Encircled Energy Measurements for the M10 WFC3 1R-MUX Pinhole Images – Set 2

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Abstract
The present ISR describes the encircled energy (EE) analysis of pinhole images made on the M10 WFC3 1R-MUX at the Goddard Space Flight Center (GSFC) Detector Characterization Lab (DCL) on 29 May 2001. Analysis shows that the pinhole image’s centroid is stable within a 1-pixel area and the 80% of the encircled energy is contained within a radius of 1.08 pixels of the pinhole center, vs. 86% of the energy within 0.83 pixels in the theoretical limit. We analyze the systematic error introduced by the strong undersampling of the PSF showing that the standard centroid analysis overestimates the encircled energy for any given radius.

1. Introduction

Two groups of 100 pinhole images each with 100 corresponding dark images have been obtained at the GSFC DCL on 29 May 2001 in their Offner setup. Projecting a 633nm HeNe laser beam onto an 8um pinhole creates the pinhole image on the 1R-MUX. The M10 WFC3 1R-MUX is a 1024 x 1024 pixel array with 18um x 18um pixels. The pixel size was reported incorrectly as 18.5um X 18.5um in WFC3 ISR 2001-11.

2. Data

The data collected by the DCL on 29 May 2001 are divided in two groups. The first group, “A”, consists of a total of 100 pinhole images and 100 dark images, taken in groups of 10 alternating between 10 pinhole image acquisitions and 10 dark image acquisitions. The group “B” also consists of 100 pinhole images and 100 dark images. However, the B group
images were collected in groups of 50, alternating between 50 darks and then 50 pinhole images.

In this study, we were only interested in the cumulative encircled energy (EE) for both groups. The IRAF task IMCOMBINE was used to median all of the pinhole and the dark images, for each group. The IMCOMBINE task was used with sigma clipping to reject pixels above 3 sigma limit. The median dark image was then subtracted from the median pinhole image to create the image used in the EE analysis. The final A and B group images are called “pinAgrp.fits” and “pinBgrp.fits” respectively.

3. Analysis Technique

An IDL routine created by George Hartig of the Advanced Camera for Surveys (ACS) group called “acs_eer.pro” is used to measure the EE of the pinhole images. The “acs_eer.pro” source code is available on the ACS web site at http://adcam.pha.jhu.edu/instrument/calibration/software/idl/image/. A sample of the IDL commands used appears below:

```idl
image=readfits('pinAgrp.fits')
cntrd, image(708:807,700:799), 50, 50, xout, yout, 5
print, xout, yout
acs_eer, image(708:807,700:799), xout, yout, r, ee, /adjust, /show
openw, 1, '/data/spartan3/WFC3/PINHOLE/Version3/Agroup/ee.dat', /more, /append
printf, 1, 'Aperatures', r(1:10)
printf, 1, 'pinAgrp', xout, yout, ee(1:10)
close, 1
```

First the image to be processed is read into an image variable. Next, the centroid of the pinhole is determined within the 100 x 100 pixel subsection of the input image. Finally, the “ace_eer.pro” routine is called to do the EE determination. A postscript file is then generated showing the EE as a function of radius and the centroid position and first 10 points of EE plot are appended to an ASCII log file.

When making the EE measurements, it was necessary to only include a 100 x 100 pixel area approximately centered on the pinhole. This was necessitated by the large variations in the background levels that prevented the EE routine from doing a linear fit to the background levels. This fitting problem causes the IDL routine to fail in producing a zero slope in the EE vs. radius plot at the edge of the field. The region used for the A group reductions was (708:807,700:799). The B group reductions used the region (708:807,698:797).

3 Results

Figures 1 and 2 show the EE curve for the group A and B images respectively.
In the first set of M10 1R-MUX data (WFC3 ISR 2001-11) the centroid position of the individual pinhole images fell into two distinct distributions. For this set of data, we again
examined the centroid distributions for both the group A and B data sets. The results are found in Figure 3 and 4 below.

Figure 3, Group A, Centroid Position Pixel Map
From the two pixel maps we can see that the bimodal distribution of pinhole centroids that was seen in the Set 1 data does no longer appears.

Finally, the cumulative results for the set two data are compiled below in table 1.

<table>
<thead>
<tr>
<th>Aperture Radius (Pixels)</th>
<th>0</th>
<th>0.5</th>
<th>1.5</th>
<th>2.5</th>
<th>3.5</th>
<th>4.5</th>
<th>5.5</th>
<th>6.5</th>
<th>7.5</th>
<th>8.5</th>
<th>80% EE Radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>PinAgp EE</td>
<td>0</td>
<td>0.61</td>
<td>0.92</td>
<td>0.98</td>
<td>0.99</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.08</td>
</tr>
<tr>
<td>PinBgrp EE</td>
<td>0</td>
<td>0.61</td>
<td>0.93</td>
<td>1.00</td>
<td>1.01</td>
<td>1.01</td>
<td>1.01</td>
<td>1.01</td>
<td>1.02</td>
<td>1.02</td>
<td>1.07</td>
</tr>
</tbody>
</table>

Table 1
4. Error Analysis

Assigning an error value to the 80% EE Radius results in Table 1 is complicated by the under sampling of the pinhole PSF by the MUX pixels in addition to the centroid measurement error. In order to quantify sampling error, a number of PSFs were generated each centered on a specific point within a pixel (see Figure 5 below).

Two sets of Gaussian PSFs were generated, one with a FWHM equivalent to what is seen with the WFC3 M10 1R-MUX images, approximately 1.5 pixels, and one with 10 times the FWHM to provide a well sampled PSF for comparison. The EE is then measured using the technique described in section 3. The EE for the PSFs with a FWHM of 15 pixels was then plotted against aperture values 10 times smaller than were actually used in the EE measurements. This was done to simulate the EE curve for a “well sample” 1.5 pixel FWHM PSF. The results of this study appear in Figure 6. We see that for the 80% EE measurement the radius at which it occurs differs between 0.5 and 1.2 pixels depending on the location of the PSF center. This is a classical example of the problems connected with undersampling the PSF.
Figure 6. Plot of EE versus aperature radius for the simulated PSFs. The solid red line represents the EE measurement for a “well sampled” PSF. The other lines represent the EE measurements of the PSFs based upon the location of the PSF center within a pixel. For Example, the “Gauss00” line represents the EE of a PSF whose center lies at the corner of four pixels.

5. Conclusions

The group A and B EE results are consistent with those seen in the previous M10 1R-MUX data set (WFC3 ISR 2001-11). There are still large variations in the background levels of the images that make processing of these images to large apertures difficult. The 80% EE point is 1.08 pixels for the A group image and 1.07 for the B group image and 100% of the flux is seen within a 3.5 pixel radius. The systematic error on the 80% EE point is substantial due to the undersampling of the large MUX pixels, and always tend to underestimate the radius. However, the optical system appears to provide stable performance down to the theoretical diffraction limit of the DCL Offner setup, set to 86% of the energy within 15µm pixels.

6. Acknowledgements

We would like to express our gratitude to Yiting Wen and Scott Johnson of the Detector Characterization Lab at the Goddard Space Flight Center for their work in acquiring the 1R-MUX data and their feedback when interpreting the results.