POST-COSTAR FOS FLAT FIELDS

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Abstract. Post-COSTAR FOS photocathode granularity is shown to be variable on size-scales as small as 0.2 arcseconds. Modest temporal variation is reported for only one detector/disperser combination, FOS/RD G190H. Substantially different flat field correction is required for single and paired apertures, however little aperture-dependence exists between individual single or individual paired apertures. A substantial blemish is reported for FOS/BL G160L that requires quantitative science at 1550Å be performed with UPPER paired apertures only. High S/N FOS observations (typically, S/N> 30) require high precision target acquisition strategies in order to sample similar regions of the photocathode as are used in FOS calibration observations.

Key words: FOS, Flat-fields

1. Introduction

The Post-COSTAR FOS flat field calibration continues to follow the philosophy outlined in the SV report (Anderson, 1992). The calibration is intended to account for significant sensitivity changes (so-called granularity) on scales of approximately 10 diodes or less. This includes true diode-to-diode variations and photocathode irregularities. Smooth variations on scales of 10 or more diodes are routinely accounted for in the absolute photometry (inverse sensitivity, or IVS) calibration. FOS flat field files used in the RSDP/PODPS pipeline processing of FOS observations are stored as reference files of the form ROOTNAME.R1H and ROOTNAME.R1D in the STScI Calibration Database System (CDBS) and are available for anonymous ftp retrieval from the /cdbs/yref sub-directory at FTP.STSCI.EDU. All FOS flat field reference files are actually unity-normalized inverse flat fields, which are applied as multiplicative operators to the observational data after the conversion to count-rate, correction for paired-pulse and GIM (as necessary), background subtraction, and, if possible, scattered light correction. The flat fields discussed here are NOT APPLICABLE to FOS spectropolarimetry mode.

2. How FOS Flats are Made

Photocathode granularity is the dominant source of structure in FOS flat fields. The post-COSTAR PSF produces a beam that illuminates a much smaller portion of the photocathode, and hence samples a more discrete portion of the photocathode granularity, than the pre-COSTAR case. As a result, all post-COSTAR FOS flat field standard star observations are obtained with high-accuracy pointing of 0.04 arcseconds or better.

In principle, flat fields are produced by dividing the count-rate observations of a relatively featureless star by the pixel-to-pixel representation of the instrinsic stellar count-rate spectrum so that the quotient is, ideally, a measure of only the intrumental granularity. All post-COSTAR FOS flats are derived via the super-flat technique (Lindler, *et al.* 1993).

Observations are obtained with the target precisely centered in the 4.3 aperture and at six other positions offset by differing amounts parallel to dispersion. Or course, any feature found at the same pixel position in each of the individual spectra must be a real flat field feature and any feature that is dispaced from one spectrum to the next must be a stellar line. As Lindler *et al.* note, cross-correlation of the seven spectra yields two useful results:

1. the pixel-to-pixel array of granularity, the flat field.
2. an accurate and objective representation of the stellar count-rate spectrum at the instrumental resolution, the so-called super spectrum.

The lengthy superflat observing procedure need not be repeated at later epochs. Future observations of the same star, obtained with the same pointing accuracy so as to sample the same portion of the photocathode, can be compared with the super-spectrum to yield accurate flat fields appropriate to those later times.

All FOS flat field reference files are time-tagged with a so-called USEAFTER date (literally, use the file after this date). One post-COSTAR USEAFTER currently exists for FOS observations, and these reference files are based upon the superflat procedure. Additional observations have been made and flats will be placed in CDBS. Numerous pre-COSTAR USEAFTERs exist, which are not described here (see Lindler *et al.* 1995 and FOS WWW reference file guides).

For the purpose of clarity in all of the following, we again note that all FOS flat field reference files delivered to CDBS are INVERSE flat fields.

3. FOS Flat Field Variations

n this section we present the results of preliminary analysis of the post-COSTAR photocathode granularity for several FOS detector/disperser combinations. The figures presented will be either count-rate comparisons or ratios of count-rates and are not actual FOS flat fields. Analysis to date has shown that substantial spatial variation is present in post-COSTAR flats and that modest post-COSTAR temporal variation has been seen in at least one detector/disperser combination, FOS/RD G270H. Large temporal variations of the nature seen in pre-COSTAR flat fields have not occurred to date. Aperture dependence in post-COSTAR granularities occurs only in situations involving large blemishes (*e.g.,* FOS/BL G160L) or comparison of apertures that sample very different regions of the photocathode (*e.g.,* single versus paired apertures).

3.1 Aperture-dependence

Figure 1 presents the ratio of 1.0 aperture to 4.3 aperture FOS/RD G190H observations of G191B2B made in February, 1994. The counting statistics for both sets of observations yield formal S/N of order 200. Aside from a small color-dependence in the aperture throughput, there is no apparent aperture dependence in the comparision of these two apertures which illuminate concentric areas on the photocathode. Figure 2 presents, from top to bottom, the ratio of 1.0-PAIR-UPPER, 1.0 single, 1.0-PAIR-LOWER, and 0.3 single aperture to 4.3 aperture count-rate FOS/RD G570H observations of BD+28°4211 from June, 1994. These curves have been arbitrarily shifted vertically without magnification for purposes of clarity. The 1.0 and 0.3 apertures illuminate the same location as the 4.3 and show no indication of aperture dependence in the flat field. However, the 1.0-PAIR data, which sample regions of the photocathode more than an arcsecond above and below the single aperture centers, clearly show much larger pixel-to-pixel deviations and some substantially different features.

3.2 Spatial Variations

In November, 1994 observations were made of G191B2B with each of the high dispersion detector/disperser combinations and the 1.0 aperture. These measures consisted of one exposure with the star well-centered in the aperture and two additional exposures with the star displaced 0.2 arcseconds (roughly half the aperture width and one PSF FWHM) above and below aperture center. This set of observations represents the only consistent attempt to measure the effects of small-scale target displacement on flat field structure.

Figure 3 shows count-rate plots for FOS/RD G190H at +0.2, 0.0, and -0.2 arcseconds from 1.0 aperture center. The differences are striking. This particular spectral region contains a well-known and quite pronounced flat field feature at approximately 1950 Angstroms. Indeed, this feature was the site of substantial temporal variation in the first two years following HST launch. The 20% feature is quite apparent in the middle curve of Figure 2, which corresponds to the traditional aperture-centered location. However, the feature is completely absent in both the displaced spectra! Several other, though not all, features behave similarly.

Figure 4 presents count-rate ratios of FOS/RD G570H observations made with the 1.0 aperture in February, 1995 (well-centered) and November, 1994 (again centered +0.2, 0.0, and -0.2 arcseconds from aperture center) compared to February, 1994. The temporal variation of the well-centered data will be discussed in the next section, but again the +0.2 and -0.2 data clearly show substantial differences in structure not apparent in the well-centered data.

Figure 5 also provides a graphic illustration of spatially-dependent flat field structure. This figure presents, from top to bottom, FOS/BL G160L count-rate observations of BD+28°4211 taken in June, 1994 with the 4.3, 1.0-PAIR-UPPER, 1.0 single, 1.0-PAIR-LOWER, and 0.3 apertures. A well-known, very intense photocathode blemish (the broad "absorption line" at 1520Å) is strongly present in the 4.3, 1.0 single, and 1.0-PAIR-LOWER data. It is slightly less intense in the 0.3 aperture data, and nearly absent from the 1.0-PAIR-UPPER observations. Due to the severity of this feature, as of 15 May 1995 the FOS group recommends that all routine science observations that rely on measures of the C IV resonance lines should be performed with one of the UPPER paired apertures.

In summary, photocathode granularity changes markedly on size-scales of 0.2 arcseconds. The granularity for paired apertures may be substantially different than that for single apertures. As we shall see, spatial variations are much larger than post-COSTAR temporal variations. Only limited mapping of the spatial dependence of flat fields has been made. Although a more comprehensive analysis will be published as an ISR at a later date, we note several specific spectral regions in which spatial variations are prominent: FOS/BL G160L 1550-1550Å(affects C IV); FOS/BL G270H 2900Å; FOS/RD G190H 1800-2100Å; and FOS/RD G570H ~5000Åand ~5500Å).

The application of the pipeline flat, derived from highly precise centering, may not be appropriate for less well-centered observations. Clearly, any science program requiring high S/N (typically, S/N> 30) and precision flat fielding should center to the same degree of accuracy as the observations used to produce the flat field in order to sample the same portions of the photocathode.

3.3 Temporal Variations

Reference to Figure 4 shows that up to 5% changes have occurred in the FOS/RD G190H flat field between November, 1994 and February, 1995 (compare the first and third curves from the top – note that the flat-bottomed feature at 1900Å in the first curve is produced by a dead diode and should be ingored in this comparison). G160L for both detectors and FOS/RD G270H are being closely monitored for possible change. No other substantial post-COSTAR flat field variations are apparent at the present time.

4. FOS Flat Field Calibration Status

There is only USEAFTER date for FOS flat field reference files delivered to date. All these reference files have been based upon 4.3 aperture superflat observations. It is anticipated that additional deliveries for aperture-specific flat fields and for tracking of temporal variation will be made later this year.

All Cycle 4 single aperture high-dispersion observations obtained prior to 13 July 1994 should be re-calibrated with the current reference files as pre-COSTAR flat fields were used for these combinations prior to this date.

All Cycle 4 single aperture low-dispersion observations obtained prior to 1 July 1995 should be re-calibrated with the current reference files as pre-COSTAR flat fields may have been used for these combinations prior to this date.

All Cycle 4 paired aperture observations should be re-calibrated with new reference files to be delivered approximately 1 October 1995 (refer to FOS Homepage — see the section below, for further information). Unity flats (no correction) have been applied to all post-COSTAR paired observations to date.

Single aperture flats for apertures smaller than 4.3 also will be available in fall 1995. However, little aperture dependence is seen in post-COSTAR single aperture flat fields. Currently, 4.3 aperture flats are applied to these cases.

No flat field correction is currently made in the PODPS pipeline to observations made with the barred apertures.

5. Sources of FOS Flat Field Information

An online reference guide accessible from both the Advisories button and the Documentation button of the FOS WWW Homepage

http://www.stsci.edu/ftp/instrument_news/FOS/topfos.html

always offers the list of currently recommended flat field refernce files by USEAFTER date for all detector/disperser/aperture combinations. Separate guides are maintained for pre-COSTAR and post-COSTAR periods.

A discussion of the calibration status of the FOS with a listing of recommended reference files (current through 1 November 1994) for all usable detector/disperser/aperture combinations is compiled in Instrument Science Report CAL/FOS-130 (Keyes *et al.* 1994).

The original reference on the FOS superflat technique and a discussion of pre-COSTAR FOS/BL superflat-derived flat fields is provided in CAL/FOS-088 (Lindler *et al.* 1993). Pre-COSTAR superflat-derived flat fields for FOS/RD and more on the superflat method itself are described in CAL/FOS-134 (Lindler *et al.* 1995).

6. Practical Considerations and Summary

High-precision (S/N> 30) spectroscopic measures with FOS require that the observations must sample the same portion of the photocathode as do the flat field calibration observations. This sampling repeatability is limited by the target acquisition accuracy (typically 0.04 arcseconds for calibration observations) and filter-grating wheel positional repeatability (approximate one sigma of 0.04 arcseconds). The photocathode granularity varies by 5-15% over distances as small as 0.2 arcseconds, and no extended or detailed mapping of the granularity is available in the direction perpendicular to dispersion. Paired aperture granularity is substantially different than that for the single apertures. However, little flat field difference is seen between individual single or individual paired apertures.

Lastly, as a careful check, the closing advice offered in the flat field papers in the first HST Calibration Workshop (Keyes, 1993; Jannuzi and Hartig, 1993) remains valid; that is, compare the flat field reference file data with 1) your raw science data, 2) the raw count-rate data used to produce the flat, and 3) any raw count-rate data for any other standard stars taken as nearly contemporaneously as possible with your science data in order to assess suspicious features in your science data.

References

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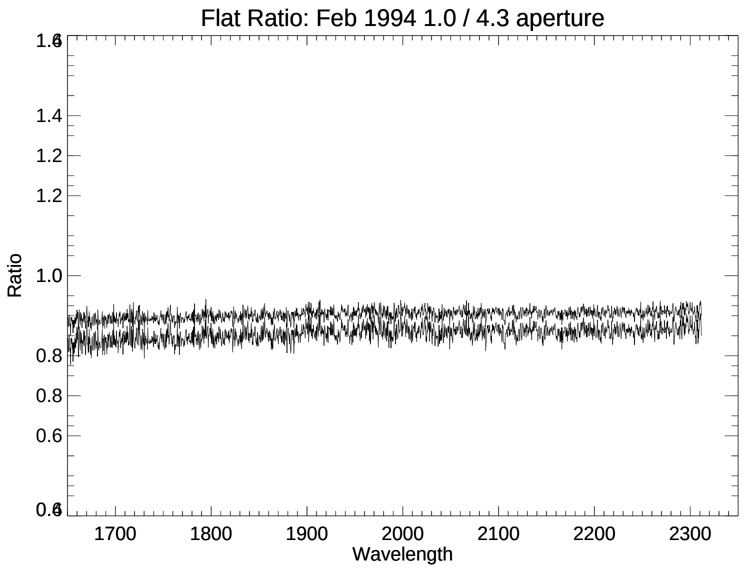


Fig. 1. Count-rate ratio for February 1994 FOS/RD G190H 1.0 and 4.3 aperture observations of spectrophotometric standard star G191B2B.

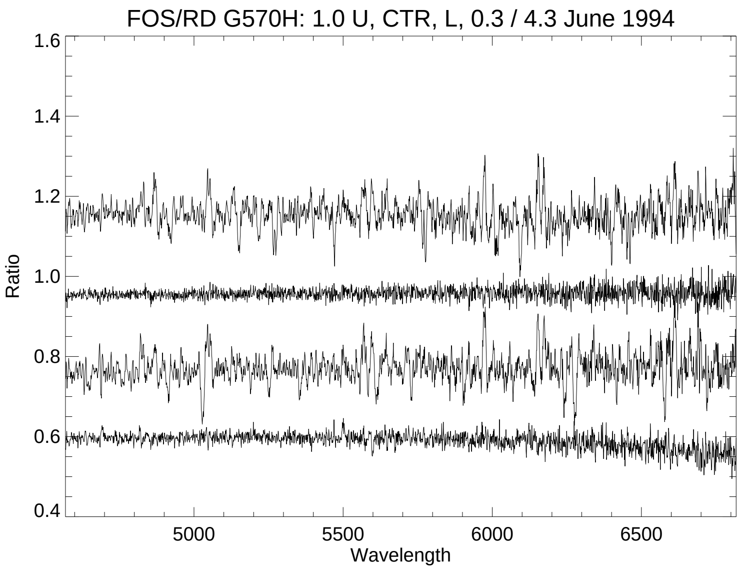
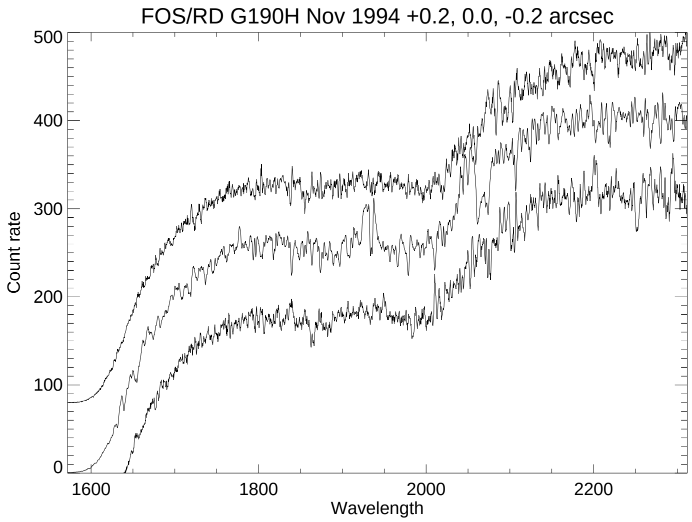


Fig. 2. Count-rate ratios for June 1994 FOS/RD G190H observations of spectrophotometric standard star BD+28°4211. From top to bottom ratio of 1.0-PAIR-UPPER, 1.0 single, 1.0-PAIR-LOWER, and 0.3 single to 4.3 aperture. The vertical scale has been shifted with no magnification for purposes of display clarity.



Fig, 3d

Fig. 3. Count-rate observations for November 1994 FOS/RD G190H 1.0 aperture observations of spectrophotometric standard star G191B2B. From top to bottom exposures displaced +0.20 arcsec from aperture center, well-centered, and displaced -0.20 arcsec from aperture center. The vertical scale has been shifted with no magnification for purposes of display clarity.

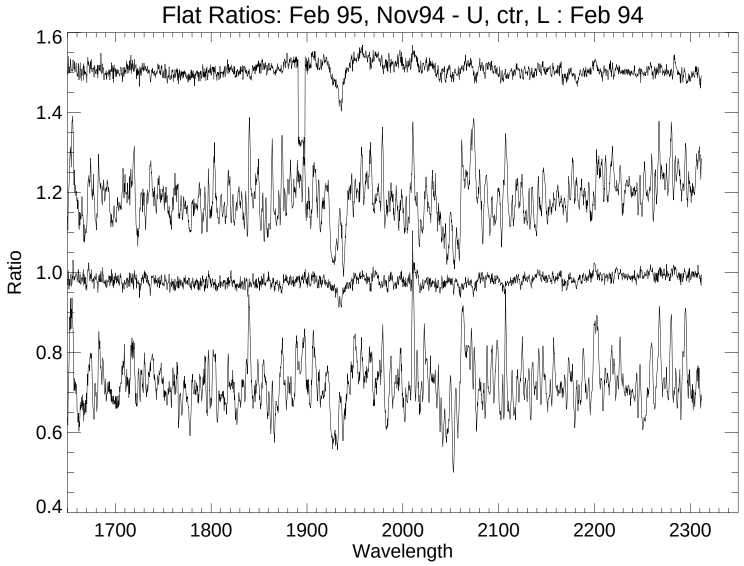


Fig. 4. Count-rate ratios for FOS/RD 1.0 single aperture G570H observations of spectrophotometric standard star G191B2B. From top to bottom ratio of well-centered February 1995, displaced +0.20 arcsec November, 1994, well-centered November 1994, displaced -0.20 arcsec November, 1994 to well-centered February 1994 data. Note flat-bottomed feature at approximately 1900 A. in upper curve is produced by a dead diode. The vertical scale has been shifted with no magnification for purposes of display clarity.

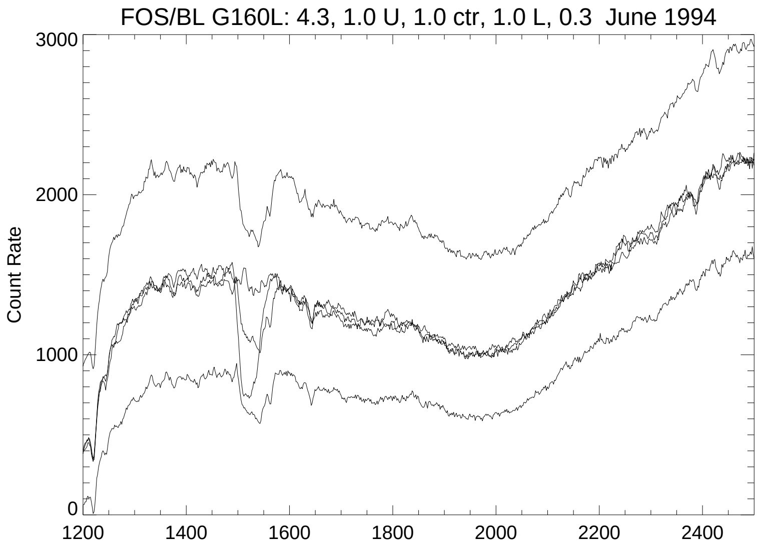


Fig. 5. Count-rate observations for June 1994 FOS/BL G160L observations of spectrophotometric standard star BD+28°4211. From top to bottom 4.3 aperture, 1.0-PAIR-UPPER, 1.0 single, 1.0-PAIR-LOWER, and 0.3 single apertures. The vertical scale has been shifted with no magnification for purposes of display clarity.