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Correcting Background Streaks in WFPC2 Data

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ABSTRACT

We present an algorithm designed to eliminate the horizontal streaks seen in WF4 images with low bias values. This is a stand-alone task and should be used after all other corrections for bias, dark, flat field and gain have been performed. The algorithm uses data from the entire image to compute the correction to be applied to the streaks. While the input parameters are adjustable, their default values provide satisfactory results for most streaked images. This routine can also be used to correct the streaks/bias jumps that are occasionally seen in the other WFPC2 chips. This algorithm has been converted to a task called “wdestreak” in the forthcoming version of STSDAS for Pyraf.

Introduction

Around the time of Servicing Mission SM3B in March 2002, the WF4 detector of the Wide Field Planetary Camera 2 started showing anomalous behavior seen as low or zero bias level episodes occurring every 4 to 6 hours. These bias anomalies occurred at the temperature peaks of the WFPC2 Replacement Heaters (Biretta and Gonzaga 2005). Images with low bias often show horizontal streaks in the background (See Fig. 1) with the streak amplitude

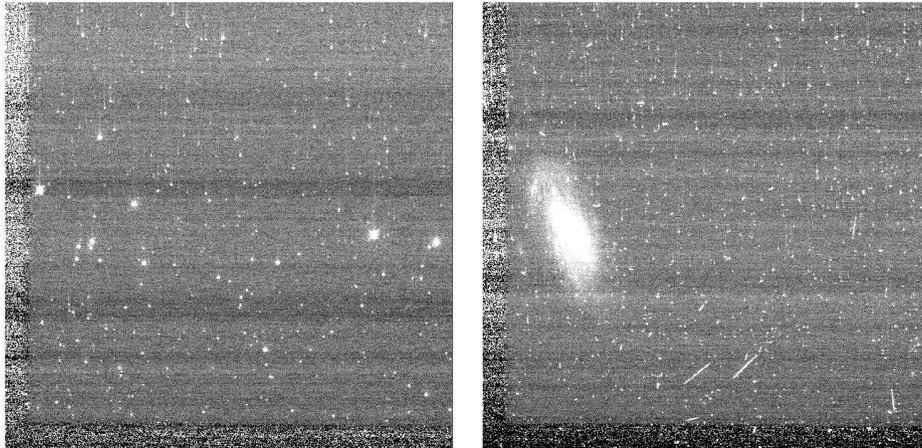


Fig. 1.— *Examples of WF4 images showing horizontal streaks.*

reaching as much as ~ 1 DN RMS for very low bias values (bias < 200 DN). The temperature of the WFPC2 electronics has been reduced five times since January 2006 (McMaster et al. 2008). Each temperature change has temporarily restored the WF4 bias and gain to near-normal levels (Dixon et al. 2007).

A large number of WF4 images were obtained during periods just before the temperature reductions when the bias levels were low or zero. Data for the zero-bias images is completely lost, but the data with low bias values can be rescued and used by removing the effects of the low gain and the streaks. A new pipeline task corrects the gain of low-bias images. While this task restores the counts and thus the photometry (to a large extent), it does not remove the streaks seen in these images. It is important to remove the streaks, especially in case of faint sources where the noise due to the streaks dominates. Also, if several streaked images with faint objects are combined, large errors in photometry can arise based on the position of the star (whether it is on a brighter or darker row).

Because the locations and strengths of the streaks are random in the data, it is nearly impossible to use a “one size fits all” program to remove them.

The Algorithm

A new routine has been developed to remove the streaks in the low bias images. The goal of this routine is to reduce or remove the horizontal streaks while preserving the photometry.

Low bias is presumed to result from an instability in the CCD amplifier that reduces the gain, and hence is a multiplicative effect. The streaks are thought to arise from the same gain error, where there are short timescale, small fluctuations in gain (on the order of 0.02% over a few milliseconds) resulting in background streaks as the image is read out. The streaks are thus a multiplicative effect also, appearing primarily in the “X” direction due to the short timescale. Although strictly a multiplicative effect, it can be treated as an additive effect due to the large offset value in the amplifier.

The first step involves creating a mask in which all pixels affected by cosmic rays or bright sources are given zero values. The correction for each row is estimated using only “good” pixels - those not affected by cosmic rays or sources. The algorithm used for identifying sources and cosmic rays is iterative, based on fitting a model to the image data, estimating the scatter, and rejecting outliers. The “good” pixels define a mask that is output to a file.

The masking of cosmic rays and sources consists of two steps. First, extreme outliers caused by cosmic ray hits or bright sources are masked. We conceptually split the image into two halves: we then take the median of the top half (pixels with $401 < Y < 800$) and the median of the bottom half (pixels with $1 < Y < 400$). These two points define a straight line and the scatter about this line is estimated by the median of the absolute values (known as the MAD) of the deviations of the image values; for a normal distribution the MAD is approximately 2/3 of the standard deviation. The slope and intercept of this line define a plane that can have a slope in the Y-direction and is constant in the X-direction. Values in the image that exceed this plane by more than 15 MAD (10σ) are flagged as bad and will not be used for subsequent processing. Because the purpose is to identify cosmic rays and bright sources, only positive outliers are rejected.

The second step is to fit a plane (using least-squares) to the image data, ignoring the previously rejected outliers. The scatter is estimated by the standard deviation of the differences between the fit and the image data. Values in the image that exceed the scatter by more than 4 sigma are flagged as outliers. When a cosmic ray or bright source is identified in one pixel as a positive outlier, neighboring pixels are screened for large positive values using a lower threshold than that used for identifying the initial bright pixel, allowing additional pixels to be flagged as outliers. This iterative procedure of fitting and rejecting is repeated several times, with the rejection criterion (specified by the number of standard deviations) reduced in later iterations. After the last iteration, the fitting is done once more, with all

previously identified outliers excluded from the fit.

Now that the mask has been created, the corrections can be calculated. For a given image, the correction for each row is the difference between the mean value of the unmasked pixels within the row and the global mean of all unmasked pixels within the image. The correction can be either positive or negative and is applied to all pixels in the row.

The user can optionally supply a mask instead of having the program calculate a mask. This option allows the user to fine-tune the process, by first running the program and allowing it to create a mask, editing the mask, then running the program with the edited mask as input.

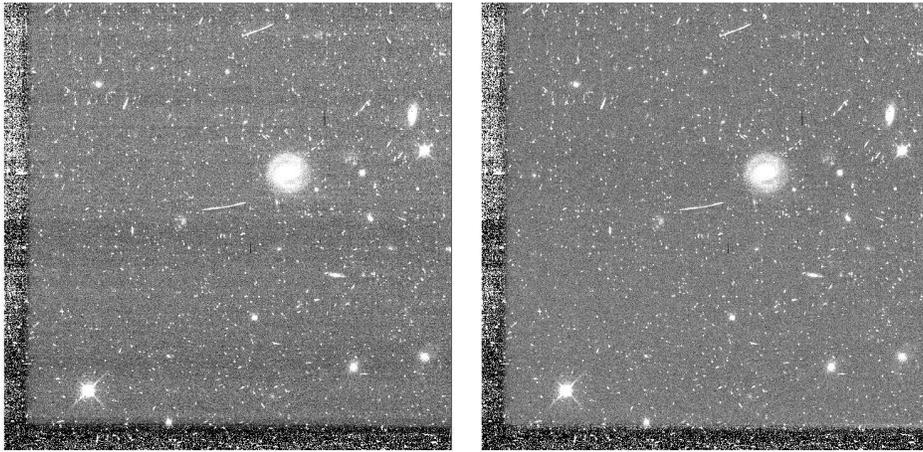


Fig. 2.— *Left: A streaked image with a small galaxy and a few stars. Most of the pixels in this example are “sky” and hence it is easy to get good estimates of the actual sky background. Right: The corrected image with the streaks removed using only the default values in the routine*

Examples and Results

An example of an application of this routine is shown in Figure 2. In this case, the image consists of a small galaxy and a few stars. Using the default parameters, it is possible to correct the streaks and get a clean output image. Figure 3 shows a more complex example of

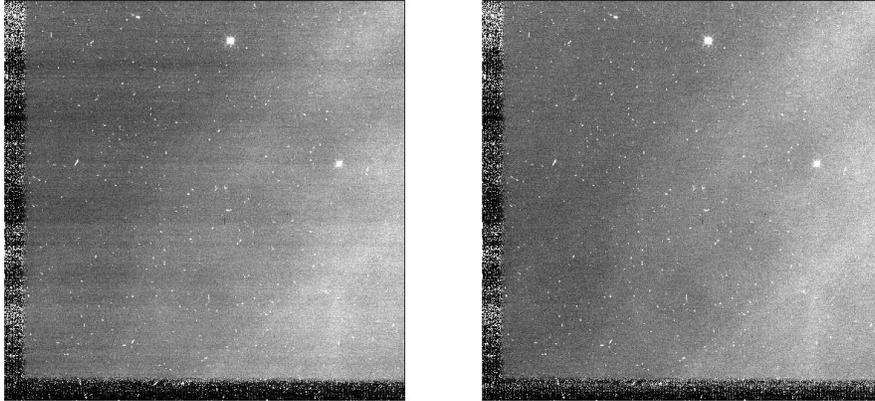


Fig. 3.— *Left: An image of the Orion Nebula showing streaks. In cases like this, the image is made up of patchy dark and bright regions. Right: The corrected image with the streaks removed using only the default values in the routine*

streaks in an image of the Orion nebula. The background in this case is made up of patchy dark and bright regions. However, running the routine using the default parameters can remove the streaks successfully as shown.

A more challenging example of how this routine works is the streaked image of a large spiral galaxy shown in Figure 4. The default mask image created by the routine is shown in the top right panel. Note that though the iterative process masks the brightest regions in the galaxy, the diffuse background contributes to a large number of pixels, especially in the lower part of the image. These pixels will contribute to both the global and the row means. Because they affect the row mean in this region substantially more than the global mean, they yield a row mean that is higher than the sky value and thus, an over-subtraction. This effect is seen clearly in the lower left image. Though the streaks have been removed in this image, some regions look darker than the background sky. We edited the default mask and masked out the diffuse regions of the galaxy. Using this new mask and running the routine again, we obtained the final image at the lower right. This image does not show streaks or regions with over- subtraction. In this way, the routine can be run interactively to get the best possible images with no streaks.

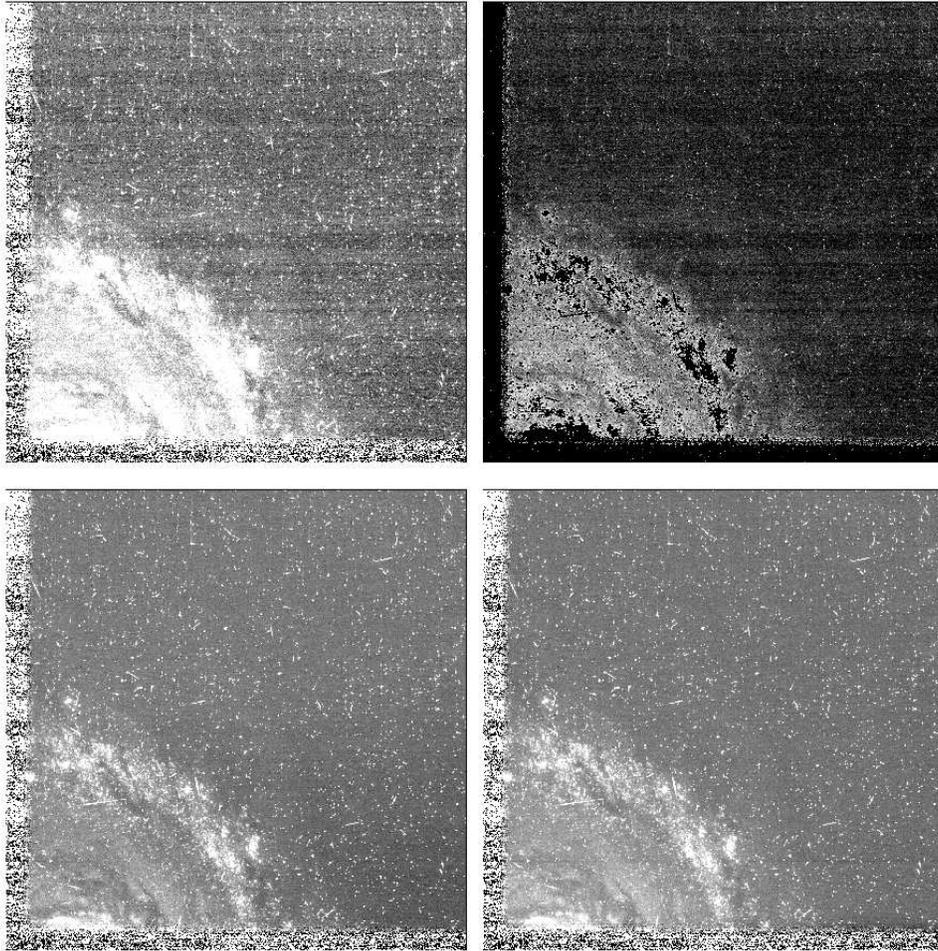


Fig. 4.— *An illustration of the streak removal process. Top Left: An image of a galaxy with several streaks. Top Right: The mask created by the program. The masked pixels have a value of 0.0. Lower Left: The output of the program. Note that even though the streaks has been greatly reduced, some regions in the lower right corner of the image show oversubtraction. (See text for a detailed discussion). Lower Right: The corrected image obtained after editing the default mask. The oversubtraction seen earlier has been removed.*

Interactive Parameters

The routine has been tested intensively and a set of default parameters has been assigned which give good results in most cases. However, the user has the option to change most of the parameters to fine tune the output image.

This algorithm has been converted to a task called “*wdestreak*” in Pyraf and can be

found within “*stsdas.hst_calib.wfpc*” in the forthcoming version of STSDAS for Pyraf. The graphic user interface parameter file for “*wdestreak*” is shown in Fig. 5.

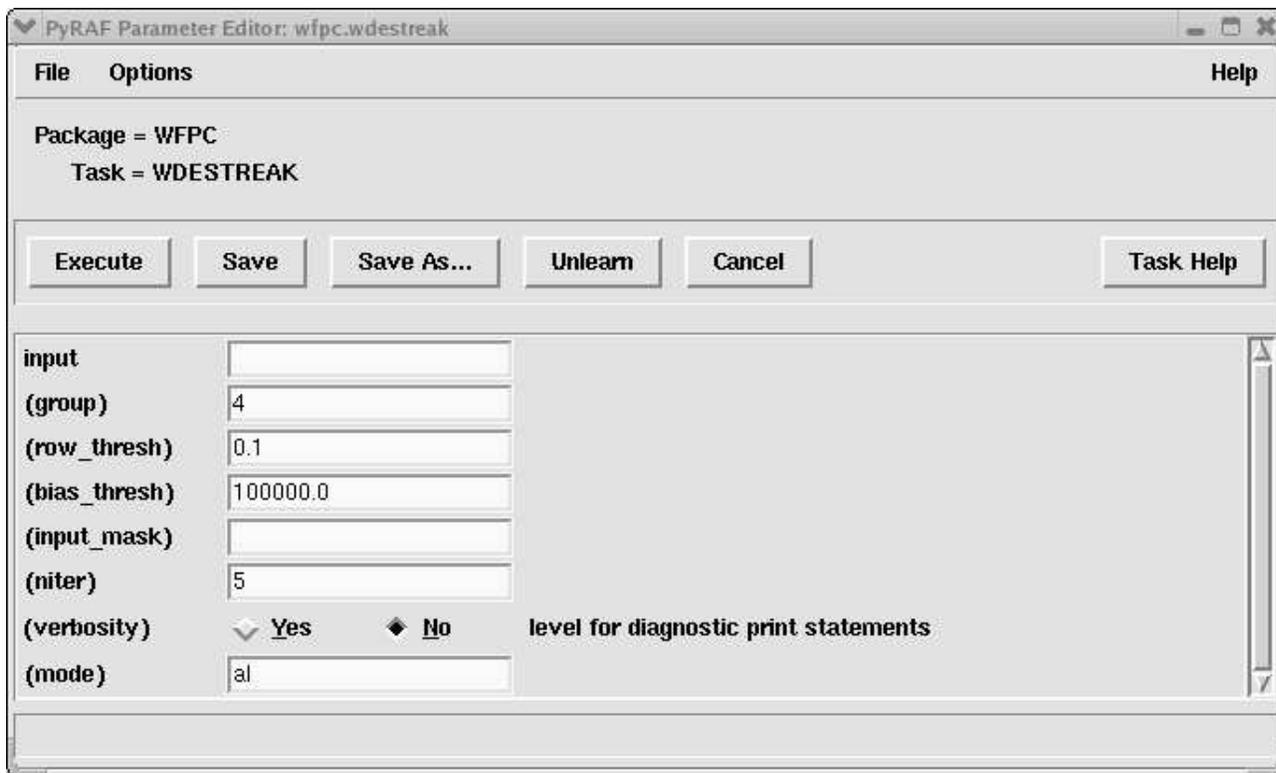


Fig. 5.— *Parameter file of the task wdestreak within Pyraf.*

As mentioned earlier, the user can edit the default mask image run the routine again. In addition, there are other parameters the user can optionally set:

- The “group” parameter sets the group within the dataset to correct and has a default value of 4 for WF4. This procedure can also be used to correct streaks in any of the WFPC2 chips by specifying the appropriate value (1,2,3 or 4). To correct streaks in multiple chips, the procedure must be run multiple times, specifying one group at a time. Note that the streaks or bias jumps seen in PC1, WF2, and WF3 are unrelated to the anomalous behavior of the WF4 amplifier.
- The row threshold parameter “row_thresh” sets the minimum absolute value of the allowed correction, so if a calculated correction is less than this value for a given row, no correction will be applied to that row. The default value for this parameter has

been set to an arbitrary value of 0.1. It is important to have a value greater than zero and ideally equal to the mean sigma of the sky in the background image for this parameter to avoid over smoothing of the background.

- The parameter “bias_thresh” is compared to the mean of the pixels remaining after clipping. If the bias threshold is exceeded by the image mean, no correction will be applied to the image. The default value for this parameter is 10^5 . As this value exceeds any dataset’s bias value, by default the task will calculate and apply the corrections. This parameter is provided to allow the user to apply the task to multiple input files from within his/her higher-level script.
- The parameter “niter” sets the number of iterations to use in the source masking step; the default is 5, and the maximum allowed value is 10. A greater (lesser) value generally results in more (fewer) pixels being masked around bright sources or cosmic rays.

Comparison of Photometry

The examples discussed above show that the routine can successfully remove the streaks in the background and produce clean images. However, it is important to verify that the routine does not affect the photometry of the sources. To check this, we considered two sets of data of the cluster Omega Centauri with WF4 bias level < 270 DN. Each set consists of images with exposure times 10s, 14s, 100s and 400s with the F814W filter. Source finding was done using daofind and aperture photometry was done in each case. Streaks seen in these images were then removed and aperture photometry performed again on the corrected images. Figure 6 shows a comparison of the stellar magnitudes derived using the uncorrected and the corrected images for different exposure times for datasets u9ux0105m through u9ux010hm. Figure 7 shows the comparison for datasets u9ux5306m through u9ux530hm. Since we are interested in the relative photometry, we have not transformed the magnitudes to any standard system and the magnitudes are given in an arbitrary scale.

A number of tests have been done (Dixon and Bedin 2008) in which images with normal bias were compared with low bias images that had been corrected for gain. Some of these images had streaks. They find that the stellar magnitudes measured from high- and low-bias images differed greatly in the uncorrected images, but were much closer in the set that was corrected for gain. No correction for the streaks was applied. They also looked at before and after images of a standard white dwarf and found that, for the corrected photometry,

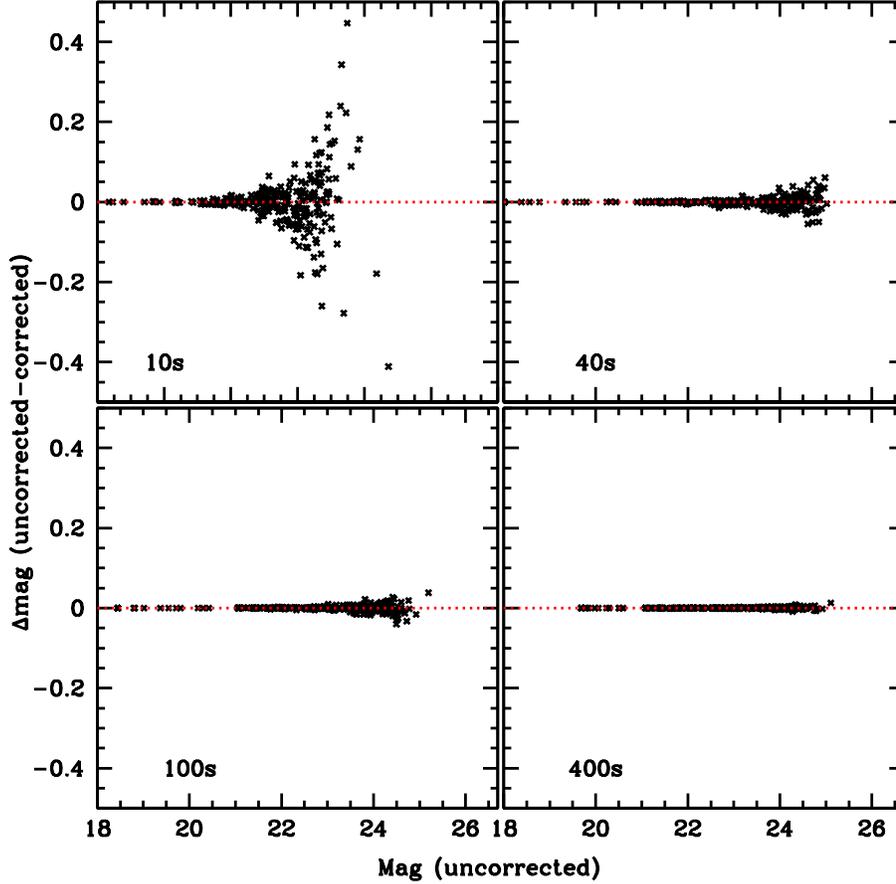


Fig. 6.— Comparison of photometry before and after streak removal for the dataset *u9ux0105m* through *u9ux010hm* for different exposure times in F814W for the same field. Note that the magnitude scale is arbitrary. For bright sources and for deep exposures, the photometry does not appear to be affected. For faint sources observed with short exposure times, the background noise takes over and a large scatter is seen.

the 1-sigma error is ~ 0.025 mag. Therefore, it is reasonable to infer that the gain and the destreaking corrections preserve the photometry of the stars.

It is clearly seen from the plots that the destreaking procedure preserves the photometry of bright sources, for which the background noise is much lower than the photon noise. However, in case of faint stars and some faint extended (but small) nebulosity or short exposures with counts \sim few DN, removing the ~ 1 DN streak artifact will increase the accuracy of the photometry (and morphology). In these cases, the streaks are a greater source of noise than the normal photon noise, since the streaks are correlated from one CCD

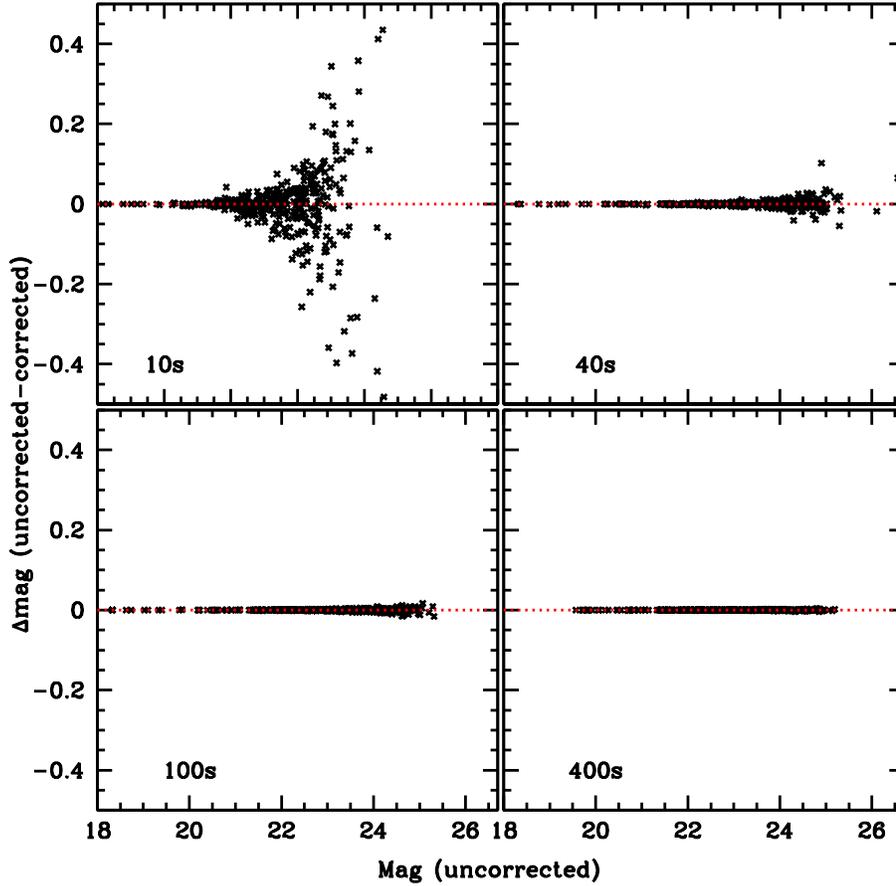


Fig. 7.— Same as Fig. 6 but for the dataset *u9ux5306m* through *u9ux530hm*.

column to another.

Conclusions

We have designed an algorithm that corrects background streaks seen in WFPC2 images with low bias. The algorithm flattens the background and gives more accurate photometry for faint objects. This routine has been tested on several types of data (images with stars, small extended sources, large galaxies, etc.) and is seen to work satisfactorily. The routine allows the user to change parameters to fine tune the resultant image. This algorithm has been converted to a task called “*wdestreak*” in the forthcoming version of STSDAS for Pyraf.

References

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