FOS Internal/External Wavelength Offsets

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Abstract

We investigate the wavelength offsets observed between the internal calibration lamps with respect to an external calibration lamp using data obtained with the FOS during the March 1988 and August 1988 calibration runs at Lockheed. The offsets are quite different than those observed in earlier calibration data and in general are considerably smaller. The improvement is most likely due to better alignment of the Digicons that was achieved using a new procedure just prior to the March calibration and was used again in August for the final alignment.

I. Introduction

Systematic differences in the derived wavelengths from external sources and internal calibration lamps have been noticed previously and investigated in two reports of the CAL/FOS series (Sirk and Bohlin 1987; Bohlin, Sirk, and Hartig 1987). The offsets between internal and external sources have been observed to be more than 10 times the typical rms residuals in an individual wavelength solution in some cases, may be unstable over long time periods, and may limit the accuracy of wavelength calibration of FOS spectra on orbit. In this report, we investigate these wavelength offsets again to analyze the effects of the recent rework of the FOS on the wavelength offsets and to measure their current values for both Digicons and a variety of dispersers and apertures.

II. Data and Analysis

The data used in this report were obtained with the procedure YIEOFF during the March 1988 calibration run at Lockheed, and again in August 1988 after the Digicons were re-installed following the installation of the new heat pipes. Since the August data are representative of the FOS in its final flight configuration, we will concentrate on the August data in this report and compare with the March data where appropriate. The YIEOFF procedure steps through a variety of grating and aperture combinations; at each step a sequence of three spectra are obtained (direct internal, cross-strapped internal, and external Pt-Ne-Cr lamps) without moving the aperture wheel (AW) or filter/grating wheel (FGW) mechanisms. Hence, offsets between these three spectra cannot be ascribed to any mechanical non-repeatability. Control spectra were obtained at the beginning and end of the procedure with H27 and aperture A4 to test short term stability. External spectra were also obtained at several rotation angles of the MgF_2 diffuser to test the uniformity of illumination by the external lamp. The range of data obtained permit the offsets to be studied as a function of aperture and disperser for any combination of the three lamps. Also, since many of the apertures are pairs, upper and lower aperture spectra can be compared for consistency as well.

The data have been analyzed at Johns Hopkins using modified versions of IDL-based programs and subroutines obtained from Martin Sirk. The main program is called IEOFF.PRO and the basic technique is to compare the measured line centroids of sharp, unblended spectral lines between two spectra taken with the same disperser using a cross correlation routine. The differences can be plotted as a function of diode number to investigate systematic effects. The mean and rms of the data are also calculated and displayed. The program permits interactive elimination of lines with particularly bad residuals (i.e. lines that were not properly identified by the routine) using a graphics cursor. Separate data files and plot files are output for each comparison of two spectra.

Some difficulties were encountered for spectra obtained with the larger apertures because line blending causes some line centroids to be inaccurate and even causes some lines to be missed entirely or misidentified. The reduction program allows bad points to be deleted interactively and in most cases we were able determine reasonable offsets. However, the spectra obtained with aperture C1 (1.0-PAIR) are basically useless because of this problem. Also, some lines in the red tube spectra from March 1988 overflowed the 2^{16} counting buffer, causing problems for the centroiding routine. (This may have been partially due to the higher sensitivity of the new red tube with respect to the old red tube.) In some cases we were able to repair the overflows, but this is very tedious and does not always work. The H78 red spectra were nearly useless because of this problem. Exposure times were modified in the August procedure to avoid this problem.

One inconsistency was found between the header information on the data files and the information in the calibration log sheets. In the middle of the procedure (on both the red and blue sides) the log sheets show spectra were obtained with H27 and H40 and the A2 aperture (0.5-PAIR). The headers for these files all list the aperture as C1 (1.0-PAIR). Comparing the FWHMs of lines in these spectra with other C1 data obtained elsewhere in the procedure, we conclude that the spectra were obtained with A2. The reason for the incorrect information in the headers of these files is unknown. This problem persists for both red and blue data and for both the March and August data sets.

We have used the program described above to extract offsets for all of the red and blue tube data obtained with the YIEOFF procedure. We have used the external lamp as the reference spectrum and extracted the offsets for DIRECT - EXTERNAL and XSTRAPPED - EXTERNAL for further analysis. (Note: this is contrary to what was done in CAL/FOS-041, where the internal direct lamp was used as a reference. However, it makes more sense to us to reference both internal lamps to the external source, since this is really what we are after.) Figures 1a,b and 2a,b show example output from the August data for the red tube and blue tube, respectively. Below we discuss various aspects of the results from our analysis.

Uniformity of External Lamp Illumination

Observations were made in March at the beginning of the red side portion of the procedure to insure that the MgF_2 diffuser was uniformly illuminating the external entrance port of the FOS. External spectra were taken with H27 and aperture A4 at several different rotation angles of the diffuser, and searched for any significant differences in line centroids. None were found, with a resulting rms of 0.017 diodes (36 lines were used in the comparison). We conclude that the external illumination was uniform. This test was not repeated on the blue side. Because of this result and because of time constraints, this test was not repeated in August.

Short Term Stability

Short term stability of the offsets was investigated each time the procedure was run by comparing the H27-A4 spectra obtained at the beginning and end of the procedure. The time difference was roughly 4.2 hours (3 hours) for the red side data and 2.5 hours (2.3 hours) for the blue side data from March (and August), respectively. The differences formed by comparing DIR to DIR, XST to XST, and EXT to EXT spectra from the beginning and end of the procedure in March are shown in Figure 3a,b,c (red side) and Figure 4a,b,c (blue side). The corresponding data from August are shown in Figures 3d,e,f (red side) and Figure 4d,e,f (blue side). For stability, one would expect these differences to be flat, with any zero-point offset being due to the non-repeatability of the FGW/AW assemblies. This is what is seen in the March blue side data, for instance, with an average zero-point offset of -0.041 diodes (using average of both upper and lower aperture spectra). Zero-point offsets for the other comparisons range from +0.09 to -0.14 diodes.

A disturbing aspect of the DIR - DIR and XST - XST comparisons is the apparent systematic drop of ~0.02 diodes toward higher diode numbers; This drop is not apparent in the EXT - EXT comparisons. Although this drop is small, it does appear to be significant, especially given its apparent absence from the external comparison. Since the internal lamps do not fully illuminate the FOS optics, the different FGW/AW positions (and hence a slightly different light path) for the beginning and end observations may contribute to the observed effect. Another possibility may be the non-repeatability of the the internal calibration lamp mirror which is mounted on the back of the entrance port door. In either case, we note that the trend is for the comparisons to drop toward higher diode numbers regardless of whether the zero-point offsets are positive or negative.

Aperture Dependence

For both March and August data sets, spectra were obtained on both red and blue sides for the H27 and H40 gratings with the following apertures: A4 (0.1-PAIR), A2 (0.5-PAIR), B2 (0.3 circle), and C1 (1.0-PAIR). As mentioned earlier, the C1 data do not provide much useful information. Comparison of upper and lower aperture spectra in these (as well as other) data show no significant differences between the offsets derived from upper or lower apertures, although occasionally individual points will be discrepant. These discrepant points are due to faint, marginally detected lines that do not centroid accurately.

For apertures A4, A2, and B2, no significant differences in the shape or magnitude of the offsets is seen for either red or blue side and for either H27 or H40 data. Figure 5 shows a sample of August H27 red data that are representative; Figure 5a,b,c shows the DIR - EXT data for apertures A4, A2, and B2, while Figures 5d,e,f show the same comparison for XST - EXT. The March comparisons are slightly different shape from the August comparisons, but are internally consistent with this result. We conclude that the offsets derived are independent of the choice of aperture, which is consistent with the previous results of Bohlin, Sirk and Hartig (1987).

Disperser Dependence

The remaining item of interest is the behavior of the offsets with respect to disperser. Previously, Bohlin, Sirk, and Hartig (1987; hereinafter BSH) found striking differences of offset with respect to disperser, and found very different results for the red and blue detectors (summarized in their Figures 4 and 5). For the red tube, non-linear offsets with magnitude ≥ 0.3 diodes were seen for all three dispersers for which full coverage was obtained, and a systematic negative shift in the mean was observed with disperser (from H19 to H27 to H40 to H57 to H78). For the blue tube, BSH saw linear offsets (in diodes) with a magnitude of about 0.2 diodes for H19 and H27, but leveling off to about 0.1 diode for H40 and (part of) H57. Data at several different focus (Z) positions permitted BSH to conclude that the observed offsets were at least partially due to the fact that the various gratings do not all focus in the same plane and that the Digicons were not properly aligned with respect to the incoming spectra.

The August 1988 data for the red detector as a function of disperser are shown in Figure 6 (DIR - EXT) and Figure 7 (XST - EXT). The DIR - EXT data are summarized in Figure 8, which can be compared with BSH Figure 4 (although note the difference in reference spectra--BSH used the DIR spectra and we use the EXT). The behavior of the offsets with disperser for DIR - EXT is very different than it was before the instrument rework and installation of the new red tube. For H27, H40, H57, and even H78 it appears that the magnitude of the offsets observed are lower than they were by roughly 30% - 70% (i.e. 0.1 - 0.2 diodes instead of ≥ 0.3 diodes). Unfortunately, the situation is reversed for the portion of H19 that can be observed without vacuum; this was quite flat with a magnitude <0.1 diode previously, while the current data show a range of ~ 0.3 diodes. For XST - EXT, there is a systematic "bowl-shaped" distribution to the offsets, with the magnitude of the overall effect decreasing from ~ 0.4 diode for the portion of H19 that is observable down to ~ 0.1 diode for H78 (if the initial low diode point is assumed to be a bad line).

The August 1988 data for the blue detector as a function of disperser are shown in Figure 9 (DIR - EXT). The DIR - EXT data are summarized in Figure 11, which can be compared with BSH Figure 5. The behavior of the offsets with disperser is also different than it was before the instrument rework. The magnitude of variation in offsets for the DIR - EXT comparison is ≤ 0.1 diodes for all dispersers studied and is smallest for H19 and H27 (while before the variation was much worse for H19 and H27). The variation of offsets for the XST - EXT comparison is shown in Figure 10. The end to end variations are all 0.2 diodes or less with H27 showing the largest effect. There may be a slight trend toward flattening or even turning over for longer wavelength dispersers.

III. Discussion

The magnitude of the internal/external offsets are in general considerably less than they were previously (with the singular exception of H19-red). One of the conclusions made by BSH was that detector mis-alignment was at least partially responsible for the offsets that were measured previously. In February 1988, a new alignment procedure was followed when the Digicons were re-installed that permitted the tube alignment and positioning at best compromise focus for the gratings to be more readily accomplished. We conclude that the improved alignment and positioning is largely responsible for the decrease in internal/external offsets that has been observed.

While the magnitude of the internal/external offsets has been significantly decreased, the offsets are not negligible. Offsets on the blue side are all less than 0.1 diode, while on the red side the offsets are somewhat higher, typically 0.1 - 0.15 diode. The larger offsets for the H19 grating are probably due to the fact that the focal plane for this grating is somewhat displaced from the focal planes of the other gratings, especially on the red side. The best compromise focus position thus leaves H19 slightly more out of focus than the other gratings. The observed offsets are larger than the typical rms of a wavelength solution (~0.03 diode), but are comparable to the zero-point offsets that occur because of mechanism non-repeatability. Hence, for FOS data with concurrent comparison spectra (i.e. taken without moving any mechanisms), the derived absolute wavelength scale should be accurate to roughly 0.15 diodes. For FOS data without concurrent comparison spectra, the derived absolute wavelength scale should be accurate to 0.2 - 0.3 diodes (perhaps slightly better on the blue side).

The internal calibration lamps do not fully illuminate the spectrograph optics, and because of this the wavelength calibration from the internal lamps appears to be sensitive to many subtle instrumental effects. For instance, the comparison lamp lens cannot focus properly over the entire FOS wavelength range; chromatic aberration from this lens thus leads to a wavelength dependent variation in the illumination of the spectrograph optics. It may also be that the alignment of the cal lamp beam with the spectrograph optics is not ideal, and that minor intrinsic aberrations in the optics themselves contribute to the observed offsets. These effects are suspected to be the causes of the remaining offsets seen between the internal lamps and an external source.

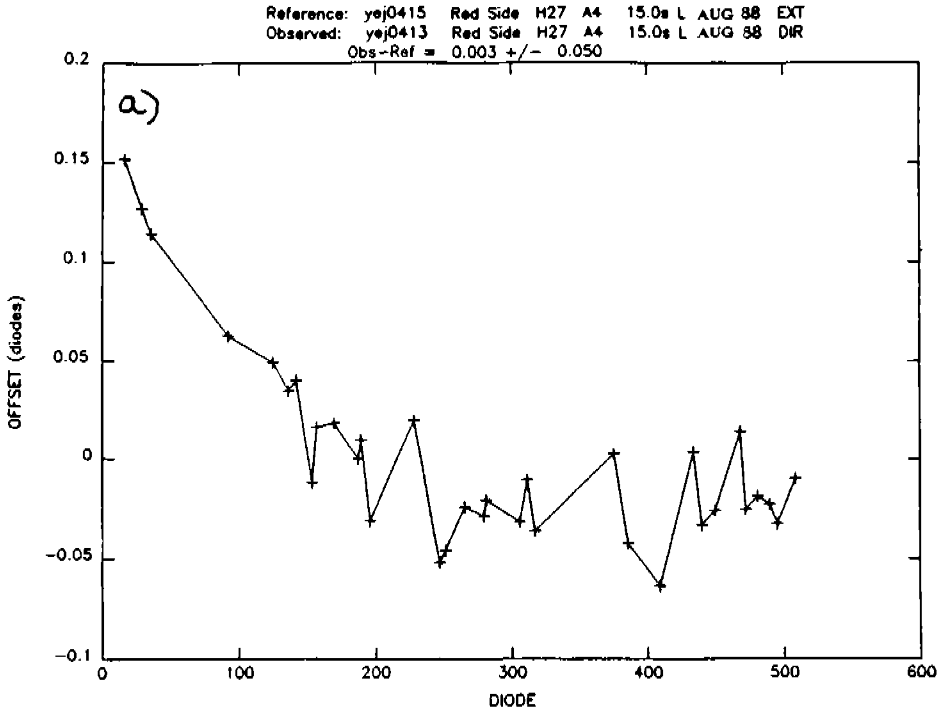
BSH expressed concern about the long term stability of the internal/external offsets. Because of the extensive rework of the instrument, we cannot and will not be able to address this question further.

We thank George Hartig and Ralph Bohlin for comments on an early draft of this report.

References

Bohlin, R., Sirk, M., and Hartig, G. 1987. CAL/FOS-044, *Limiting Accuracy of FOS Wavelength Calibration.*

Sirk, M., and Bohlin, R. 1987. CAL/FOS-041, *Wavelength Offsets Among Internal Lamps and External Sources.*



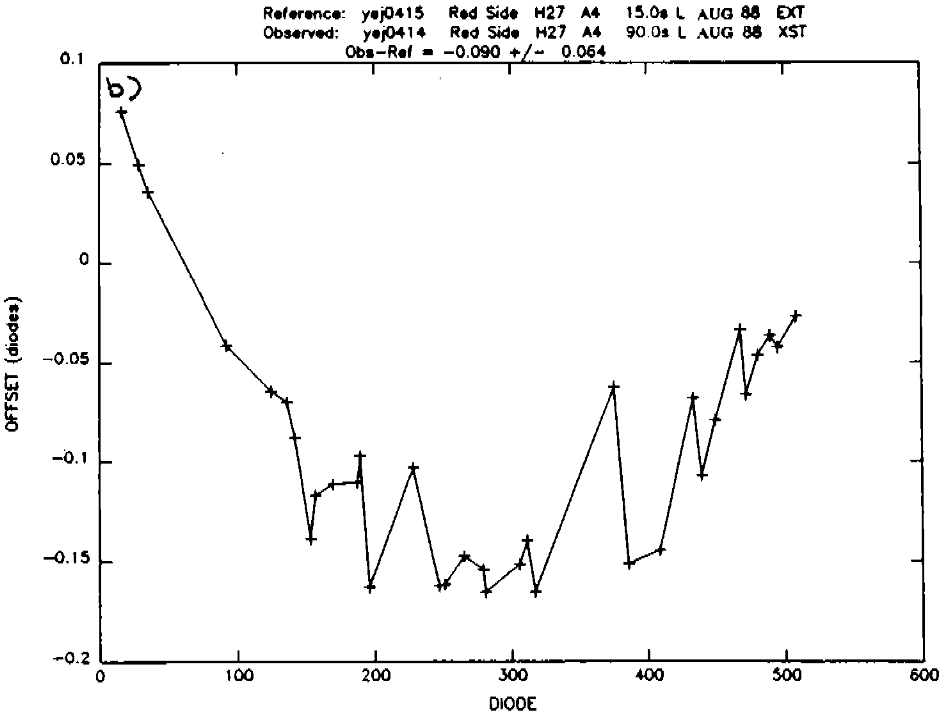
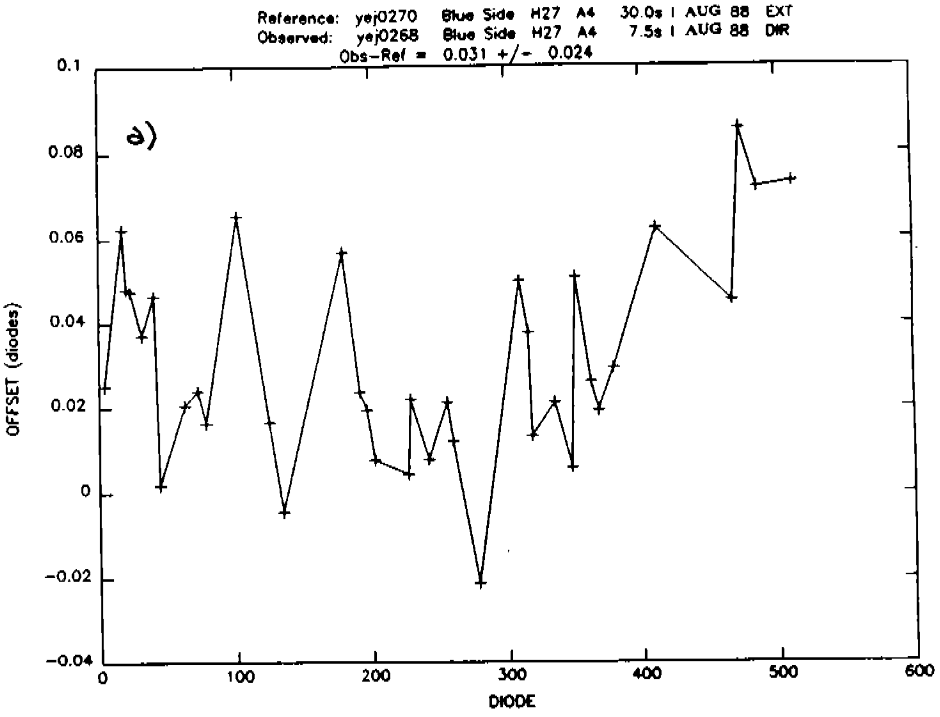


Figure 1: Examples of offsets derived from August 1988 red side FOS data. a) DIR - EXT comparison. b) XST - EXT comparison.



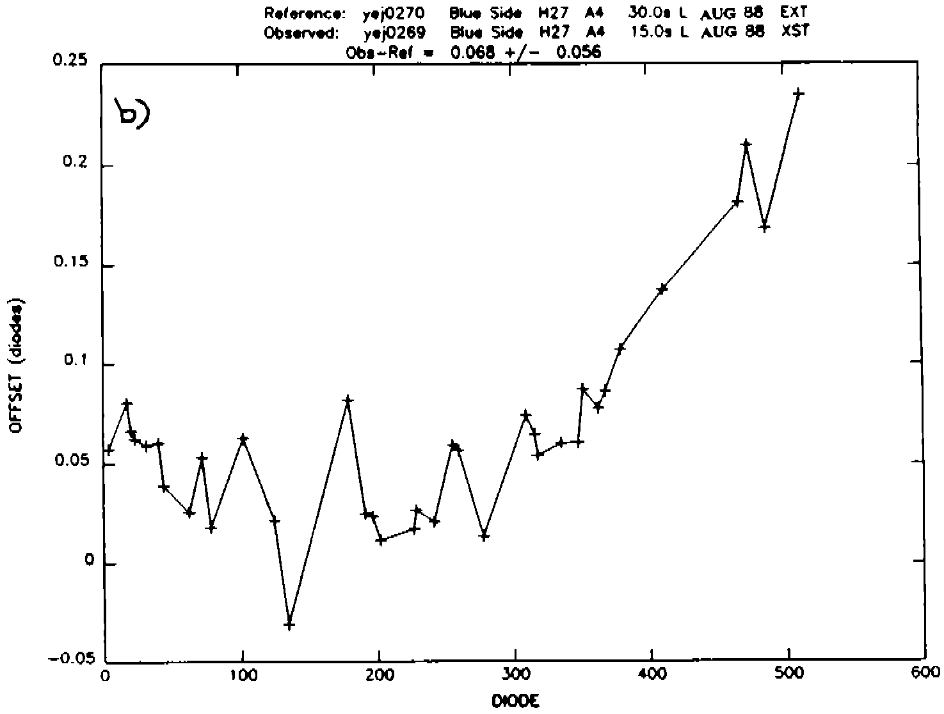


Figure 2: Same as Figure 1, but for August 1988 blue side data.

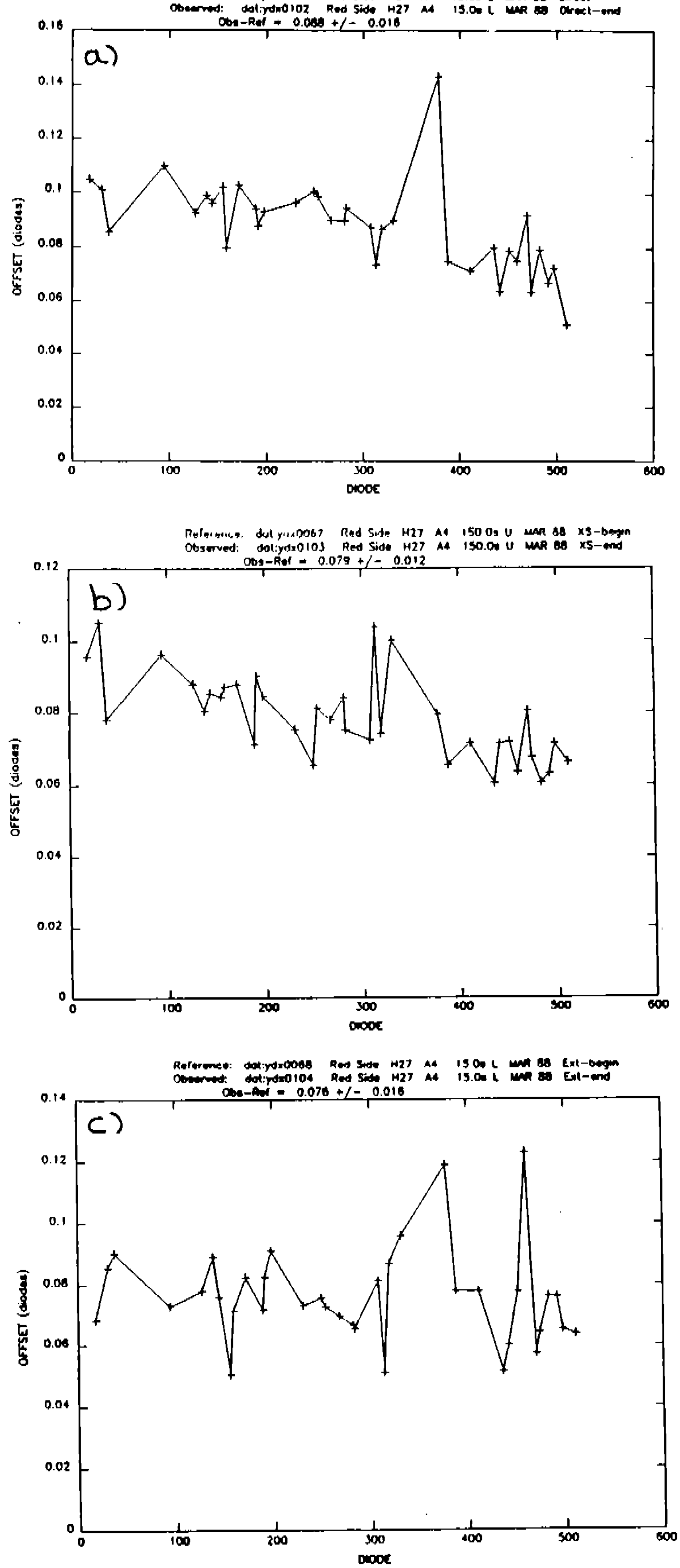
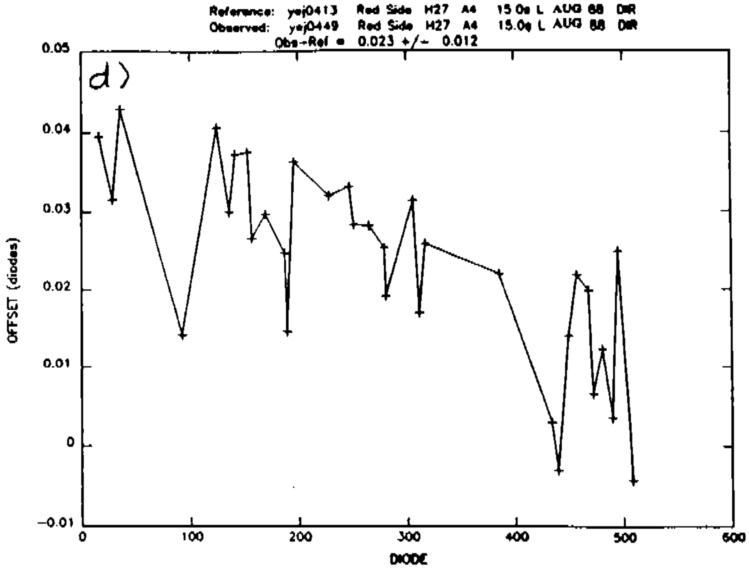
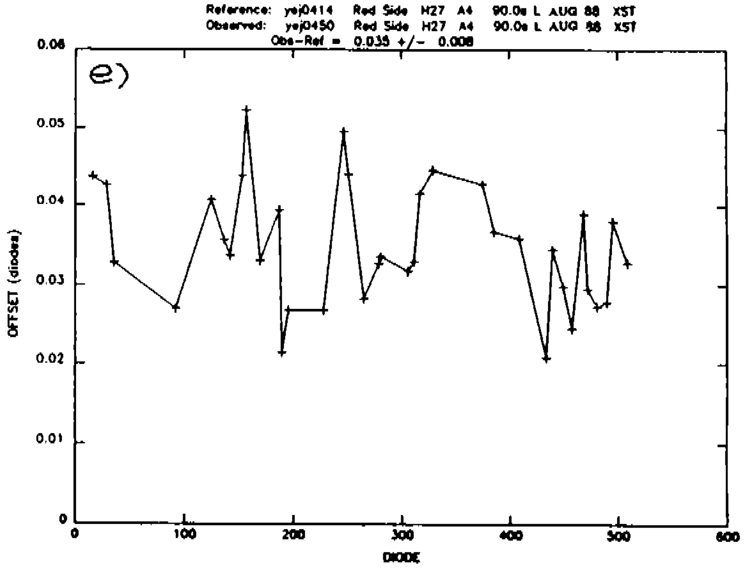


Figure 3: Red side short term stability examples. These figures show the offsets derived by comparing H27-A4 exposures from the beginning and end of the procedure. a) DIR(end) - DIR(beg). b) XST(end) - XST(beg). c) EXT(end) - EXT(beg) from March 1988. Figures d), e) and f) show the same three comparisons for the August 1988 data. Notice the apparent systematic drop by 0.02 diodes in many of the DIR - DIR and XST - XST comparisons.





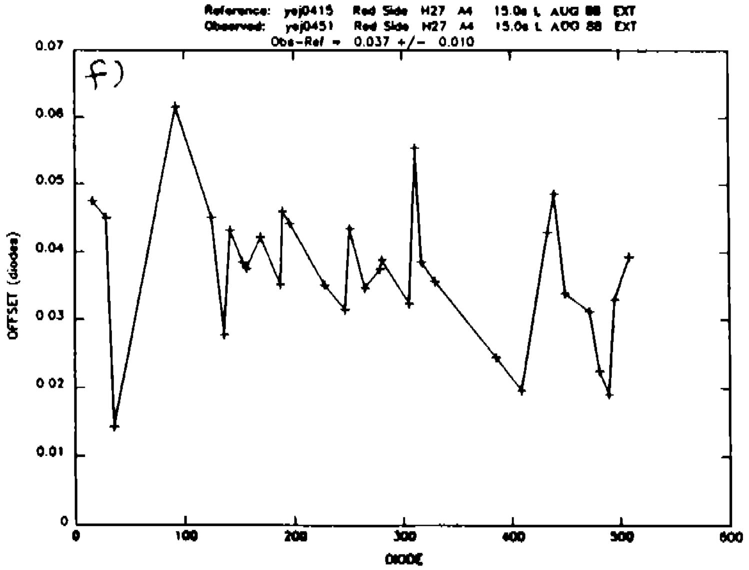


Figure 3 - Continued

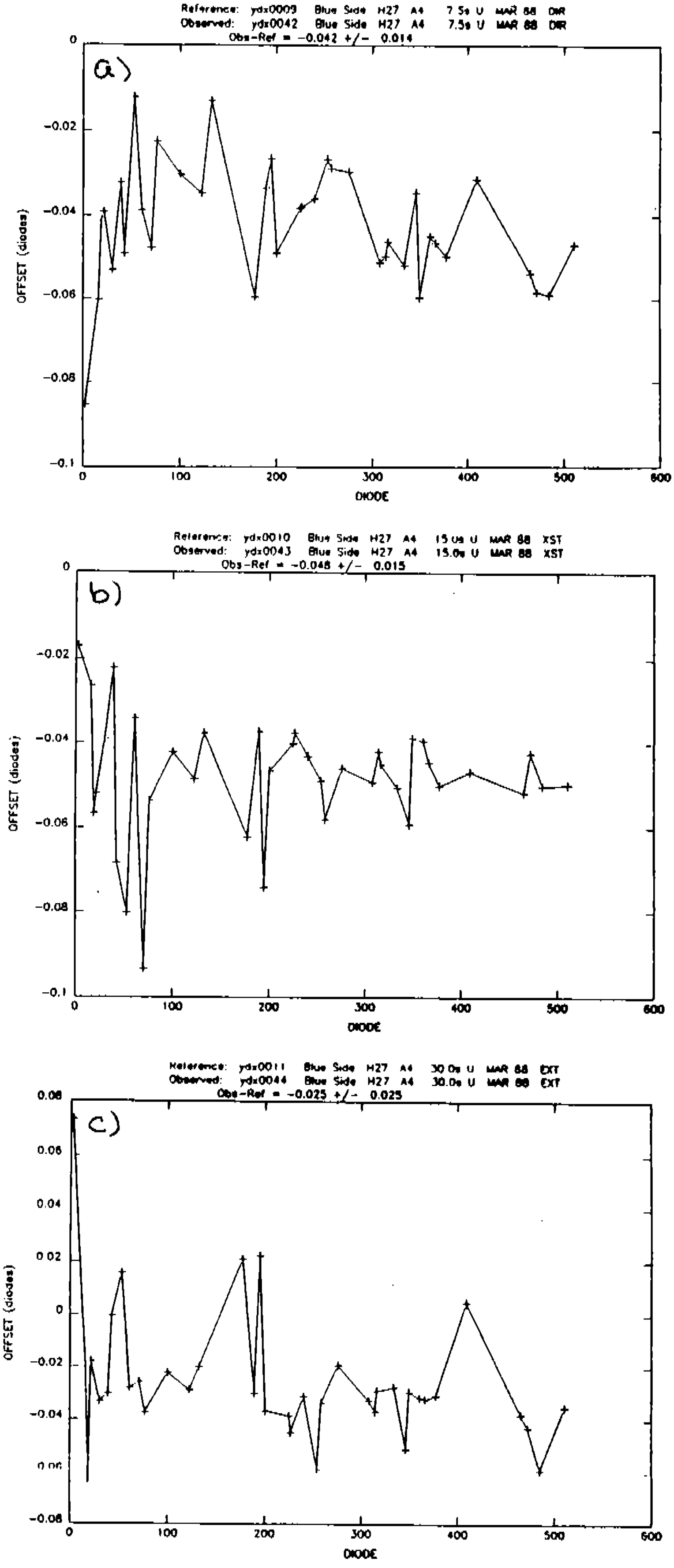


Figure 4: Same as Figure 3, but for the blue side. No systematic effects are seen in the March 1988 blue side data.

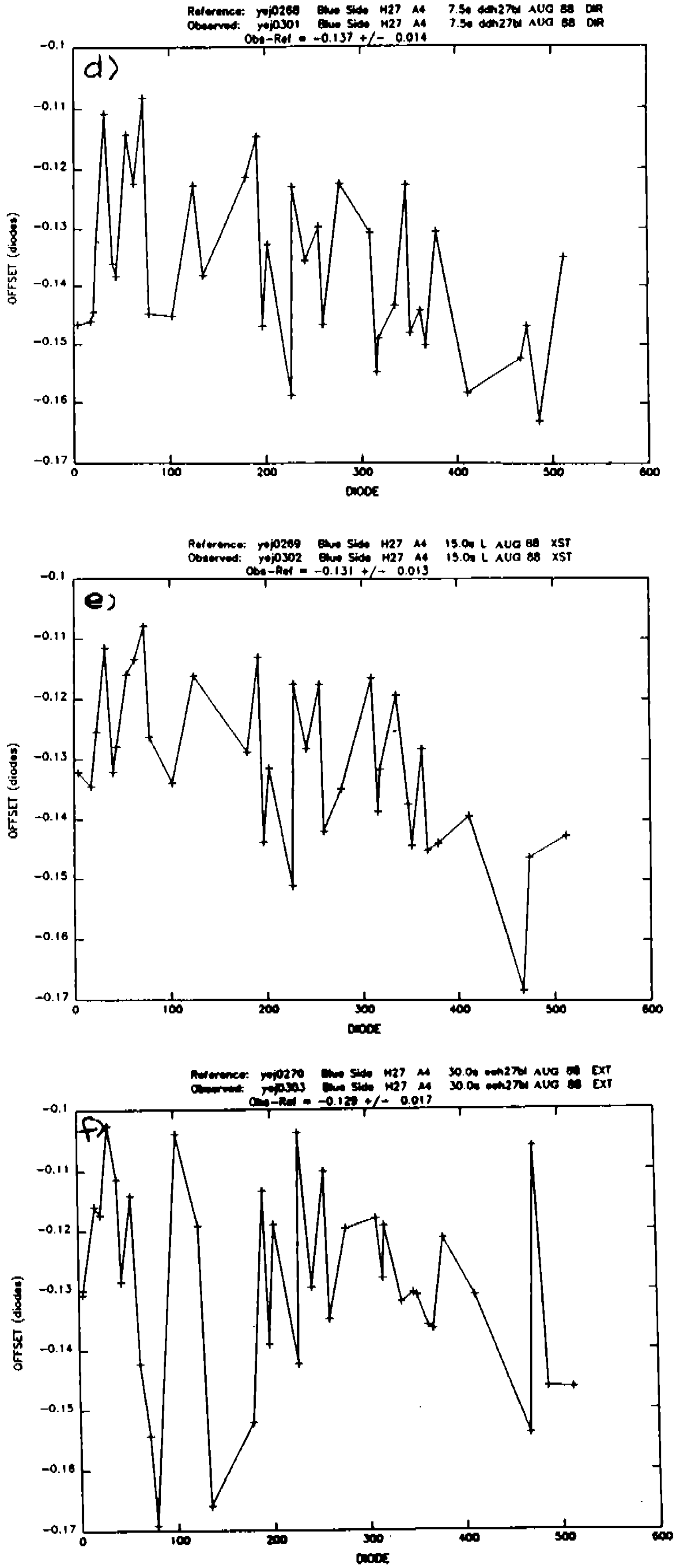


Figure 4 - Continued

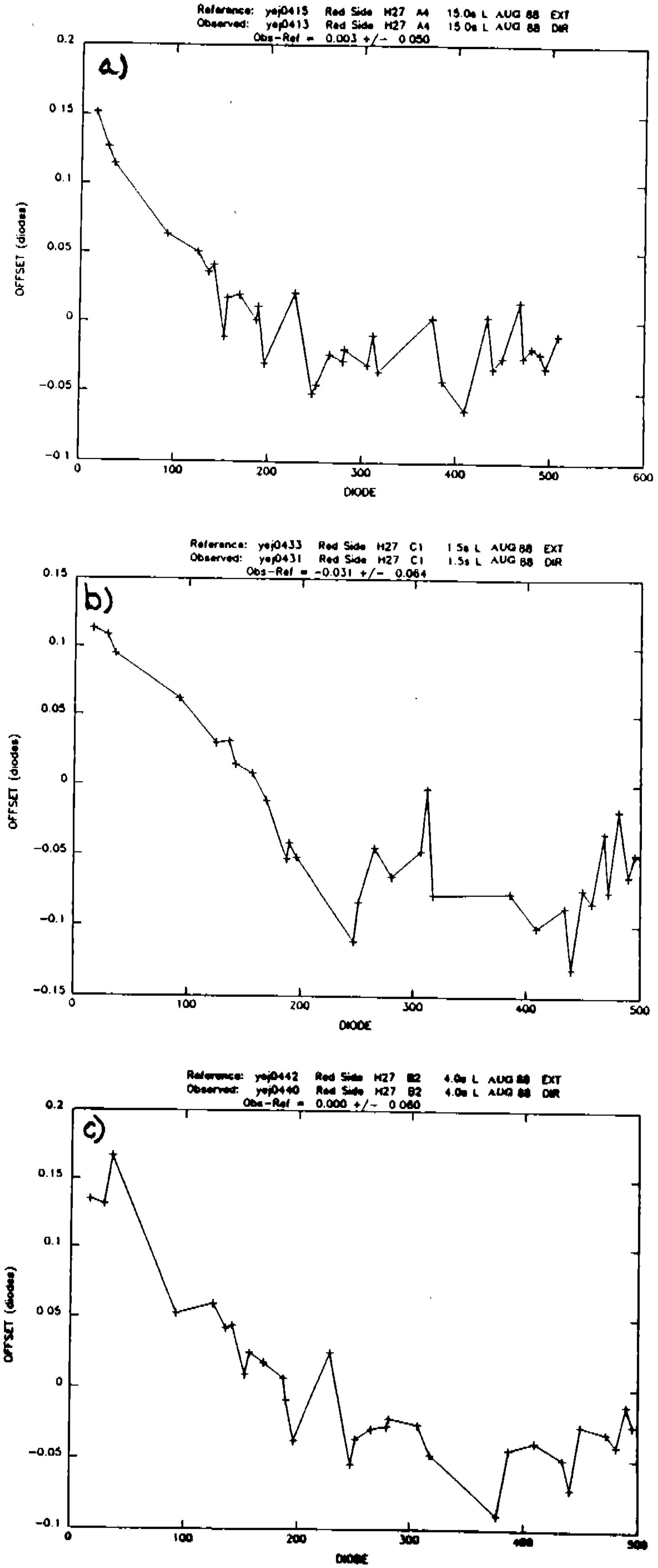
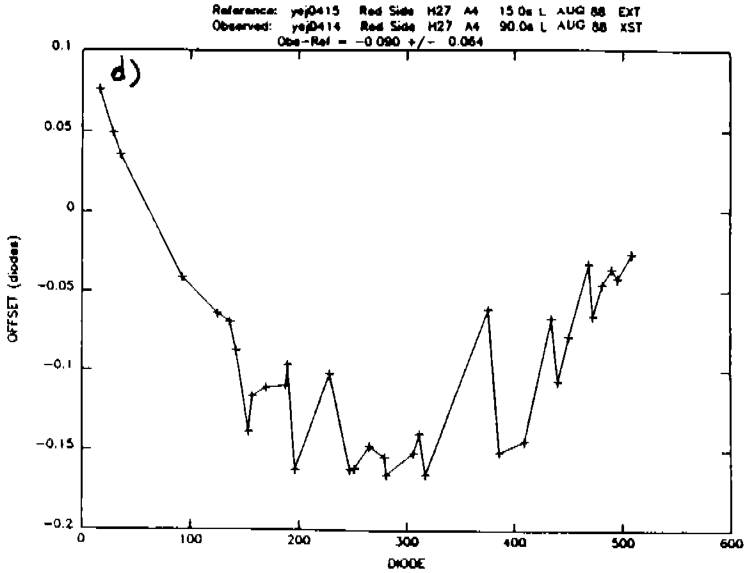
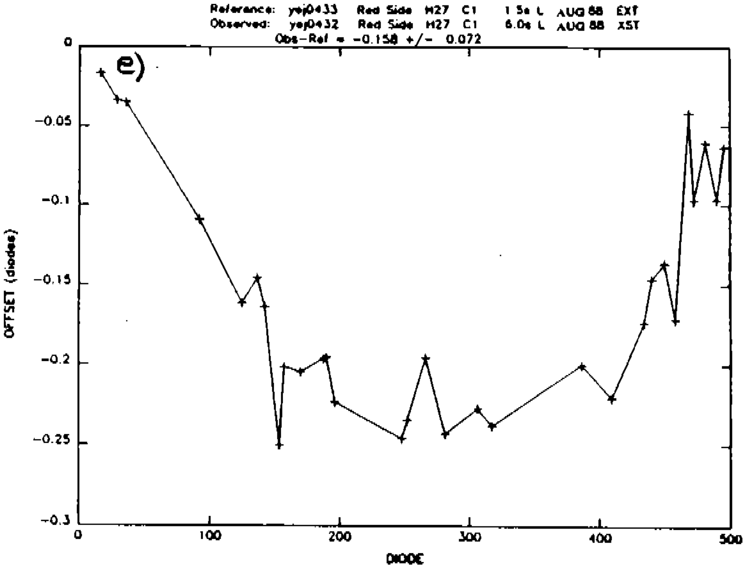
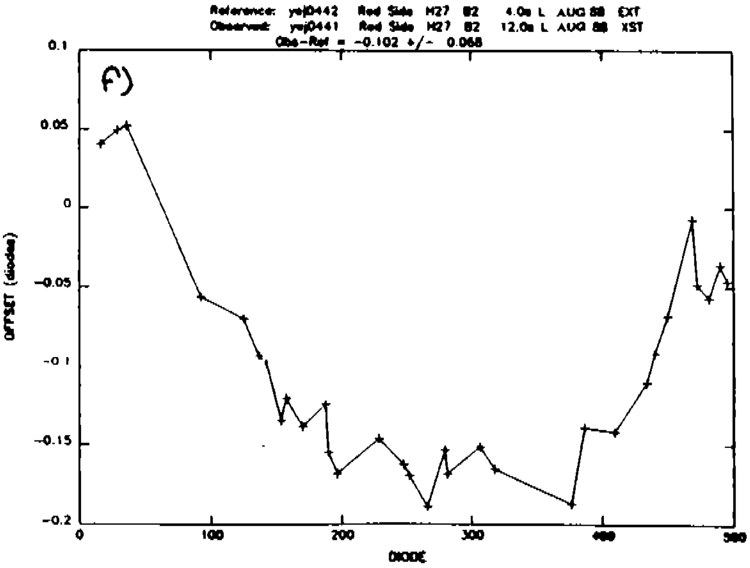


Figure 5: Examples showing stability of derived offsets for different apertures. All data shown are from H27 and the red tube. The DIR - EXT data are from apertures a) A4 (0.1-PAIR), b) A2 (0.5-PAIR), and c) B2 (0.3 CIRCLE). Figures 5d,e, and f show the same comparison for the XST - EXT data.







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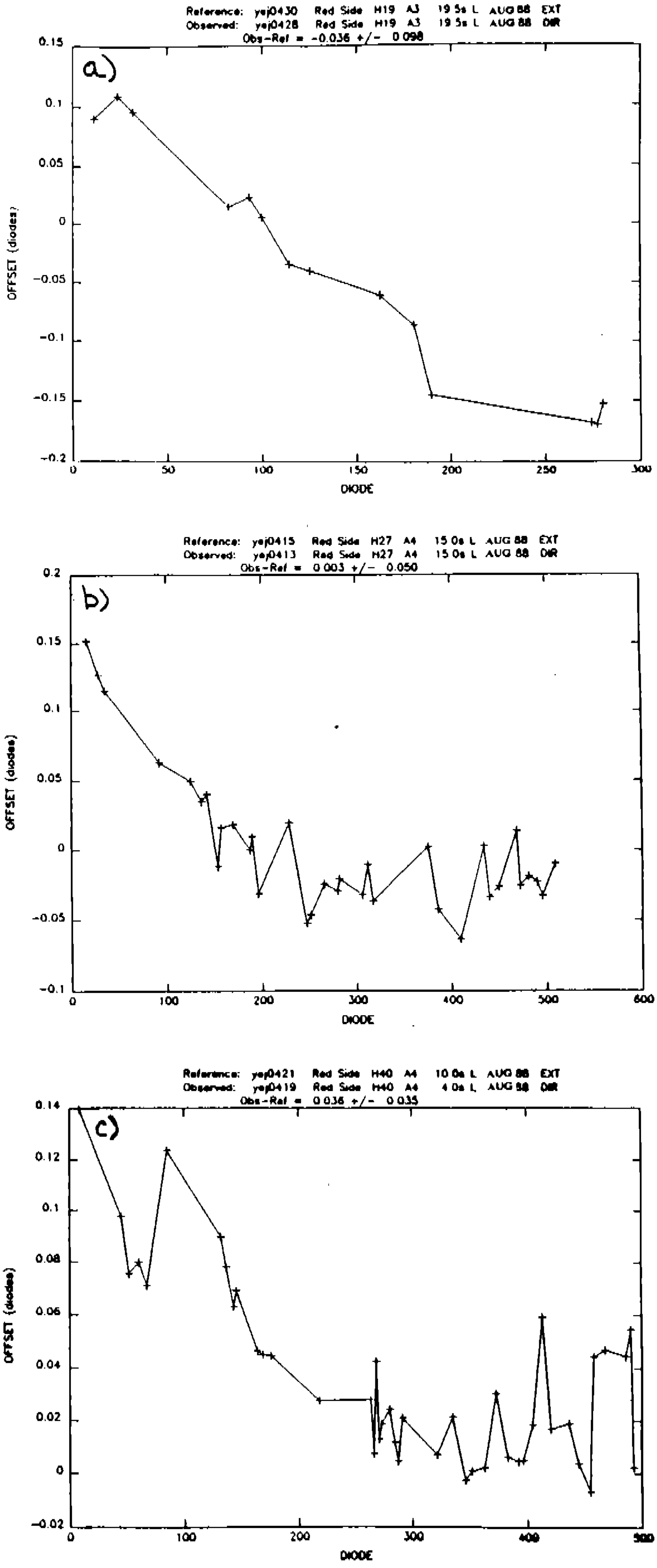
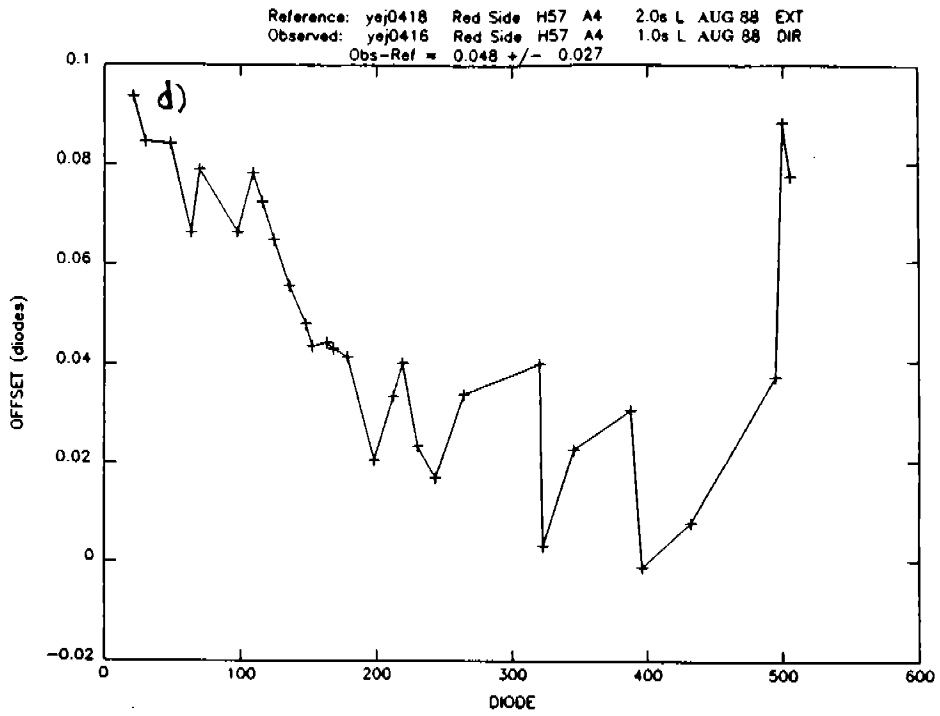
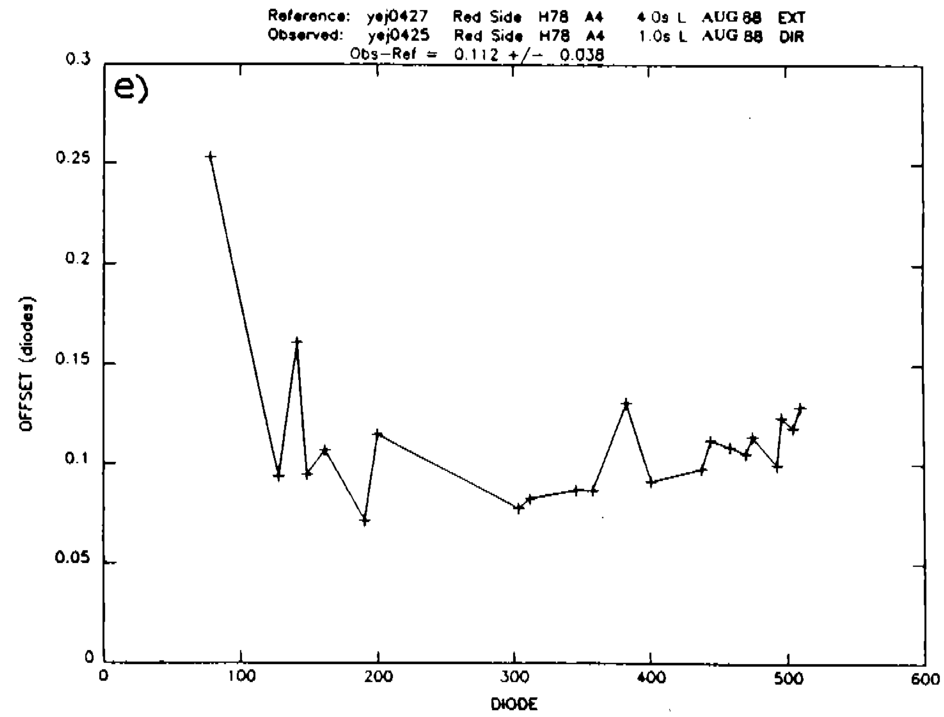


Figure 6: Behavior of the DIR - EXT offset with disperser for the red Digicon. a) H19, b) H27, c) H40, d) H57, and e) H78.





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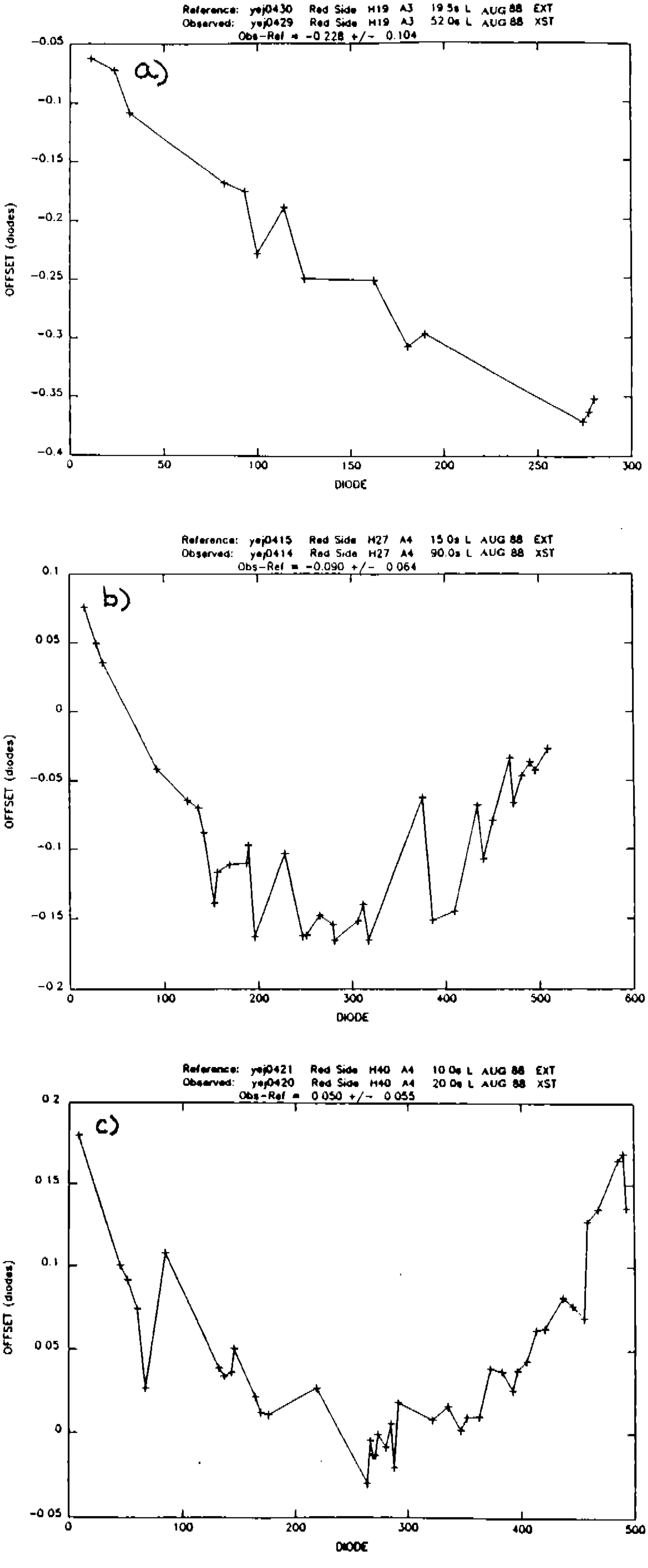
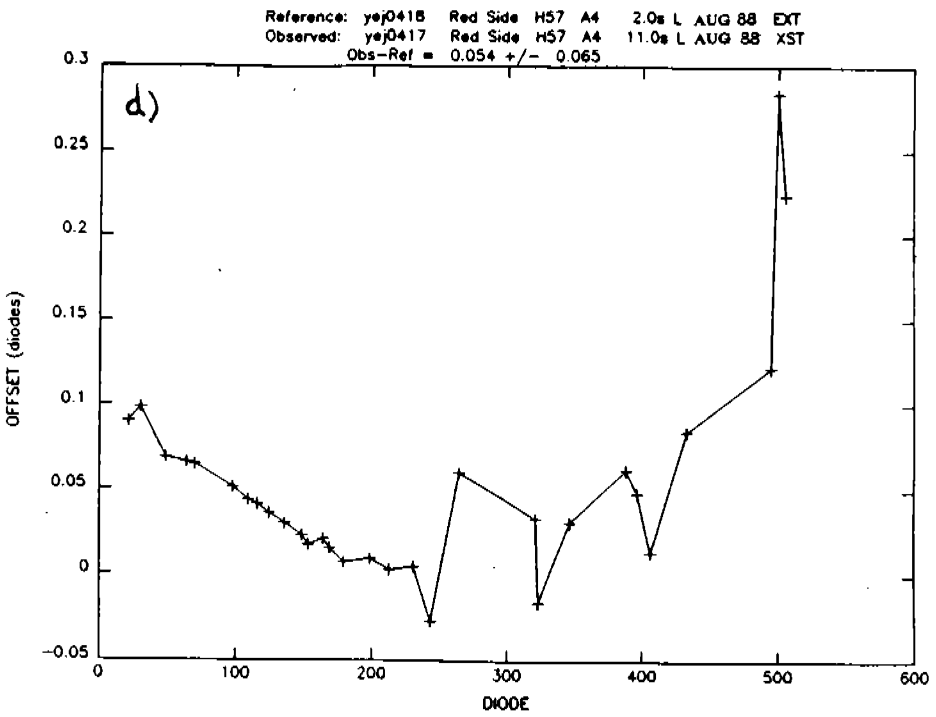
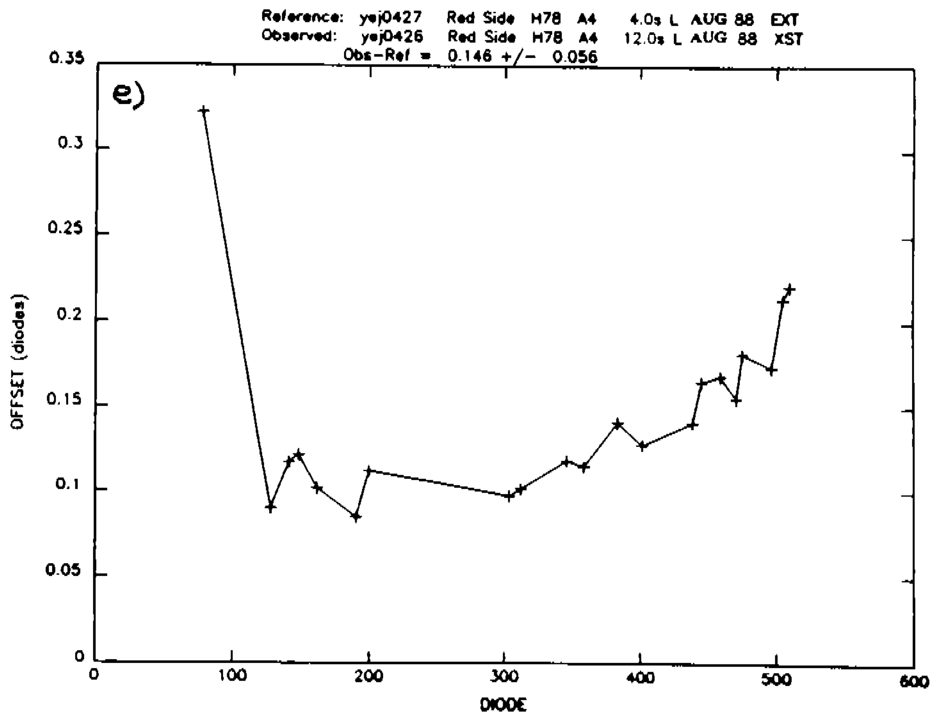


Figure 7: Same as Figure 6, but for the XST - EXT data. (No data for H78.)





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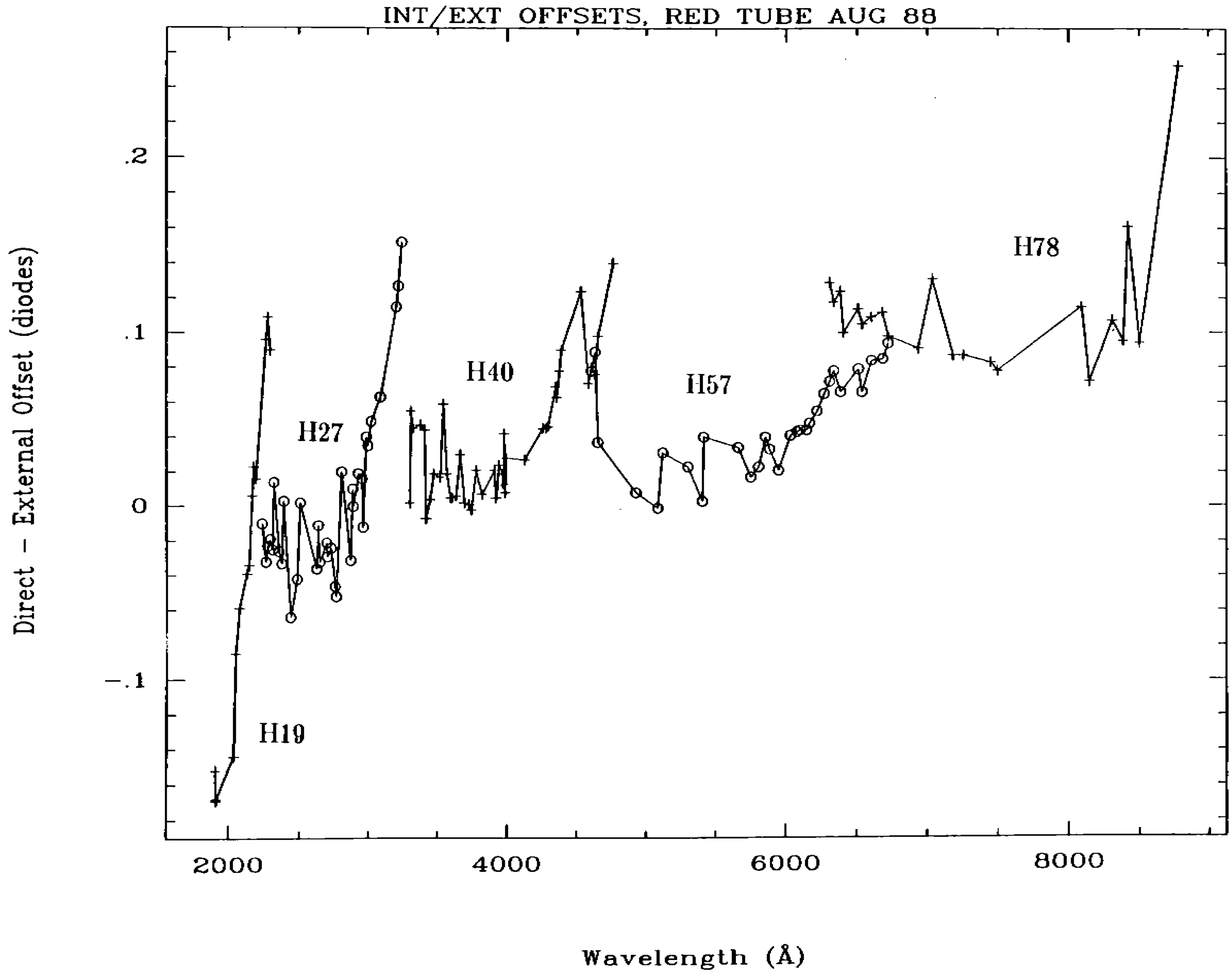
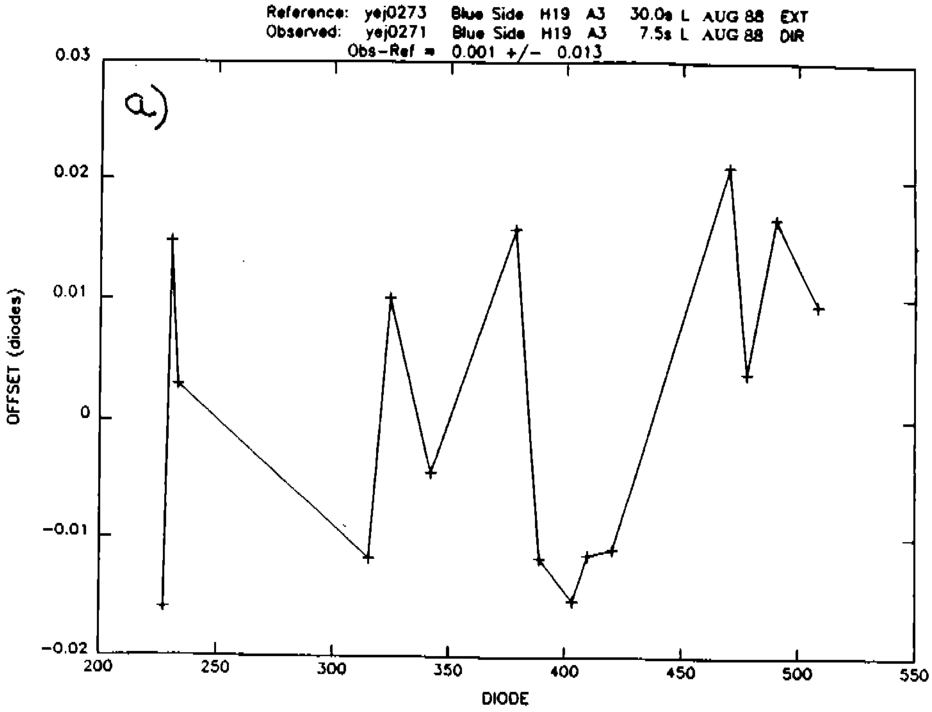


Figure 8: Summary of DIR - EXT red offsets for comparison with BSH Figure 4.



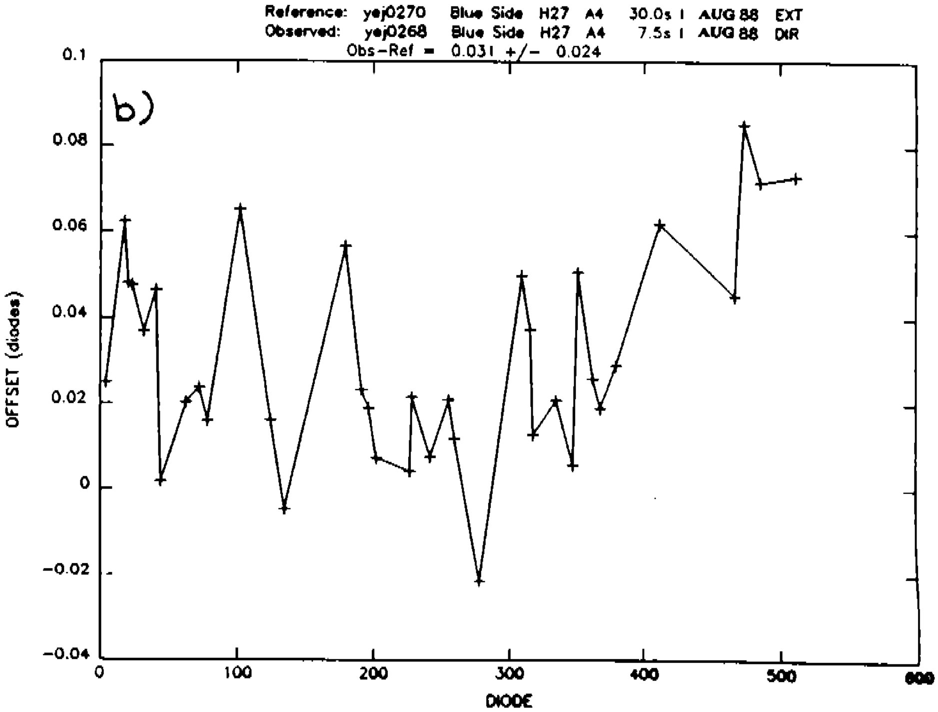
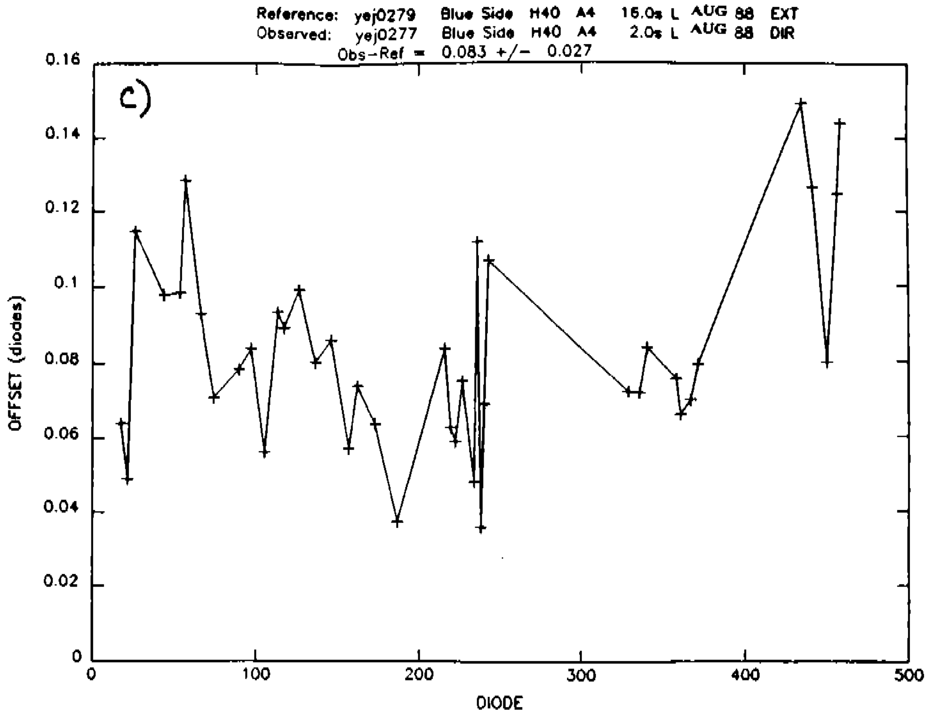
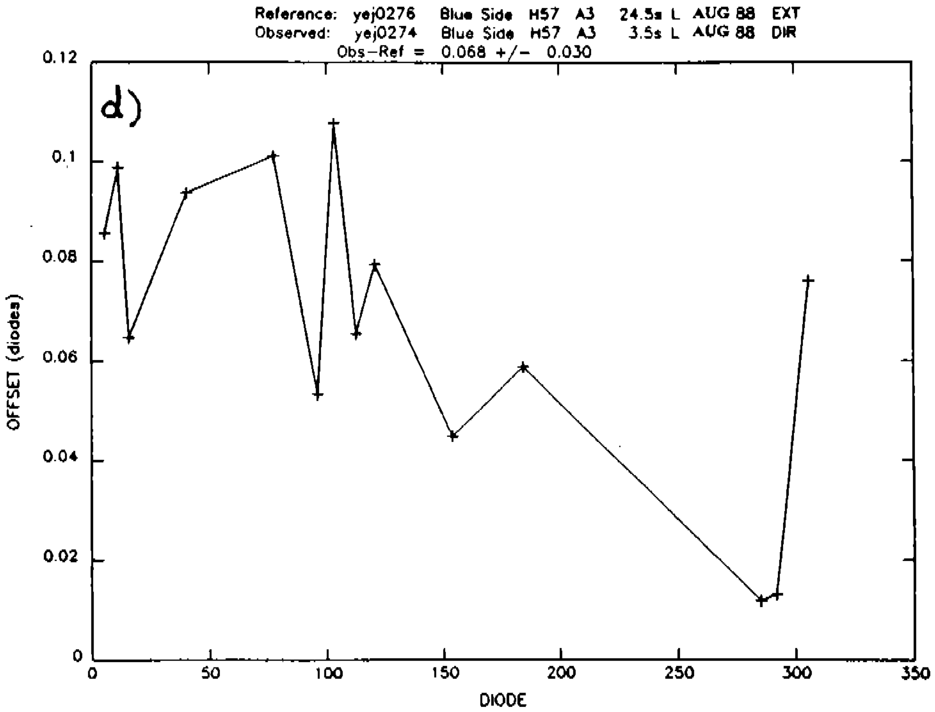


Figure 9: Behavior of the DIR - EXT offset with disperser for the blue Digicon. a) H19, b) H27, c) H40, and d) H57.





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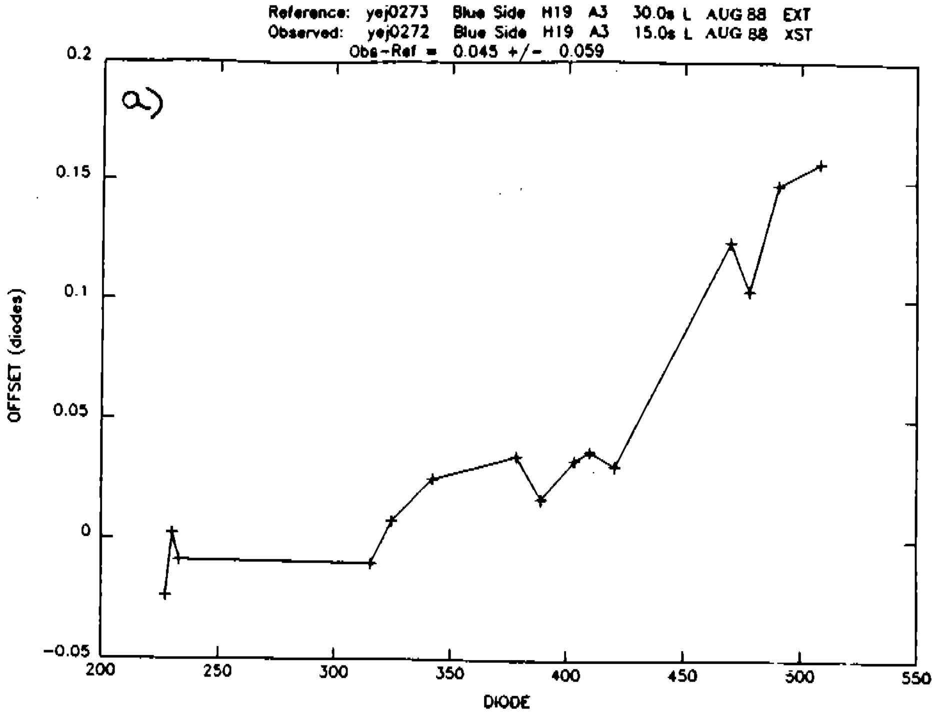


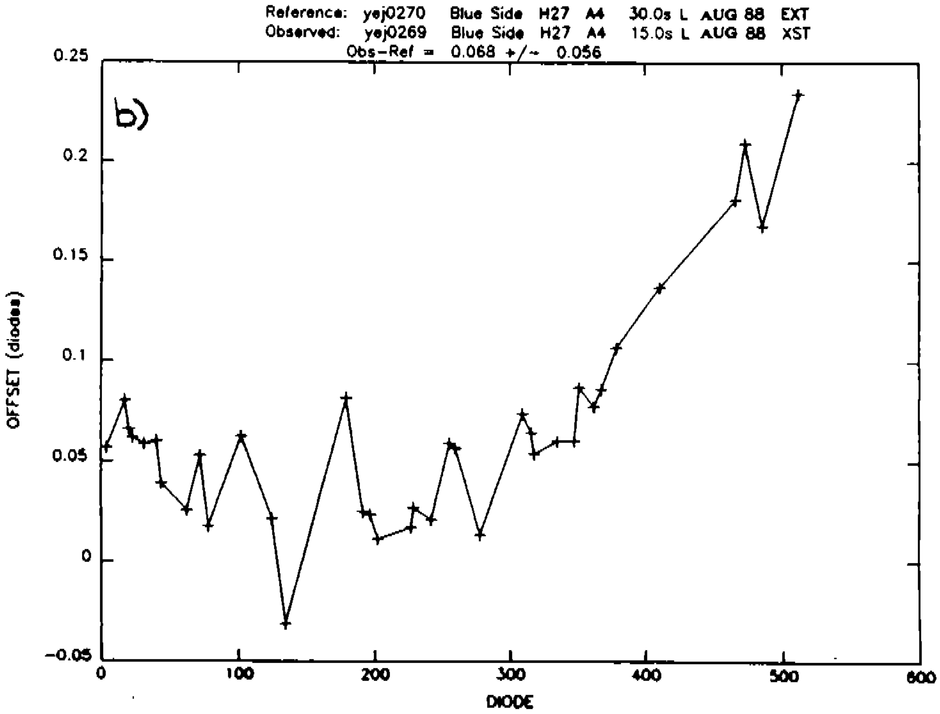
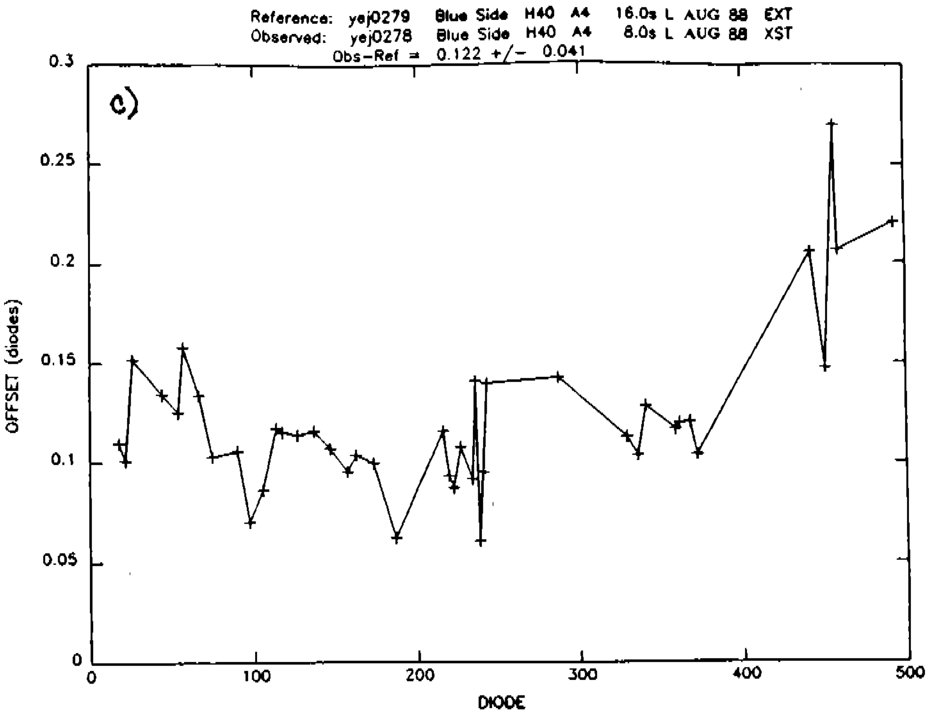
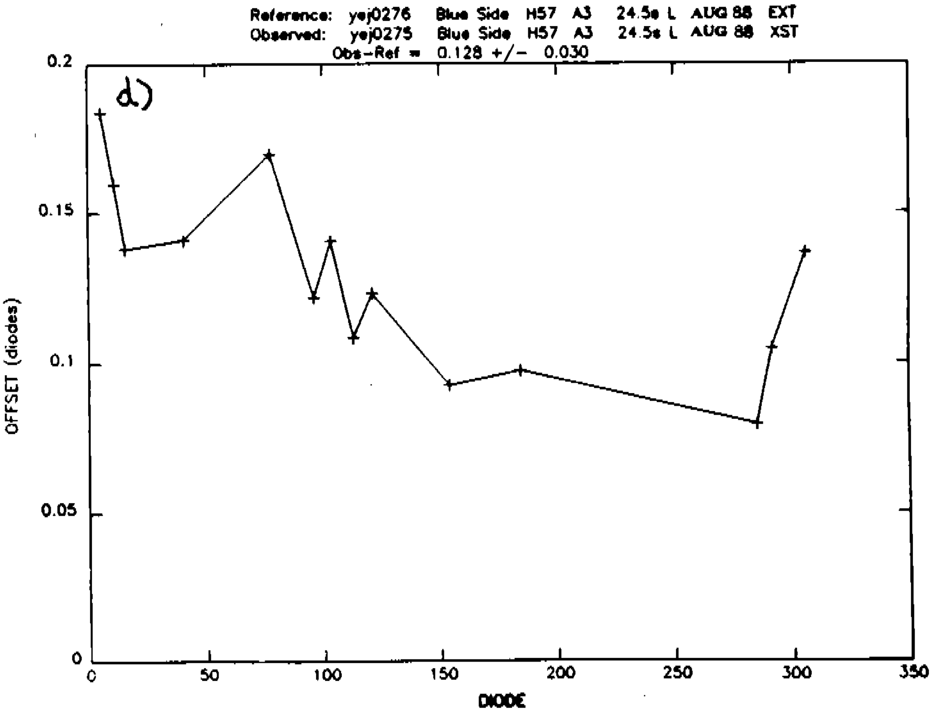


Figure 10: Same as Figure 9, but for the XST - EXT data.





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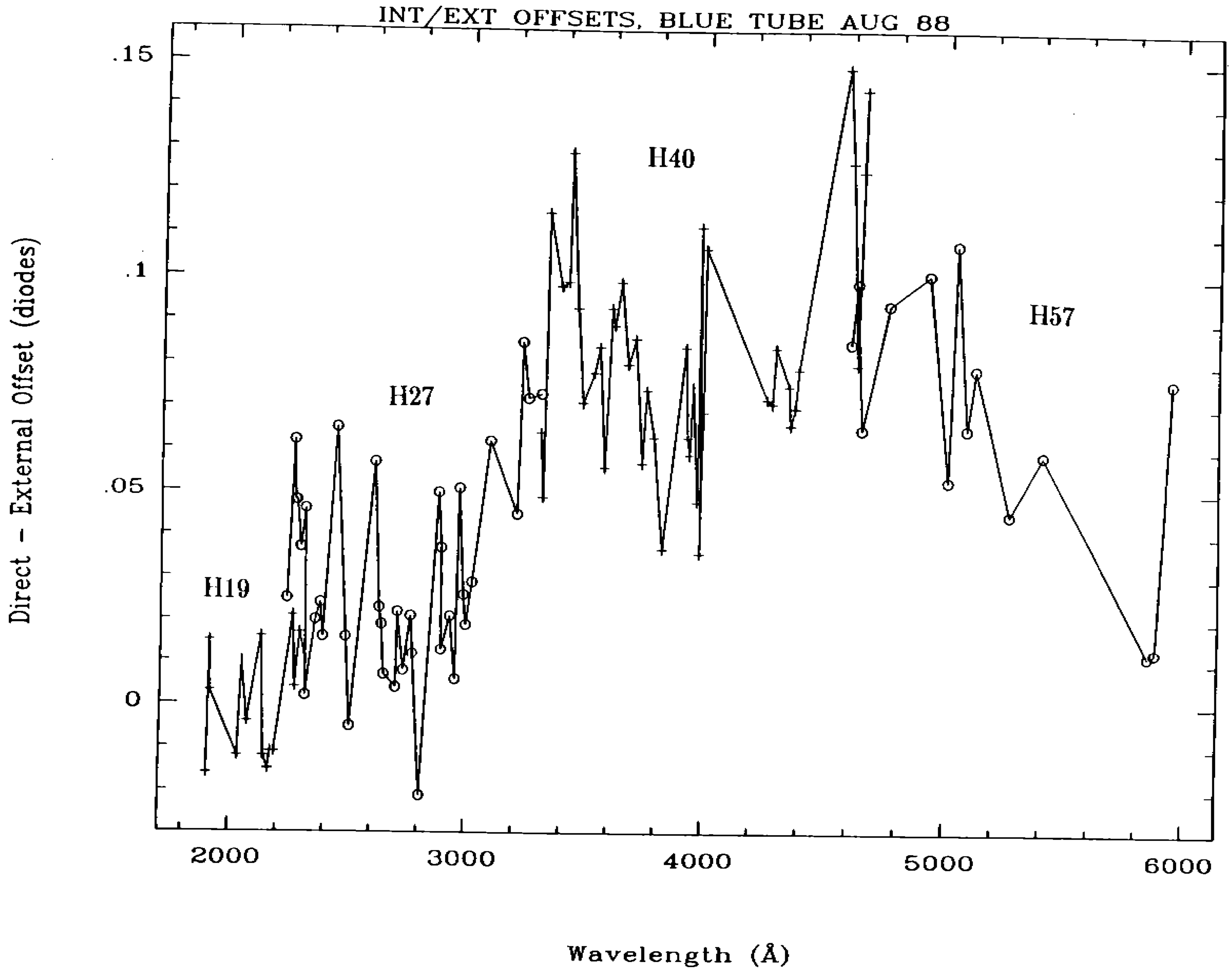

Figure 11: Summary of DIR - EXT blue offsets for comparison with BSH Figure 5.