVIS CCDs and the IR detector, which can be multiplied into the _flt images to yield uniform point-source photometry across the detectors. The normalization of the PAMs has been set to a specific reference pixel near the center of the UVIS two chip mosaic and the IR detector, and the SCALE in the IDCTAB has been set to the square root of the area of these reference pixels. For the UVIS camera, the reference pixel is located at (x,y) = (2072, 2046) on the UVIS2 CCD and the SCALE is 0.039621 arcseconds, whereas on the IR camera the reference pixel is (x,y) = (557, 557) and the SCALE is 0.128243 arcseconds. This convention will permit users to achieve the same point-source photometry on _flt and _drz images, for objects approximately centered on the detectors. At this stage, the default output pixel scales from drizzle have also been set to the scale above, although this may be fixed to a nominal value later (e.g., through a second parameter in the IDCTAB). Users are still free to adjust this in the multidrizzle process for their specific needs (e.g., set the WFC3/UVIS output pixel scale to 0.04 arcseconds and the WFC3/IR output pixel scale to 0.125 arcseconds). Finally, we point out that despite the discussion in this ISR, users are encouraged to perform photometric measurements on _drz images which are distortion free, and which have cosmic-ray and bad pixel rejection.

The WFC3 PAMs and the IDCTAB are available at these web pages:
`http://www.stsci.edu/hst/wfc3/pam/pixel_area_maps`
`http://www.stsci.edu/hst/observatory/cdbs/SIfileInfo/WFC3/reftablequeryindex`.

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