REPORT TITLE WISE Scanner Linearity Analysis	DOCUMENT NUMBER SDL/09-215
PREPARED BY Brent Haslem	DATE April 16, 2009

1. DATA COLLECTION

The data for this analysis was taken on November 5, 2008. The file prefix for all of the data is "PRF". The procedure used to capture the data needed for this measurement can be found on pages 5 and 6 of SDL/07-585. Instead of the MIC2 aperture as is called out in the procedure a focus probe was used to illuminate the collimator. This produced a collimated beam with a small angular divergence incident on the WISE entrance aperture. The MIC2 pointing mirror was positioned to illuminate a 5x5 grid of points roughly filling the WISE FOV and 5 frames of data were taken at each location. At each grid location the flight primary scanner was commanded to 5 different angles (-11,230, -3,759, 3,712, 11,183, 18,654). The MIC2 pointing mirror was commanded to a new pointing angle for each scanner position to roughly keep the point source in the same location on the focal plane. The 5x5 grid of data will be used to measure the angular response of the scanner across the scan range. To achieve sufficient signal levels as seen on the WISE focal planes, 2 different focus probe voltages were used. The first level of 0.21 V was used for Band 1, and the second level of 0.086 V was used for Bands 2, 3, and 4. This resulted in a signal level of approximately 4500, 600, 1600, and 3500 counts for Bands 1, 2, 3, and 4 respectively. MIC2 operating parameters were recorded including the Azimuth(X angle) and Elevation (Y angle) components of the MIC2 pointing mirror position. Dark data frames were taken with the MIC2 cold shutter closed at the beginning and the end of testing for each temperature.

2. DATA EXTRACTION

To perform the data analysis required for this section the point source position on the focal plane and the point source amplitude need to be determined for each MIC2 pointing mirror position. This is done in the following manner:

1. Using only the data in the center grid position to generate PRF
    a. Apply 2a and 2b below to prepare data for PRF generation
    b. Generate an 8x up-sampled, peak normalized PRF
        i. An initial PRF was created by regridding the data so that the centroid is centered on a pixel and then cropping to 15x15 pixels around the center.

        ii. The final PRF was then found by up-sampling the initial PRF using spline interpolation to come up with a final 121x121 pixel PRF.
2. Apply the following for each MIC2 pointing mirror and scanner position, n.
    a. For each frame of a single position, n. (5 frames)
        i. Apply the bad pixel mask (BPM)
        ii. Perform background subtraction using the dark data
        iii. Additional bad pixel criteria were applied
            1. Find maximum pixel value
            2. If the mean value of the 4 pixels surrounding the maximum value is less than 60% of the max value it is not the point source stimulation and assigned NaN. (Preliminary results showed that for a good point source this should be ~70%)
            3. Repeat until previous criteria is not met
        iv. Find the frame centroid
    b. Combine Frames
        i. Find the frames that deviate by less than a pixel from the median centroid of all frames. These are the “good frames”.
        ii. Take the mean of all good frames to come up with the combined frame.
    c. Use Point Source Extraction (PSE) to determine point source amplitudes and focal plane positions
        i. Central PRF used for all PSE
        ii. X_n,Y_n (Column, Row) focal plane positions for all pointing mirror positions, n.
        iii. Amp_n Point source amplitudes for all pointing mirror positions, n.
    d. Extract MIC2 steering mirror position from the log file
        i. $MIC2Az_n$, $MIC2El_n$ for all pointing mirror positions, n.

This produced focal plane position and amplitude, along with steering mirror positions for all pointing mirror grid positions where data was taken, at all pointing and scanner positions n. This process was applied for all bands and all scan mirror positions.

3. DATA ANALSYSIS

3.1 SCANNER TRANSFER FUNCTION

This analysis will show the effects of scanner angle on the position of a point source on the focal plane. On-orbit, the scanner is used to freeze an image on the sky while the spacecraft rotates smoothly around its orbit. To keep a point source on one location on the focal plane with varying object space angles requires sweeping through different scanner angles. If the scanner rate is set to perfectly compensate for the changes in azimuth angle and there is NO distortion in the optics up to the scanner an illuminated point source that is moving relative to azimuth object space angle will not move on the focal plane. Since the WISE optics do have distortion on the front end this will cause differing locations on the focal plane to perceive different spatial changes in position for the same relative angular scanner offset. Because of this effect, rather than remaining fixed on a specific focal plane position, these differences in perceived angular rate will cause the moving point source to wander on the focal plane. This movement will be spatially dependant on the change in distortion correction across the scan range at a given focal plane position. For a discussion of distortion including plots at various scan angles please see the WISE FOV Mapping Report.

We define the angular scanner gain as the relationship between the angle of the scanner (in arc-seconds) and the scanner position, measured in resolver counts. Figure 1 to Figure 3 show the apparent angular scanner gain as seen by each of the 25 grid positions as a function of scanner position. Each trace represents a unique grid location on the focal plane and consists of 4 apparent scanner gains created from the difference between the 5 scanner angles as shown below. Band 2 results have more uncertainly in their PSE position due to larger diffraction effects. There is no data available to do this analysis for Band 1, and therefore not any Band 1 results.

$$\boldsymbol{Scanner\_Gain_n = \frac{\Delta Angle_n}{\Delta SM_n}\ 0.206265\left(\frac{arc-sec}{count}\right)}$$

$$\boldsymbol{\Delta SM_n = SM_n - SM_{n+1}}$$

$$\boldsymbol{\Delta Angle_n = \sqrt{(\Delta Az_n + \Delta X_n * IFOV_{Az})^2 + (\Delta El_n + \Delta Y_n * IFOV_{El})^2}}$$

$$\boldsymbol{\Delta X_n = X_n - X_{n+1}}$$

$$\boldsymbol{\Delta Y_n = Y_n - Y_{n+1}}$$

$$\boldsymbol{\Delta Az_n = Az_n - Az_{n+1}}$$

$$\boldsymbol{\Delta El_n = El_n - El_{n+1}}$$

$$\boldsymbol{SM_n = WISE\ Scan\ Mirror\ angle\ \ (counts)}$$

$$\boldsymbol{X_n = Column\ focal\ plane\ point\ source\ position\ (pixel\ units)}$$

$$\boldsymbol{Y_n = Row\ focal\ plane\ point\ source\ position\ (pixel\ units)}$$

$$\boldsymbol{Az_n = MIC2\ Pointing\ Mirror\ Azimuth\ Angle\ (urad)}$$

$$\boldsymbol{El_n = MIC2\ Pointing\ Mirror\ Elevation\ Angle\ \ (urad)}$$

$$\boldsymbol{IFOV_{Az} = Instantaneous\ Field\ of\ View\ in\ Azimuth\ \left(\frac{urad}{pixel}\right)}$$

$$\boldsymbol{IFOV_{El} = Instantaneous\ Field\ of\ View\ in\ Elevation\ \left(\frac{urad}{pixel}\right)}$$

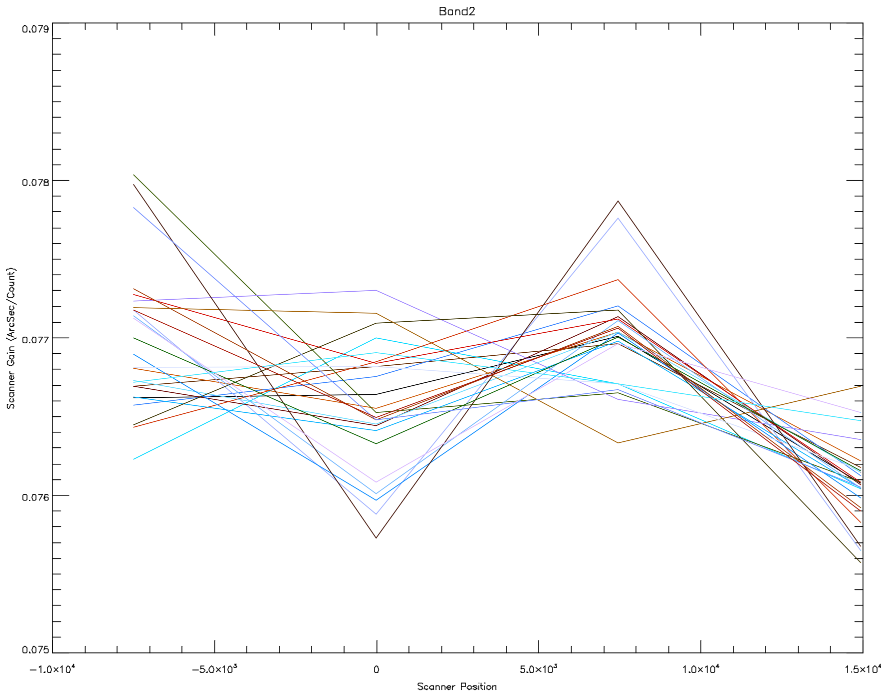

Figure 1 ANGULAR Scanner GAIN (Band2)

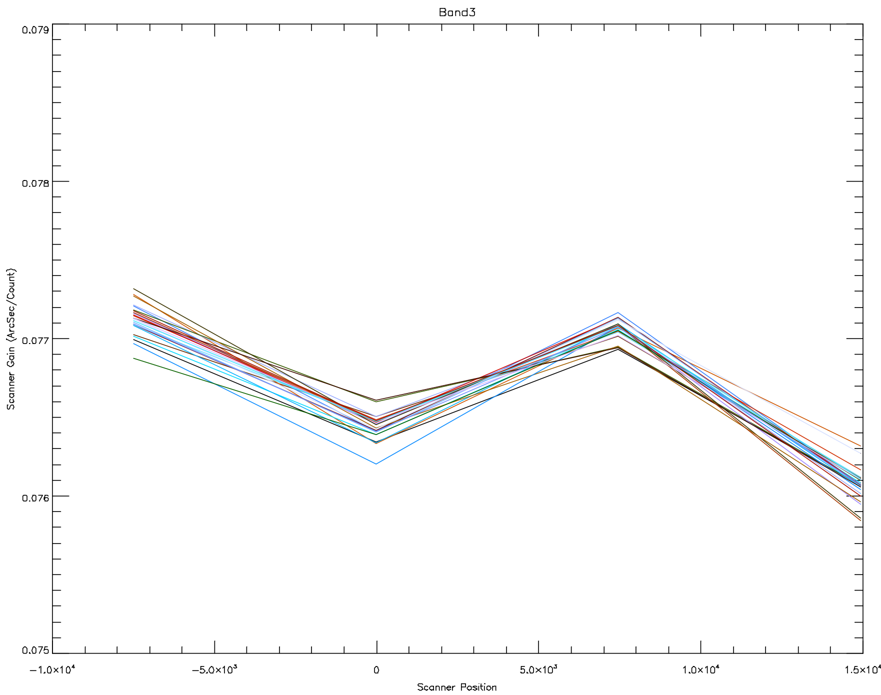

Figure 2 ANGULAR Scanner GAIN (Band3)

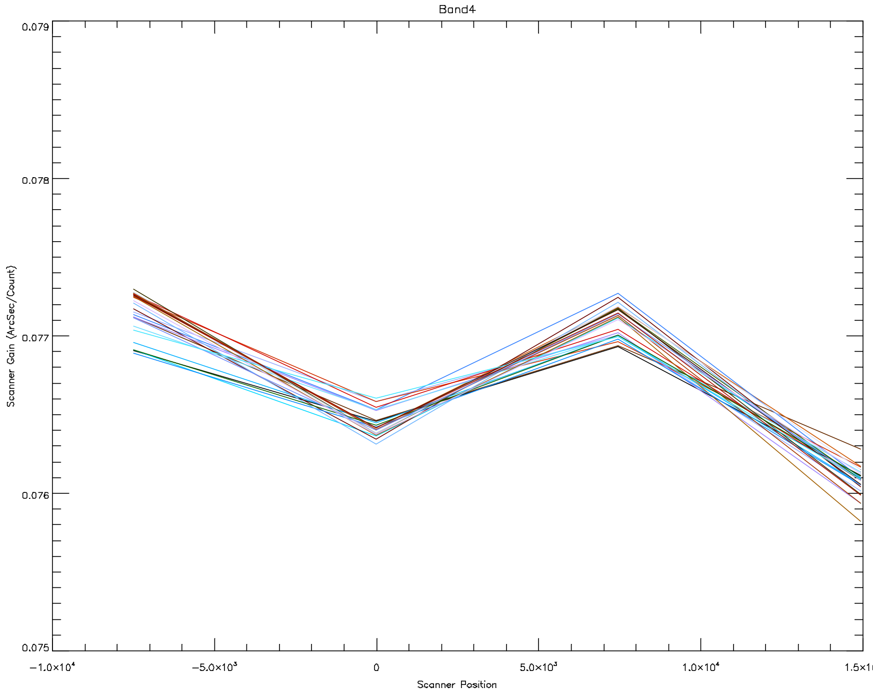

Figure 3 ANGULAR Scanner GAIn (Band4)

3.2 SCANNER POINT SOURCE MAPPING

Analysis was done to view the effects of this varying angular scanner gain on focal plane point source grouping and to also present the optimal scanner gain, this gain value can then be easily used to find the optimal scanner rate for mission operations. This analysis was done using the scan linearity data.

As a reminder this data was taken on a 5x5 grid of points on the focal plane. At each position on the focal plane 5 different scanner positions were commanded, while the MIC2 pointing mirror was also commanded to counteract the scanner motion to approximately keep the point source in the same focal plane position.

This analysis found the relative movement on the focal plane between each scanner position and the center scanner position. This was done by compensating the point source location by a single scanner rate using the differences in scanner counts, the point source was also compensated by the MIC2 pointing mirror using the IFOV values found in the FOV Mapping report. Residuals were calculated by finding the difference in Row and Column between each projected point source location and the corresponding center scanner point source location. In order to find the optimal scanner transfer function the standard deviation of all row and column residuals was computed for several scanner gains. The results of this analysis can be found in Figure 4 to Figure 6. The row (cross-scan) standard deviation remains constant for all scanner gains since the scanner mainly affects the column (in-scan) dimension. The column standard deviation reaches a minimum with a scanner gain of approximately 76.9 arc-sec/count. The affect of scanner position on focal plane point source grouping can be seen in Figure 7 to Figure 9. These plots used the optimal scanner gain. The difference in position between each scanner point source position and the center point source scan position has been exaggerated by a factor of 20 in order to show detail. Local Column and Row standard deviations are also shown and are in actual pixel units.

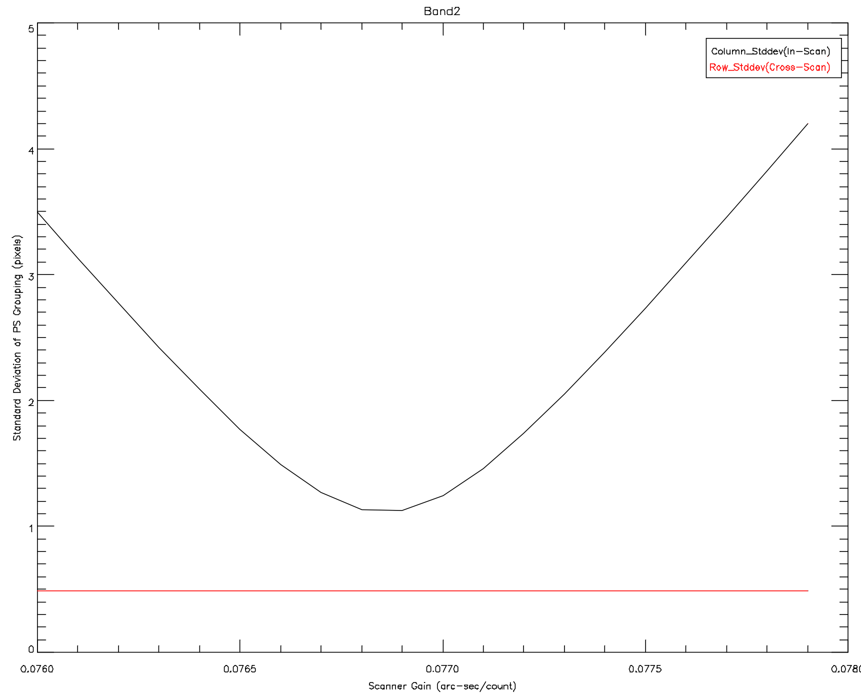

Figure 4 Optimal Scanner GAIN Using the Flight Primary Scanner (Band2)

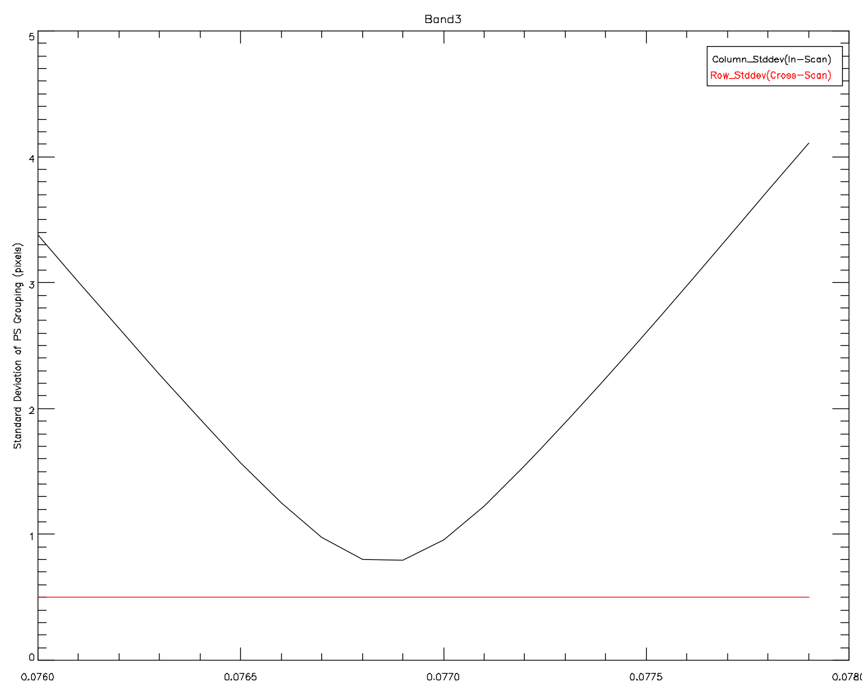

Figure 5 OPTIMAL SCANNER GAIN Using the Flight Primary Scanner (BAND3)

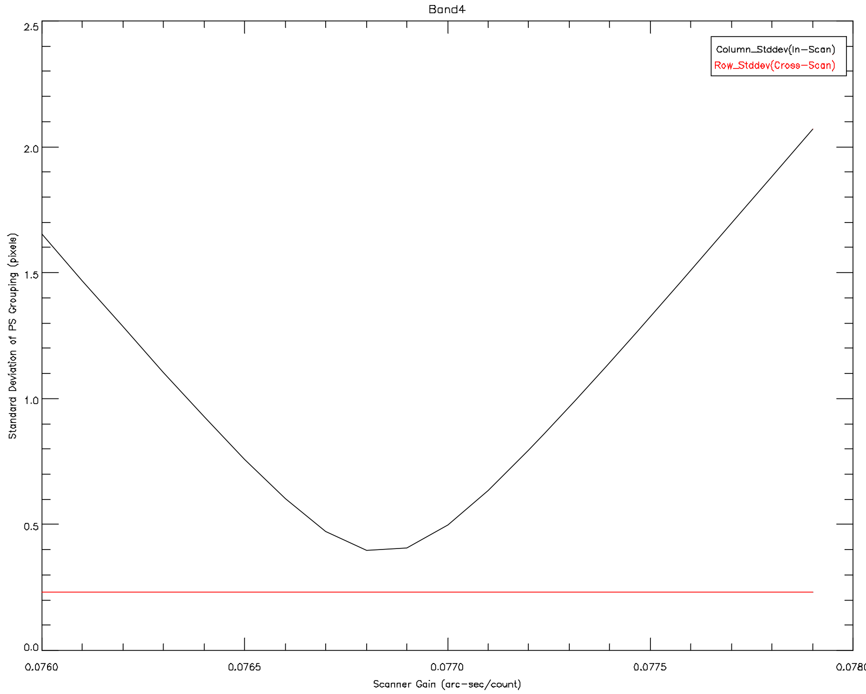

Figure 6 OPTIMAL SCANNER GAIN Using the Flight Primary Scanner (BAND4)

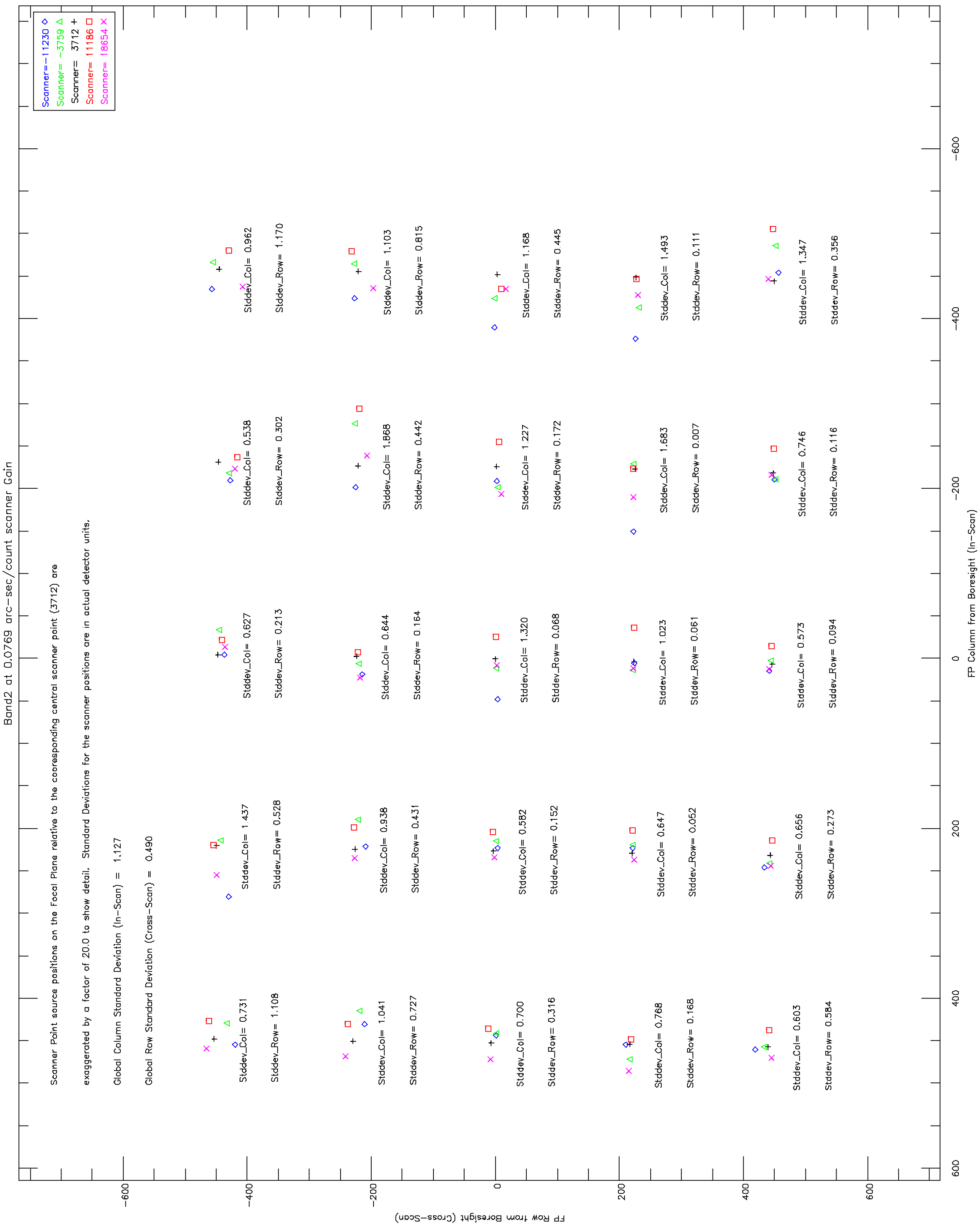

Figure 7 Point Source Mapping (Band2)

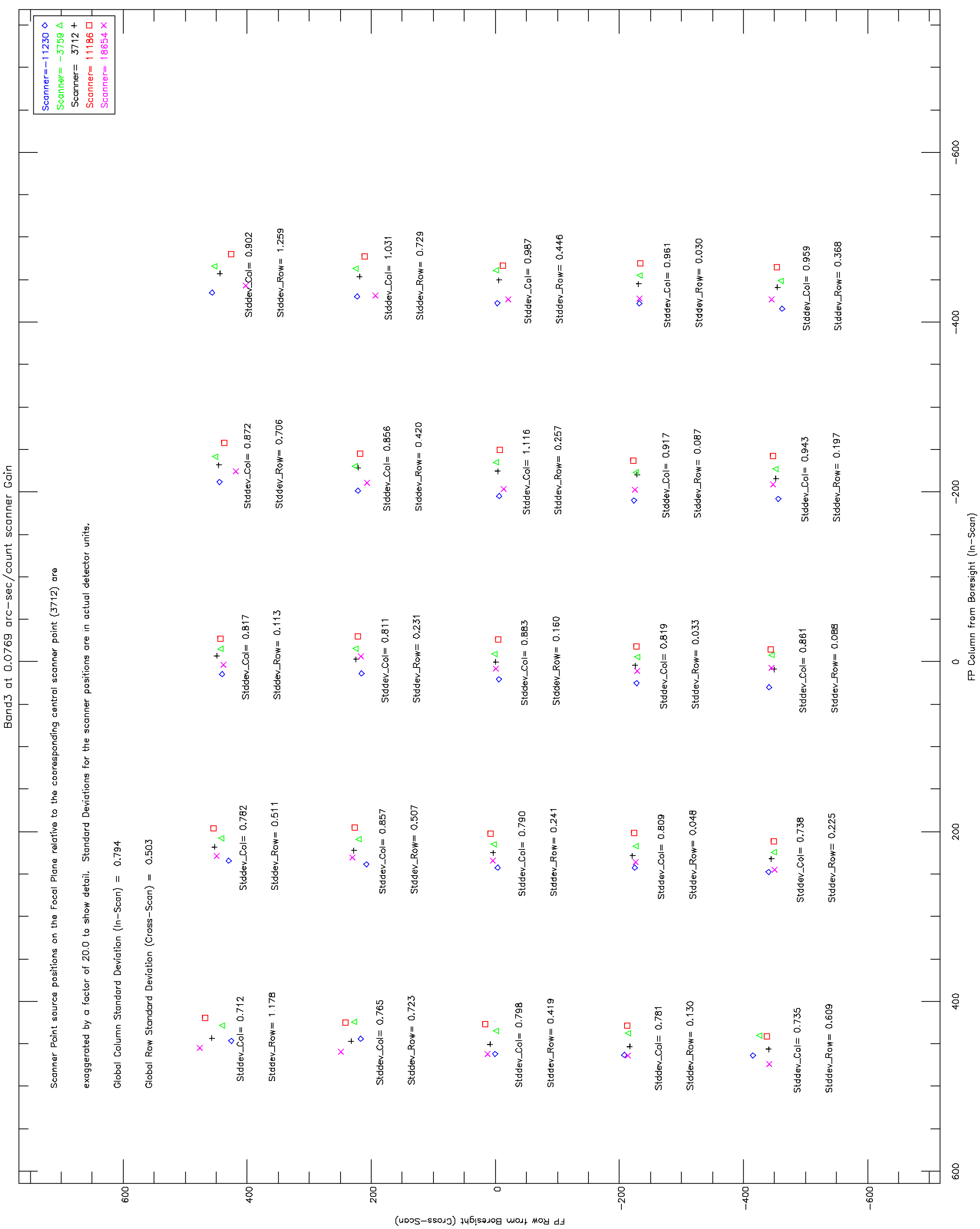

Figure 8 Point Source Mapping (Band3)

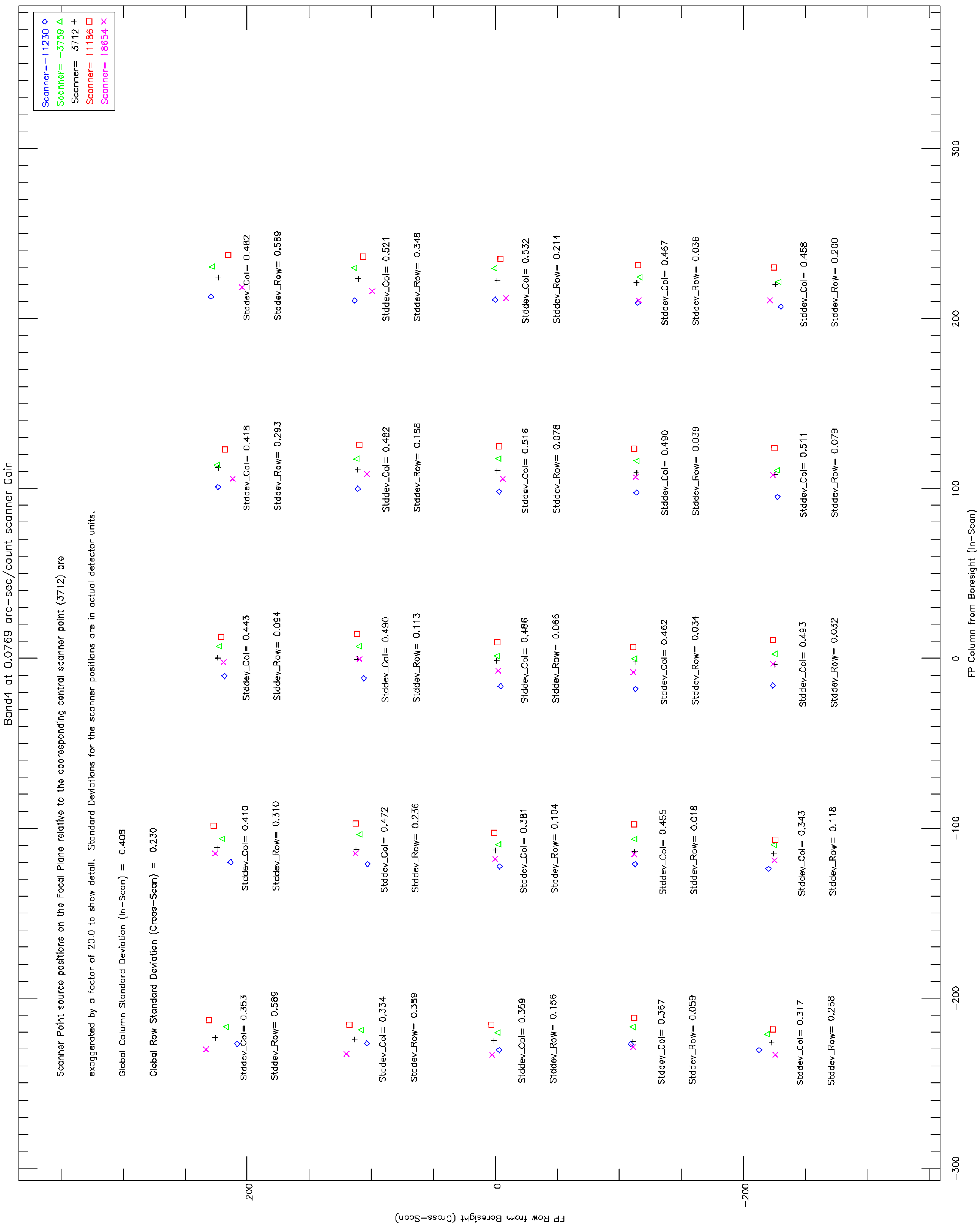

Figure 9 Point Source Mapping (Band4)

APPENDIX A. POST-VIBE RESULTS

The WISE instrument was retested following environmental testing. The scanner linearity analysis was redone to verify the stability of the calibration. During data collection on this test Band1 and Band2 were collected together using the EU Primary Scanner. Data was also collected simultaneously for Bands 2, 3 and 4 using the EU Secondary Scanner.

To match the scanner angles used for the Pre-Environmental tests using the Flight Primary Scanner the following scanner positions were used:

EU Primary Scanner: -5657, 1814, 9285, 16756, 24227

EU Secondary Scanner: -19118, -11647, -4176, 3295, 10766

As illustrated in Figure 10 and Figure 11 the EU Primary Scanner had an optimal scanner gain of 0.0773 arc-sec/count. Figure 12 to Figure 14 show the EU Secondary Scanner had an optimal gain of 0.0769 arc-sec/count which was identical to the ideal gain found for the Flight Primary Scanner as shown in the pre-environmental results earlier in this report.

Point source mapping across various scanner angles is shown in Figure 15 to Figure 19. These figures were created using the optimal gain for the particular scanner used.

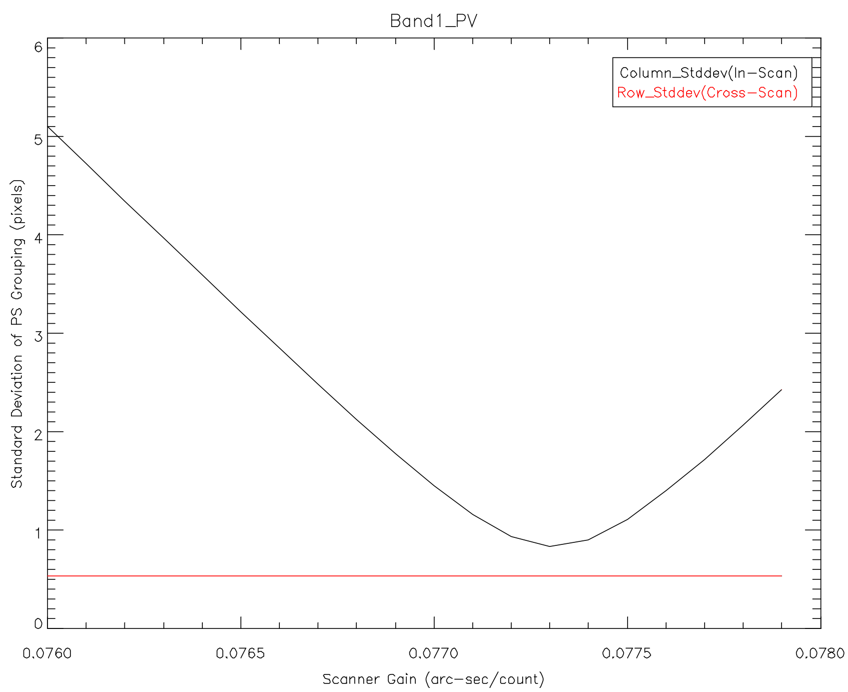

Figure 10 OPTIMAL SCANNER GAIN Using The EU Primary Scanner (BAND1)

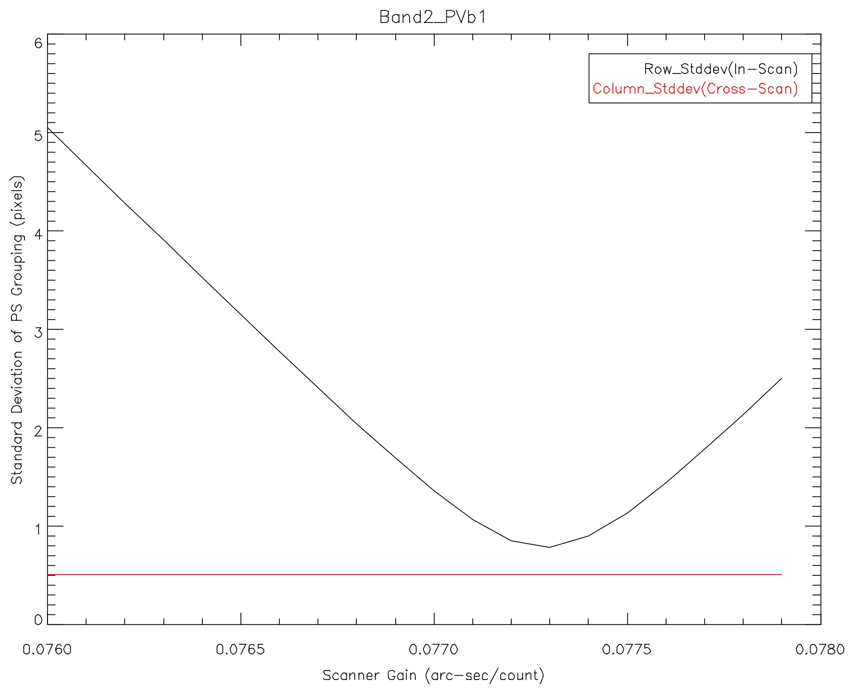

Figure 11 OPTIMAL SCANNER GAIN Using The EU Primary Scanner (BAND2)

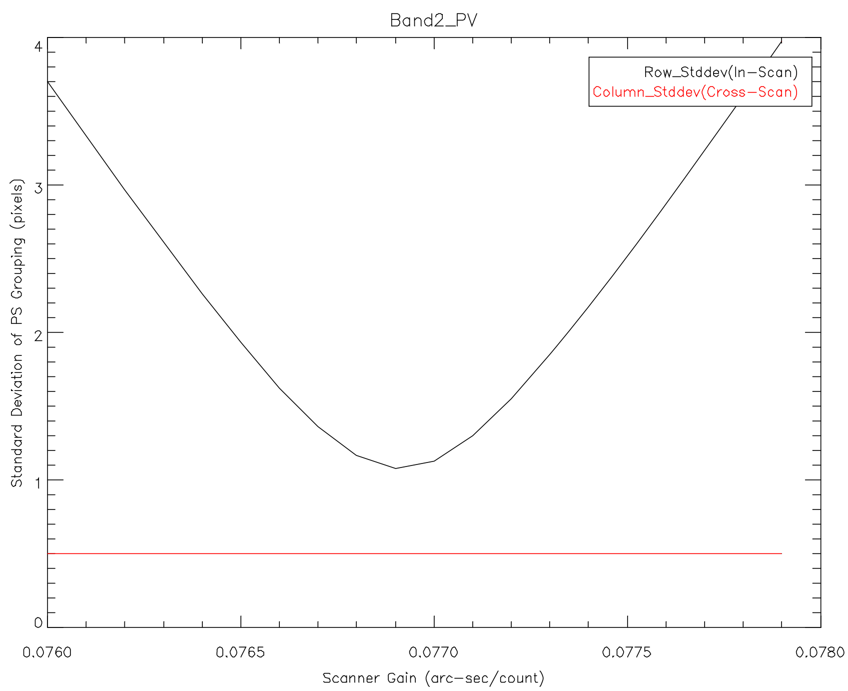

Figure 12 OPTIMAL SCANNER GAIN Using The EU Secondary Scanner (BAND2)

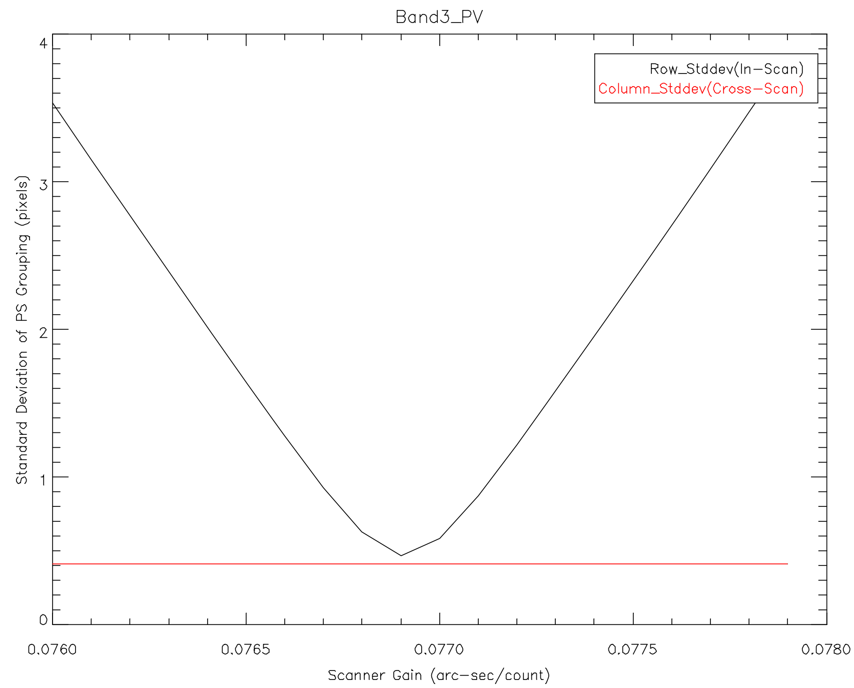

Figure 13 OPTIMAL SCANNER GAIN Using The EU Secondary Scanner (BAND3)

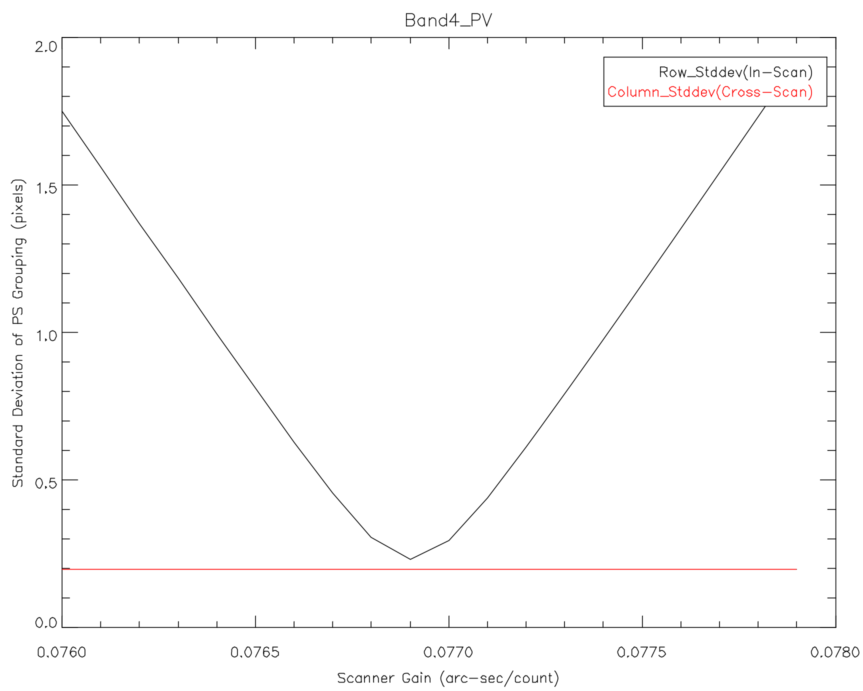

Figure 14 OPTIMAL SCANNER GAIN Using The EU Secondary Scanner (BAND4)

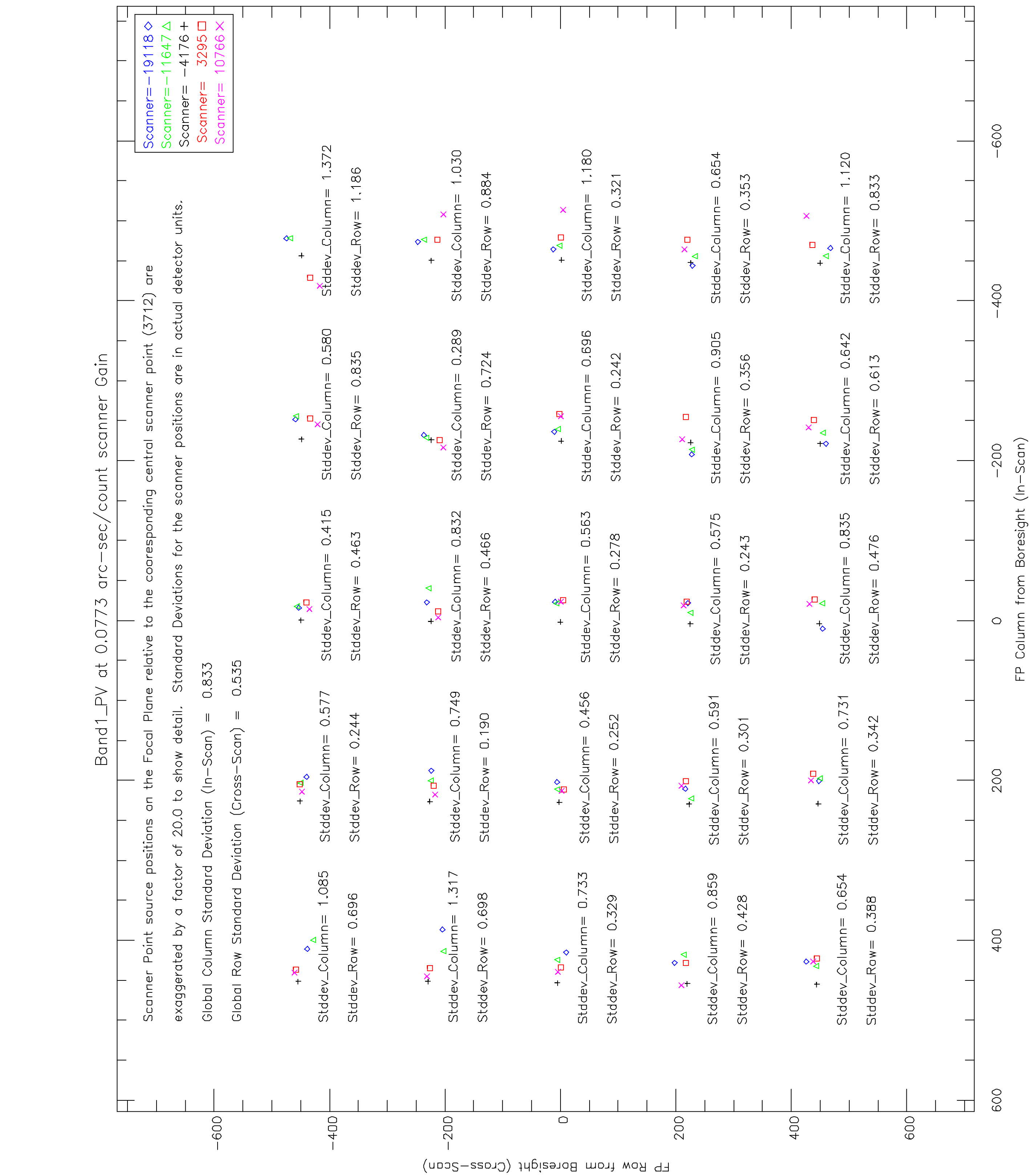

Figure 15 Point Source Mapping Using The EU Primary Scanner (Band1)

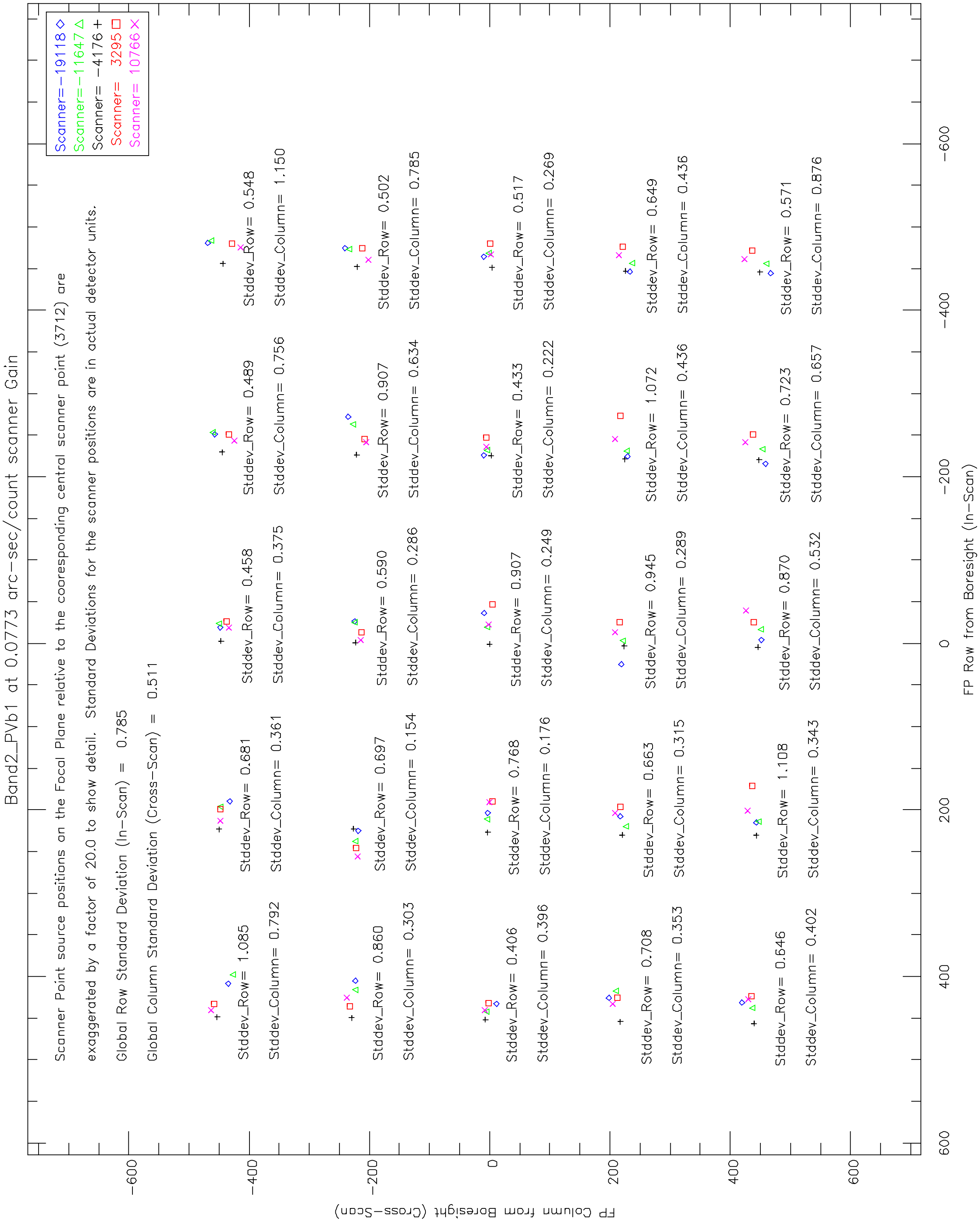

Figure 16 Point Source Mapping Using The EU Primary Scanner (Band2)

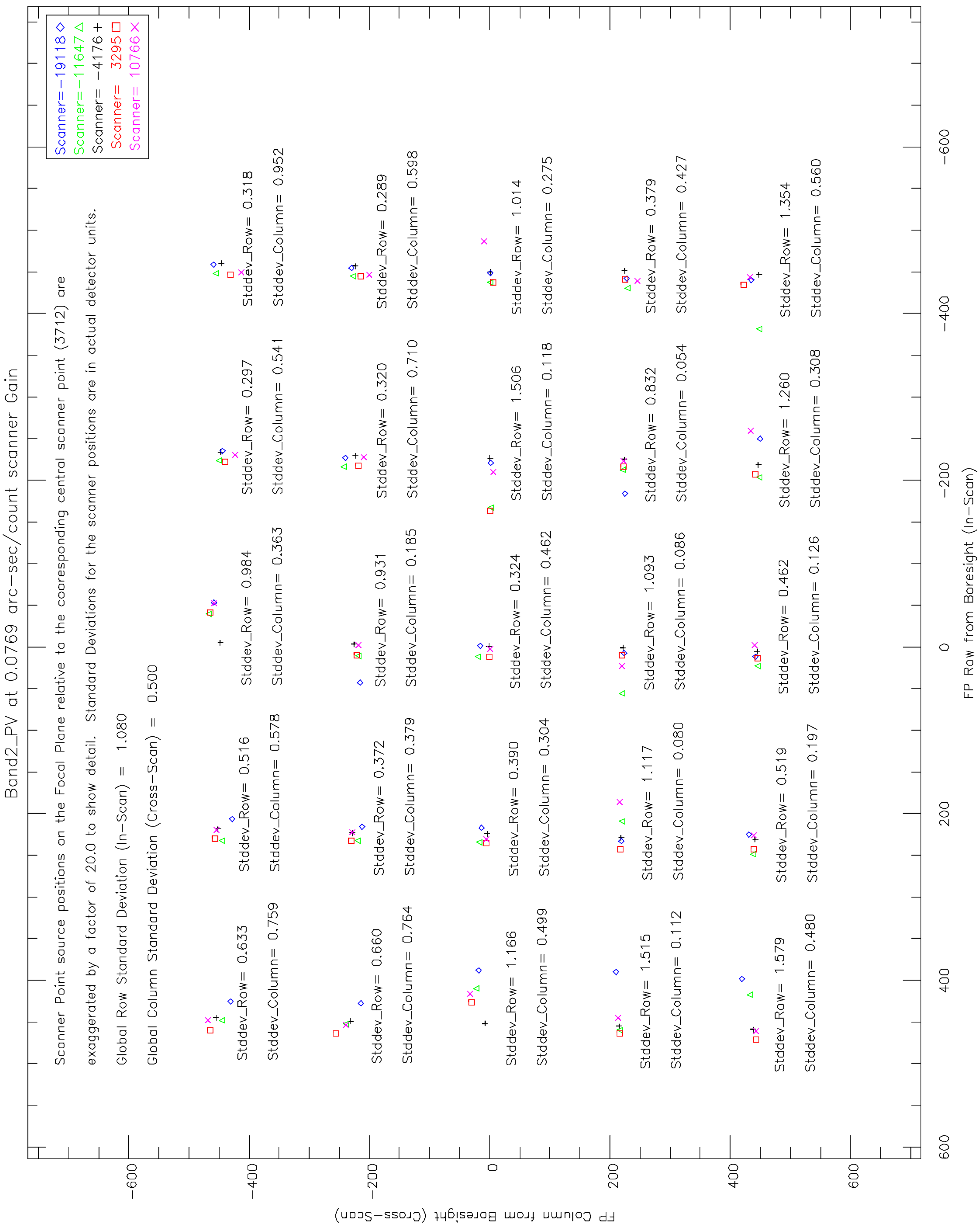

Figure 17 Point Source Mapping Using The EU Secondary Scanner (Band2)

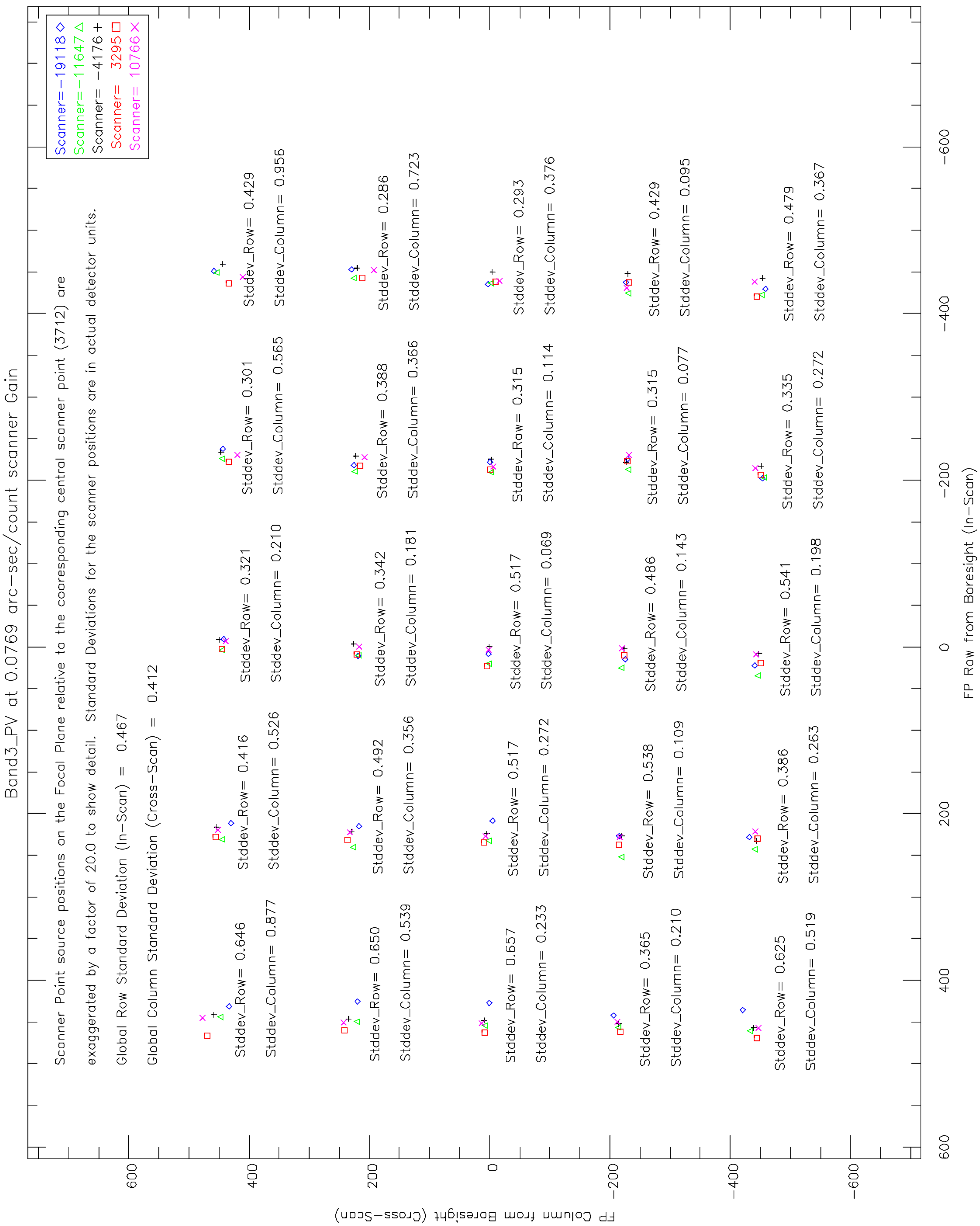

Figure 18 Point Source Mapping Using The EU Secondary Scanner (Band3)

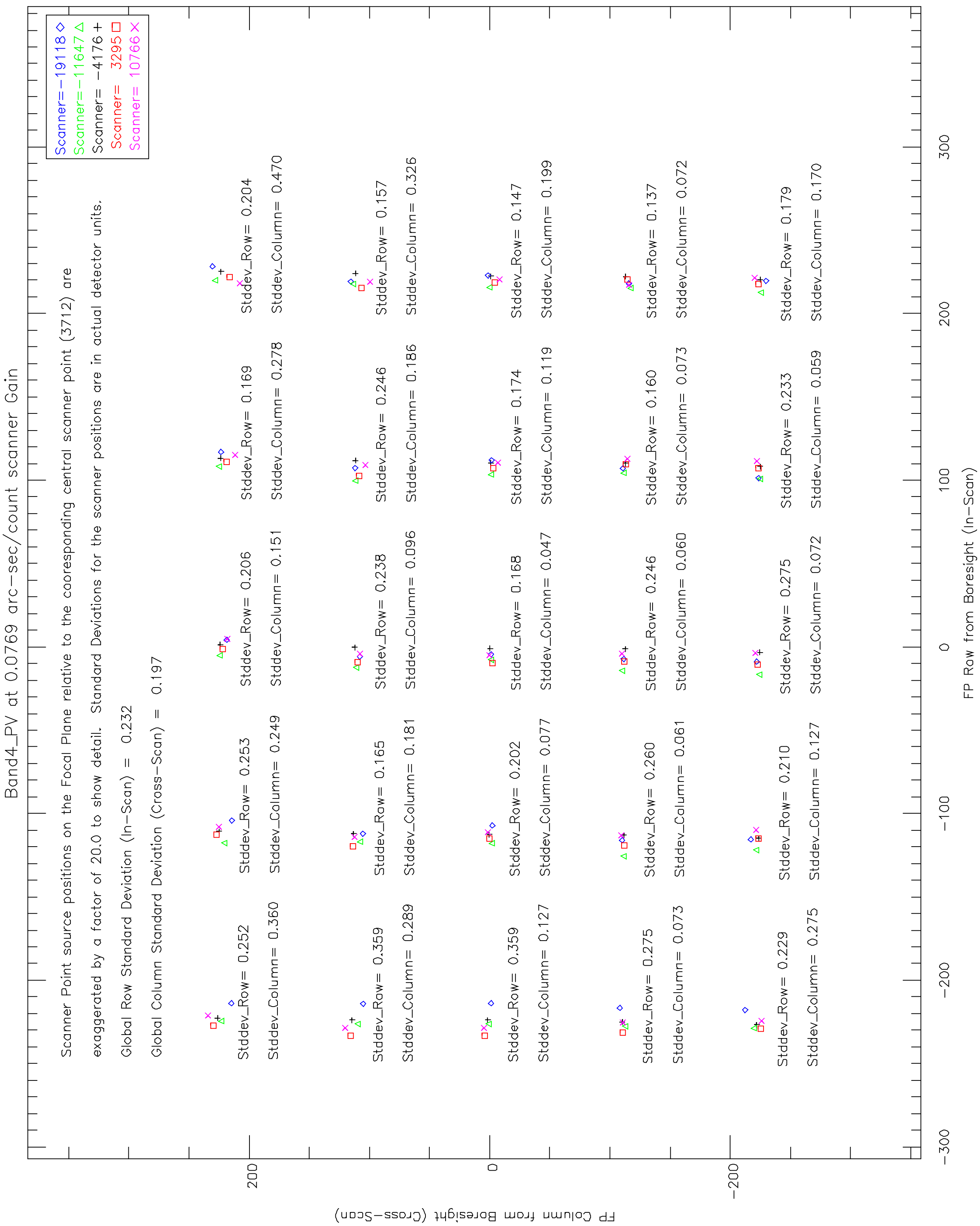

Figure 19 Point Source Mapping Using The EU Secondary Scanner (Band4)