The *HST* Quasar Absorption Line Key Project XI: Some Practical Suggestions for Flat Fielding Your FOS Data

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Abstract

We describe the procedure we use to calibrate the *HST* Quasar Absorption Line Survey Faint Object Spectrograph data for flat field features. We suggest some measures that users of the *HST* Faint Object Spectrograph can take to obtain the best available calibration of their data and how they can assess the quality of their reduction.

I. Introduction

The Faint Object Spectrograph (FOS) observations of the *HST* Quasar Absorption Line Survey are intended to provide a homogeneous and high quality database of quasar spectra suitable for a wide range of scientific studies. The primary purpose of the database is the study of the properties of the intergalactic medium and of the gaseous content of galaxies and groups of galaxies (Bahcall et al. 1993).

While the survey has not been completed (the observations are scheduled over the first three cycles of *HST* operations), over 30 quasars have been observed and as a result we have a significant amount of experience in dealing with the practical problems faced by General Observers wishing to calibrate their FOS data. For our observations, the most critical calibration problem is the proper correction of diode to diode sensitivity changes coupled to the variations in the response of the detector face plates (i.e., the flat field correction). The signal-to-noise of our spectra range from 20 to over 50 per resolution element. These levels of signal-to-noise mean that in some wavelength ranges we are limited by the accuracy of the available flat field correction and not the number of photons we have collected. Our FOS observations and data reduction procedures are described by Schneider et al. (1993). In this paper we share some of our experience in dealing with the practical problems of obtaining the best possible flat field calibration for a given spectrum and in recognizing residual (uncorrected) flat field features in a spectrum.

II. The Problem

The problem facing the users of the FOS is that the observed flat field structure in their data is variable. It is variable with time (epoch of observation), the choice of aperture, and the position of the target on the detector face plates. The observed

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temporal variability is greatest for observations using the G190H grating and the Red detector (covering the wavelength range 1600 to 2300Å). The changes with aperture are most evident when comparing flat fields generated from observations using the 4.3 arcsec square aperture to those made using the 0.25 arcsec $\times$ 2.0 arcsec slit (Figure 1). In the smaller apertures, features are sharper and deeper, and are not smoothed to the same degree (as a result of the *HST*'s poor PSF) as data taken through the larger apertures.

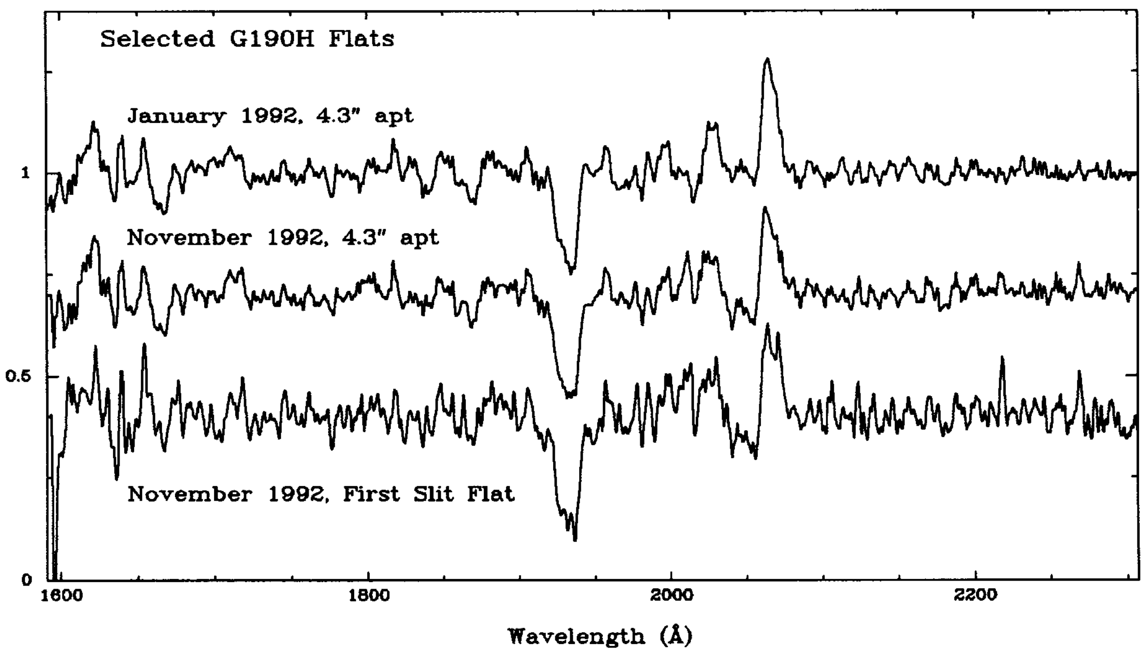

Figure 1: Three G190H Red side flat fields are shown. The date that each was obtained and the aperture used for the observations are also indicated. Note the changes between January and November 1992 in the 4.3 arcsec aperture flats and the even more dramatic difference between the slit and 4.3 arcsec aperture flats. All of the flats shown were generated using the standard STSDAS software as described by Tony Keyes in Faint Object Spectrograph Flat Fielding (these proceedings).

Most observers using ground-based optical spectrographs with CCD detectors would deal with such variability by taking flat field calibration observations for every night of observation (or more frequently if necessary) with the same observing set up they are using for their science observations. Unfortunately, such frequent calibration observations of the FOS have not been and will not be made for the practical reason that they take too large an amount of telescope time. It was hoped that the flat field structure would be fairly constant as a function of time and relatively aperture independent (this latter hope would probably have been realized if not for the well-documented wings in the point spread function of the uncorrected *HST*).

One year after launch it was evident that the flat field structure, particularly on the Red side, was growing. To cope with this problem a program to monitor the flat field structure was initiated. (For details on the time scales, degree of variability, and the efforts to monitor the variability with additional flat field observations, see the contribution by Keyes, in this volume.) Despite the monitoring program, there are still several periods of time during the first three years (cycles) of *HST* operations for which the nearest flat field calibration was taken several months before or after the science observations. Just how different the small and large aperture flat fields would be was not clearly evident until the first 0.25 arcsec $\times$ 2.0 arcsec slit flat field data were obtained in November of 1992. As is evident from Figure 1, the slit and 4.3 arcsec aperture flats are significantly different. Since no flats were obtained with apertures other than the 4.3 arcsec from 1990 through November 1992, observers with data taken through the smaller apertures during this (and other similar time periods) must decide whether to use a 4.3 arcsec flat taken relatively close in time to their data, or to use a later flat that has the same resolution (see Keyes and Taylor, CAL/FOS–090 for complete listing of STScI's recommended flat fields).

III. How to Get the Best Correction Possible

To ensure that you see the most appropriate flat field for your data you should do the following:

- Know HOW the flat fields are generated. There are at least two methods of creating flat fields from the calibration data. It is important for you to know the strengths and weaknesses of the two methods (the Standard vs. Super Flats; see Keyes for details). If they are available for your epoch of observation, flat fields that were generated with the help of the Super Flat observations will generally yield better results than the standard flats.

- Know WHEN the flats (and your data) were obtained. (Places to find when flats were taken include the STARCAT tool of the STScI data archive, STEIS, and CAL/FOS–090 by Keyes and Taylor.)

- Look at the flats and the standard star observations that were used to make them. It is very useful when you try to assess the quality of your data reduction to have had some experience actually examining the flat fields and the standard star observations from which the flats were generated. For example, some flats do not provide corrections for some wavelength regions (over which their value is unity) and you obviously need to know if and where such regions occur in your data. You will also develop a feeling for how strong the flat field features are in these data. Looking at time sequences of flat fields and comparing flats taken with different apertures but at the same epoch are particularly valuable.

The more you know about the flat fields the better you will be at assessing the quality and usefulness of your data, the subject of the next section.

IV. How to Identify Flat Field Residuals in Your Spectra

For the Quasar Absorption Line Survey spectra, we have adopted a brute force approach to identifying residual flat field features in our data. First we generate several versions of the calibrated data, each produced with a different flat. One of the flats is always the one made from calibration data taken closest in time to the science observation and, if available, the version created making use of the "Super Spectrum" of the standard star, which was generated during the "Super Flat" observations; see Lindler et al. 1993 for details. Since all of our high resolution data (G130H, G190H, and G270H) are taken with the 0.25 arcsec $\times$ 4.3 arcsec slit, we also reduce the data using the nearest (in time) available slit flat. Sometimes yet another version of the reduced data is generated. For example, from January to June 1992 there was little change in the G190H/Red flat field, so we constructed an average flat from the calibration observations available between January and June 1992. Then we compare the different versions of the reduced data to each other, to the observations of the standard stars used to generate the flat fields, and to other science observations (in our case our own observations, but archive researchers could search the database for suitable spectra) taken before and after the spectrum we are analyzing. We look for features that are common to the different spectra (and are not interstellar absorption lines!).

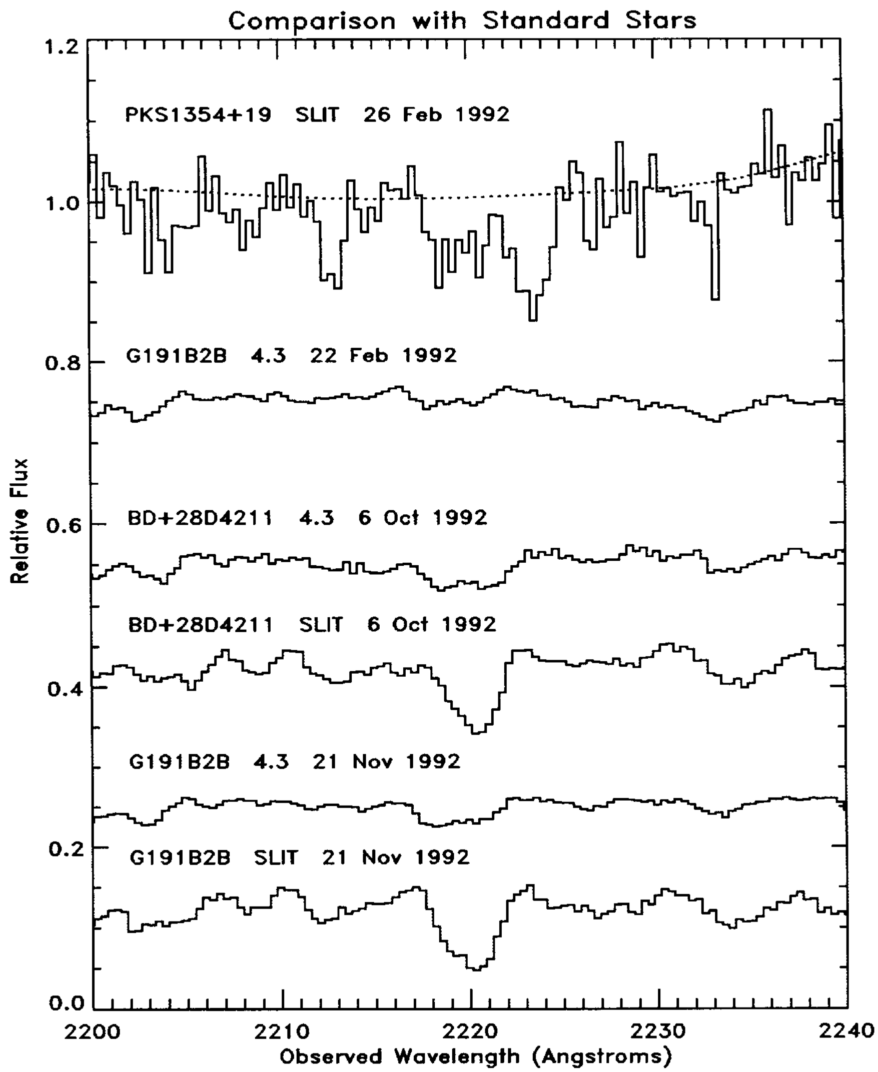

Figure 2: The top spectrum is a portion of the FOS G270H slit spectrum of PKS1354+19. The dotted line is our continuum fit to the data. Plotted below the quasar spectrum are portions of four standard star observations made in order to generate flat field calibration files for FOS data. See the text for additional discussion.

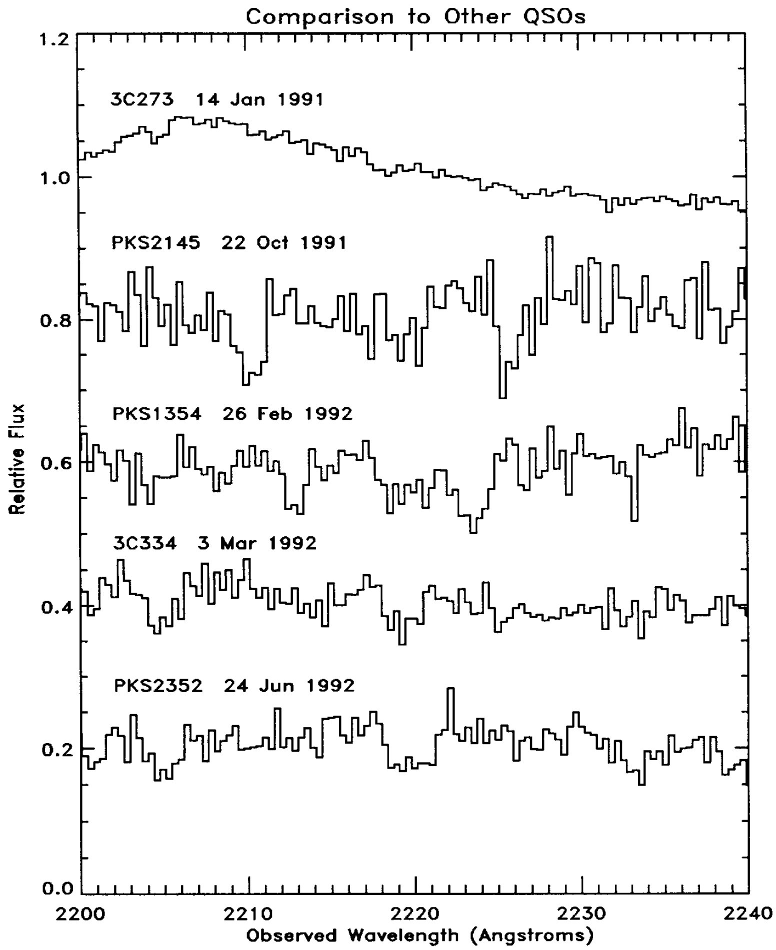

Figure 3: The FOS G270H spectra of five quasars from the *HST* Quasar Absorption Line Survey are presented in the order in which they were observed. Notice that the feature near 2220Å discussed in the text is common to four (perhaps all five) of the spectra and increases in strength from 1991 to June of 1992. As discussed in the text, this feature is most probably a residual flat field feature that is not completely corrected by the available calibration files. Note that there is another feature near 2204Å that is also likely to be a flat field residual.

It is easiest to understand what we do by examining a real example. We obtained a FOS Red detector G270H spectrum of the quasar PKS1354+19 (z = 0.720) on 26 February 1992. At the top of Figure 2 we have plotted the reduced spectrum obtained using the flat made from the January through June 1992 calibration data obtained with the 4.3 arcsec aperture. The dotted line is our continuum fit to the data. Two strong features are evident between 2220 and 2230Å. Below the quasar spectrum, we have plotted five observations of standard stars obtained in February, October, and November of 1992 through the 4.3 arcsec and slit apertures. It is dramatically clear that the feature in the quasar spectrum at 2220Å is also present (to varying degrees) in all of the standard star observations, but to a larger degree in the later (October and November) and slit observations. The strong feature near 2225Å does not repeat. The coincidence of the 2220Å feature in several spectra does not prove that it is a flat field residual, but it does raise doubts about whether we should include it in our list of absorption lines. In Figure 3, we have plotted the spectra of five quasars presented in the order in which they were observed. Again, the feature at 2220Å is seen to increase in strength with time and is clearly present in four of the five objects (and perhaps is weakly present in the 3C 273 spectrum as well). The circumstantial evidence against the 2220Å feature in PKS1354+19 is now sufficient for us to remove the feature from our line list – it is most plausibly a flat field residual. While we remove such flat field residuals from our published line lists, we always include in our papers (e.g., Bahcall et al. 1993) a separate table listing the removed lines.

V. Summary

FOS data calibration is not a trivial task, but with proper care and relatively modest effort most data can be calibrated to a degree that either removes strong (greater than 5 percent) flat field residuals or allows the identification of strong flat field residuals. Our procedure is not perfect and we undoubtedly will make some mistakes, but the procedure outlined above should allow most researchers to successfully assess the impact of flat field structure on their data.

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