SMOV REPORT IV: THE ABSOLUTE LOCATIONS OF THE FOS 1.0 APERTURES

I. N. Evans, A. P. Koratkar, C. J. Taylor, and C. D. Keyes
Space Telescope Science Institute

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Abstract

We use the data acquired during SMOV proposal 5614 to determine the absolute reference $V2$, $V3$ locations of the FOS 1.0 apertures for the blue and red detectors. The uncertainty in the absolute positions is $\lesssim 0''.3$, and is dominated by uncertainties in the FGS to FGS alignment. The data are used to estimate the diameters of the 1.0 apertures.

Preliminary estimates of the 1.0 aperture $V2$, $V3$ positions determined from these data are updated in the PDB effective starting with the 94.080 SMS. The final adopted $V2$, $V3$ positions will be updated in the PDB after incorporation of relative aperture location data obtained as part of SMOV proposal 5619.

I. Test Description

The absolute $V2$, $V3$ locations of the FOS 1.0 apertures are determined by SMOV proposal 5614. This proposal executed on 1994 February 23 (day 94.054) and 1994 February 24 (day 94.055), after the completion of all mirror moves during COSTAR/FOS alignment.

For this test, the star NGC 188-255 in the NGC 188 astrometric field is observed using both the FOS blue side and the FOS red side. For each detector, the test sequence follows: (1) acquire the target using a binary search target acquisition, and acquire a confirmatory ACQ image; (2) center the target using a 5×5 step peakup acquisition with a $0''.12$ step size and the 0.3 aperture, and acquire a confirmatory ACQ image; (3) perform spatial dwell scans to step the target across the 1.0 aperture in both the FOS X and Y directions, and measure the total number of counts from the target at each position using FOS IMAGE mode exposures with the camera mirror. FN format engineering telemetry is enabled during the dwell scans so that high time resolution FGS encoder readings of the guide star positions are available for each scan point. The length of the dwell scans in each of the FOS X, Y coordinates is $1''.5$, which is chosen to allow the scan to extend $\sim$25% of the nominal $0''.86$ diameter of the 1.0 aperture beyond each side of the aperture, plus an additional $0''.2$ to allow for uncertainties due to the initial FOS coarse alignment. Although a 17 point dwell scan in each direction is appropriate to determine the aperture center with a step size $< 0''.1$, the alignment time for such a scan is too long to schedule in a single orbit visibility period for the selected target. Therefore, the 17 point dwell scan in each of the FOS

X, Y coordinates is split into two separate dwell scans with 9 and 8 points respectively. The 9 point dwell scan covers the 1$''$.5 scan length with twice the desired spacing between points; the subsequent 8 point dwell scan is positioned so that each of the 8 points is interleaved precisely in the center of the adjacent points from the 9 point dwell scan.

II. Aperture Coordinates

For every point in each of the dwell scans, the mean $V2$, $V3$ position of the target is determined from the engineering telemetry by PASS. Although the exposure time at each point is 5 s, the $V2$, $V3$ positions are averaged over a 24 s time period between the posting of beginning-of-observation and end-of-observation. While not ideal, the error introduced by this approximation is negligible since the telescope is in fine lock throughout each dwell point. The target and guide star astrometric coordinates used to derive the $V2$, $V3$ positions are supplied by Van Altena et al. (1994; see Table 1). The coordinates are in the GSC reference frame, equinox J2000.0, mean epoch 1983.9. No corrections for proper motion are applied, since differential proper motion between cluster members should be negligible over a $\sim$10 yr time period.

The $V2$, $V3$ positions of the `1.0` apertures are computed by determining the location of X center of the X dwell scan points for which the target is in the aperture, and the location of Y center of the Y dwell scan points for which the target is in the aperture. This procedure implicitly makes the assumption that the `1.0` apertures are symmetric around the X and Y axes, and that the rotation angles of the X, Y axes with respect to the $V2$, $V3$ axes are known accurately (the fractional error is of order $\sin\xi$, where ξ is the error in the determination of the rotation angles). There is no requirement that the X and Y dwell scans form diameters of the apertures.

The positions of each dwell point in the FOS X, Y reference frame for each detector are obtained from the measured $V2$, $V3$ positions using the transformation matrix

$$\begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} V2 \\ V3 \end{pmatrix}, \qquad (1)$$

where $\theta = \theta_B$ for the blue detector, $\theta = \theta_R$ for the red detector, and we adopt the values $\theta_B = 170^\circ.78$ and $\theta_R = 98^\circ.94$, respectively, measured by Koratkar et al. (1994). Plots of the X and Y scans for each aperture are presented in Figure 1.

Once the dwell point positions are converted to the FOS X, Y reference frame, the X and Y positions of the `1.0` aperture centers are determined from the X and Y scan data, respectively, by two methods. Since the X and Y scan data appear subjectively to be very symmetric, the positions are computed first using a simple centroid weighted by the observed number of counts at each data point. All 17 dwell points are used for the red side scans; however, only the first 16 data points are used for the blue side scans, since the $V2$, $V3$ positions of the last data point in each blue side scan (last point in each 9 point scan) are not provided by PASS. Since the target is not in the aperture for the last data point of each scan, the weighting factors for the scan end points are very small. Therefore, negligible error is introduced by this procedure. The second method for determining the center position of the aperture in the scan is simply to measure the positions of the aperture edges at the FWHM level, and take the position mid-way between the aperture edges. The maximum count level in each scan is determined by taking the mean value of the counts for six scan points that form the "flat-top" region of the scan where almost all of the PSF is included in the aperture. Since the number of counts per scan point in the flat-top region of each scan is very consistent, the choice of which points and the number of points to include in determining the maximum count level influences the determination of the half maximum points only at the sub-milli-arcsecond level.

The measured $V2$, $V3$ aperture positions determined by the scan centroid and scan center methods, after back transformation from the FOS X, Y coordinates to $V2$, $V3$ coordinates using the inverse of equation (1), are presented in Table 2. The internal consistency between the $V2$, $V3$ values determined using these two methods is $\lesssim 0''.004$ in each axis. Therefore we adopt as the final $V2$, $V3$ values for the `1.0` aperture positions the means for the values determined individually from the scan centroid and scan center methods. These aperture positions are presented in Table 3, together with the previous values and the differences between the new and old values.

III. Uncertainties

Three sources of error contribute to the uncertainties in the absolute $V2$, $V3$ aperture positions derived from these data. The first source of error arises from the self-consistency of the X and Y aperture scan centroids and centers and is $\lesssim 0''.004$ in each axis. The uncertainty with which the absolute positions of the target and guide stars are known on the sky is the second source of error. According to the catalog used, the mean internal errors of the coordinates used are $\sim 0''.023$. The major contributor to the uncertainties in the absolute $V2$, $V3$ aperture positions is the uncertainty in the FGS to FGS alignment. This uncertainty is computed by PASS by comparing the observed vector separations between the two guide stars, and between each of the guide stars and the target, with the nominal separations from the catalog. The contribution to the uncertainty in the aperture positions due to the poorly known FGS to FGS alignment is $\lesssim 0''.24$ for the FOS blue side observations and $\lesssim 0''.30$ for the FOS red side observations (uncertainty in vector length). Thus, the error due to the uncertain FGS to FGS alignment is several times larger than the intrinsic uncertainties in the test.

IV. Aperture Dimensions

Although these data are acquired to determine the $V2$, $V3$ positions of the `1.0` apertures, the data can also be used to estimate the aperture sizes in arcseconds. We assume that the aperture is circularly symmetric, and that the PSF is symmetric and small compared to the aperture size (necessary so that half of the flux from a point source falls outside the aperture when the target is on the edge of the aperture). Although the assumption of circular symmetry is not strictly valid because of the anamorphic magnification of the COSTAR optics, the error introduced through is of order 2%, and is therefore ignored. With these assumptions, the aperture radius may be estimated by measuring the distance between the aperture center and the half power points of each of the scans. This measurement can be performed independently for four points for each aperture, corresponding to the $+X$ and $-X$ aperture edges for the X scans, and the $+Y$ and $-Y$ aperture edges for the Y scans. For each point we determine the distance between the half power point of the scan (assumed to be colocated with the aperture edge) in $V2$, $V3$, and the adopted $V2$, $V3$ position of the aperture center. This distance is a measurement of the aperture radius. The aperture radius measured here represents the mean distance from the aperture center where 50% of the light is lost from a point source located at the aperture edge. Because of possible diffraction effects, the aperture area computed using this radius may not be equal to the aperture area determined through photometric illumination of the aperture by a uniform source. The results are presented in Table 4.

V. Conclusions

The precise $V2$, $V3$ locations of the centers of the FOS `1.0` apertures for the blue detector and red detector are measured as part of SMOV proposal 5614. The internal accuracy of the measurements is $\lesssim 0''.05$ in each axis, although the uncertainty in the absolute positions is $\lesssim 0''.3$, and is dominated by uncertainties in the FGS to FGS alignment. The diameters of the `1.0` apertures were measured.

Preliminary estimates of the `1.0` aperture $V2$, $V3$ positions determined from these data were updated in the PDB and took effect starting with the 94.080 SMS. The final adopted $V2$, $V3$ positions agree with the preliminary estimates to within $\sim 0''.13$ for the FOS blue side, and $\sim 0''.10$ for the FOS red side. The final values will be updated in the PDB after they are combined with relative aperture location data obtained as part of SMOV proposal 5619.

References

Koratkar, A., et al. 1994, FOS Instrument Science Report CAL/FOS-123
Van Altena, W. F., et al. 1994, in preparation

Table 1
Target and Guide Star Coordinates
GSC Reference Frame, Equinox J2000.0, Mean Epoch 1983.9

Identification	Right Ascension	Declination
NGC 188-255	00 44 21.7294	+85 26 30.167
GSC 3788900229	00 55 45.6052	+85 12 21.003
GSC 3788900087	00 38 38.8086	+85 23 45.332

Table 2

Measured $V2$, $V3$ Coordinates of the `1.0` Aperture

	Blue Side		Red Side	
	Centroid	Center	Centroid	Center
$V2$	329″.846	329″.844	384″.381	384″.376
$V3$	−358″.173	−358″.180	−304″.091	−304″.087

Table 3

Adopted $V2$, $V3$ Coordinates of the `1.0` Apertures

	Blue Side			Red Side		
	New	Previous	Difference	New	Previous	Difference
$V2$	329″.845	330″.494	−0″.649	384″.378	385″.242	−0″.864
$V3$	−358″.176	−358″.433	0″.257	−304″.089	−304″.267	0″.178

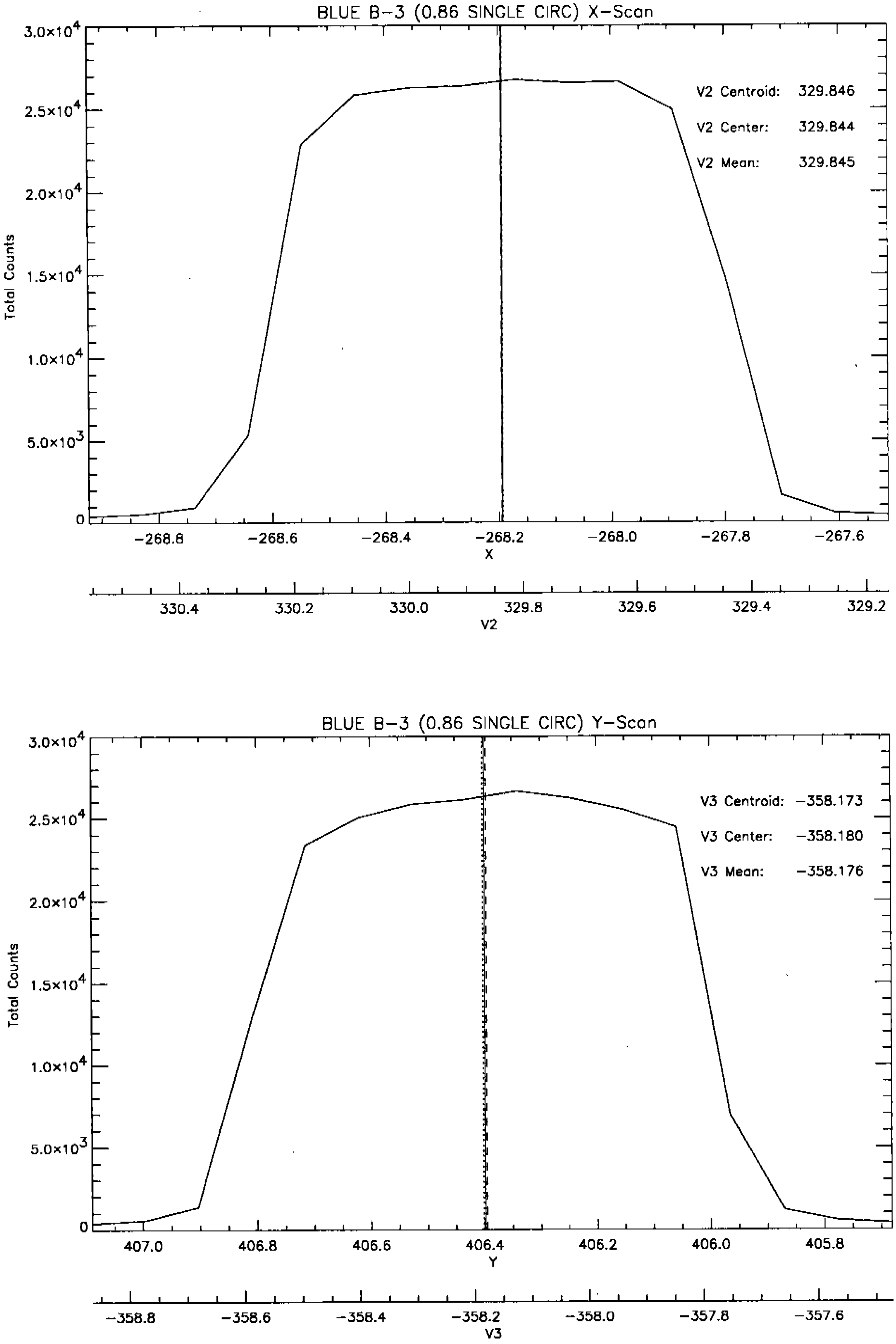
Table 4

Radius Determinations for the `1.0` Apertures

	Measured Radius				Mean	Mean
	$+V2, +V3$	$-V2, -V3$	$+V2, -V3$	$-V2, +V3$		
Blue Side	0″.4076	0″.4122	0″.4002	0″.4068	0″.4067 ± 0″.0050	0″.8134 ± 0″.0099
Red Side	0″.4201	0″.4193	0″.4195	0″.4139	0″.4182 ± 0″.0029	0″.8364 ± 0″.0058

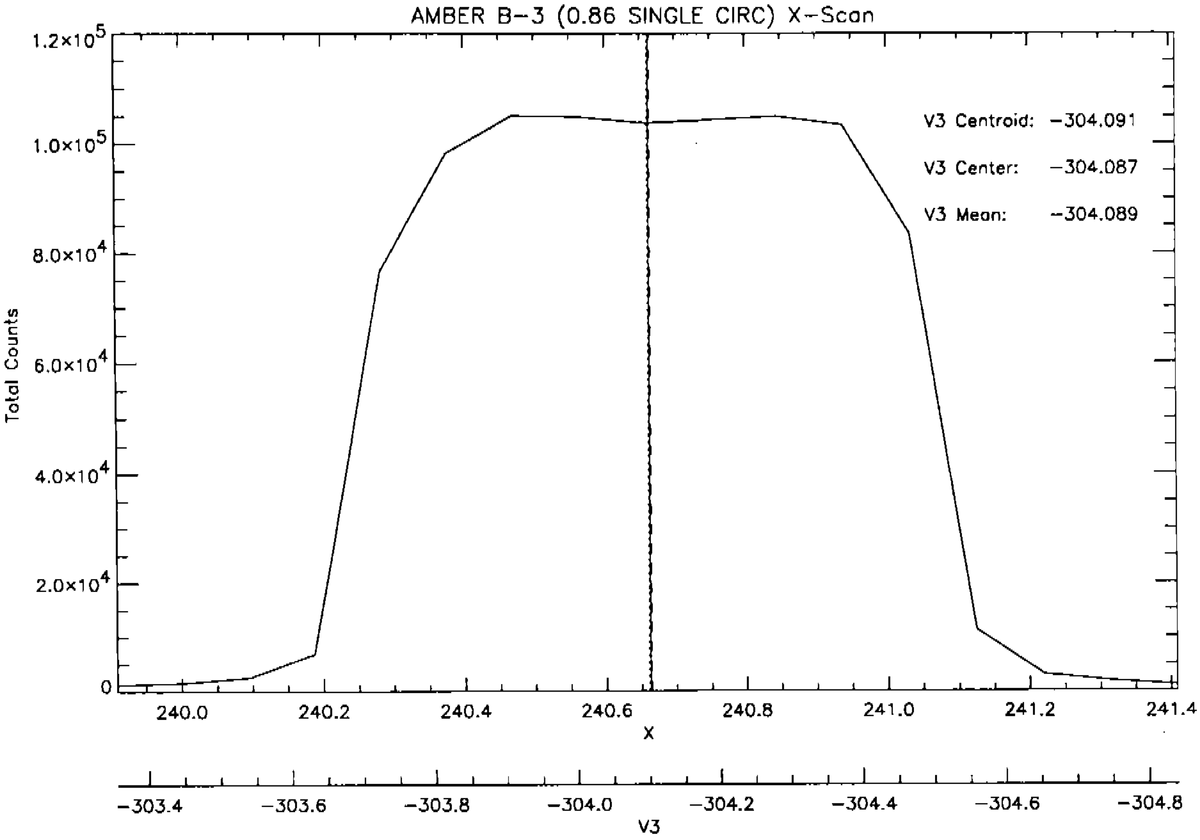
Figure Captions

Fig. 1 — FOS blue and red detector `1.0` aperture scans. The coordinates in the FOS X, Y reference frame are indicated on the abcissa (X coordinate for the X scan, Y coordinate for the Y scan; the other coordinate was kept constant during each scan), together with the $V2$ or $V3$ coordinates for whichever of the $V2$, $V3$ axis is closest to parallel to the scan direction.



BLUE B-3 (0.86 SINGLE CIRC) X-Scan
Total Counts
V2 Centroid: 329.846
V2 Center: 329.844
V2 Mean: 329.845
X
V2
BLUE B-3 (0.86 SINGLE CIRC) Y-Scan
Total Counts
V3 Centroid: -358.173
V3 Center: -358.180
V3 Mean: -358.176
Y
V3

Figure 1



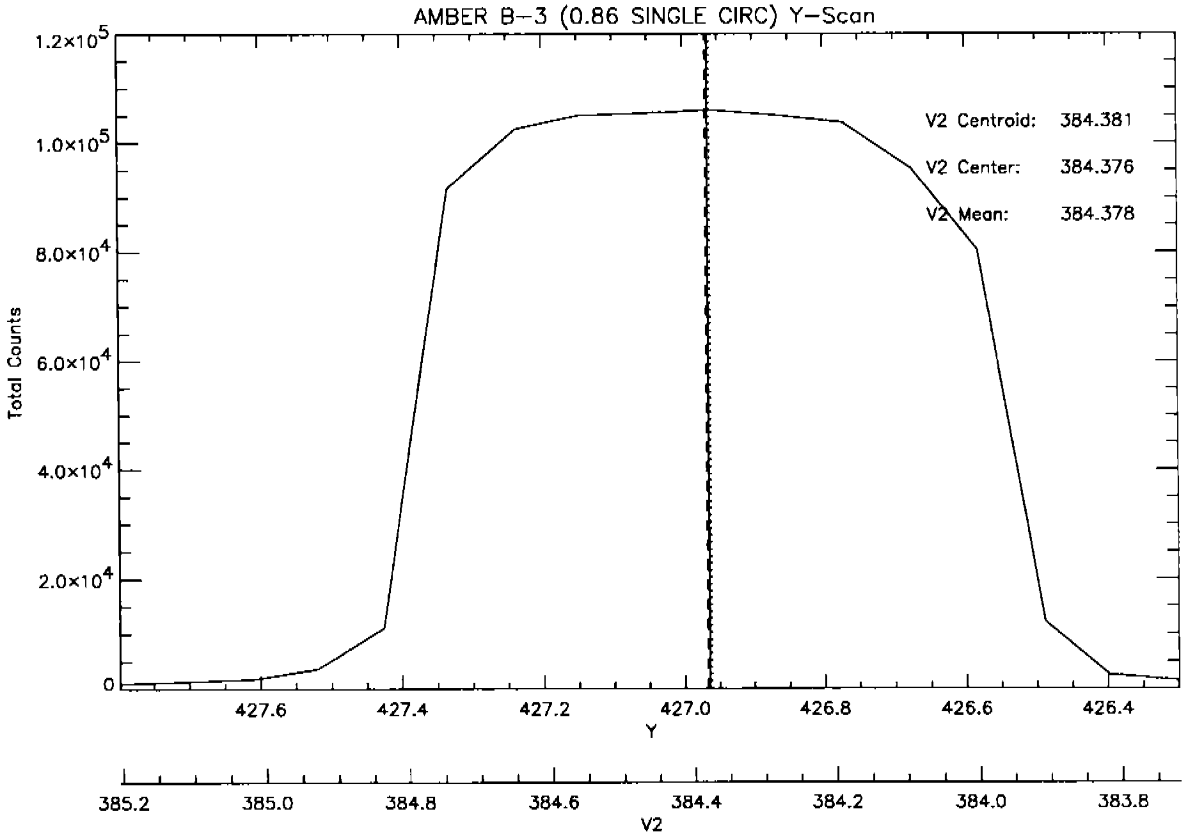


Figure 1 (continued)