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Fringe Science: Creating a STIS CCD Fringe Flat Field

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Abstract. Internal interference in the STIS CCD in mode G750L causes large amplitude fringing in spectra at wavelengths longer than 7000Å. Flat fields taken contemporaneously with a spectral observation will usually reduce the effect of fringing, but there may be occasions when previously observed flat fields will be more useful. We present a method for modifying long slit (52x0.1 arcsec) internal tungsten lamp flat observations for this use. We find that in many cases, the effect of fringing can be reduced by more than a factor of four.

1. Introduction

Fringing is a well-known problem in thinned CCDs such as the one used in STIS. Briefly, light entering the CCD will undergo a series of internal reflections which produces an interference pattern in the spectrum. This fringing pattern is a complicated function of wavelength, CCD face non-planarity and source spectrum, making modeling extremely difficult (Figure 1). The fringing becomes apparent at approximately 7000Å, where the chip becomes semi–transparent to incoming light. The amplitude is variable with wavelength, but has a maximum of $\sim \pm 20\%$ near 9000Å. This means that any observations using the low resolution G750L grating will be affected by fringing (the medium resolution grating G750M is not affected nearly as much by fringing because of the much smaller bandpass). For point source targets, the best solution in general is to take an observation of the STIS internal tungsten lamp with a short slit as close in time as possible to the primary observation. This method is discussed in detail by Goudfrooij & Baum (1997). However, there are times when this approach is not feasible. For example, a spectral observation of a Seyfert galaxy core may have several knots of emission located along the slit. In this case, the flat field must be sampled at different spatial positions. An extended source will also need a spatially well sampled flat field, and the flat field may need to include scattered light as well. A short short slit flat field will not sample scattered light well, and won't be the best choice for such an observation.

In those cases, or when a short slit flat field simply cannot be done (for example, due to overhead time constraints), a previously observed long slit flat may be the only solution. Many long slit flat fields have already been observed since launch and are public data. Processed properly, these may be useful as substitute flat fields. In this paper we discuss how to process a tungsten lamp observation so that it may be used as a flat field and to reduce fringing. We also discuss the pros and cons of this method.

We'll note here that this method is *not* a panacea for fringing; it does not completely erase the fringing, it may not be applicable in all cases, and worst of all, if not done properly

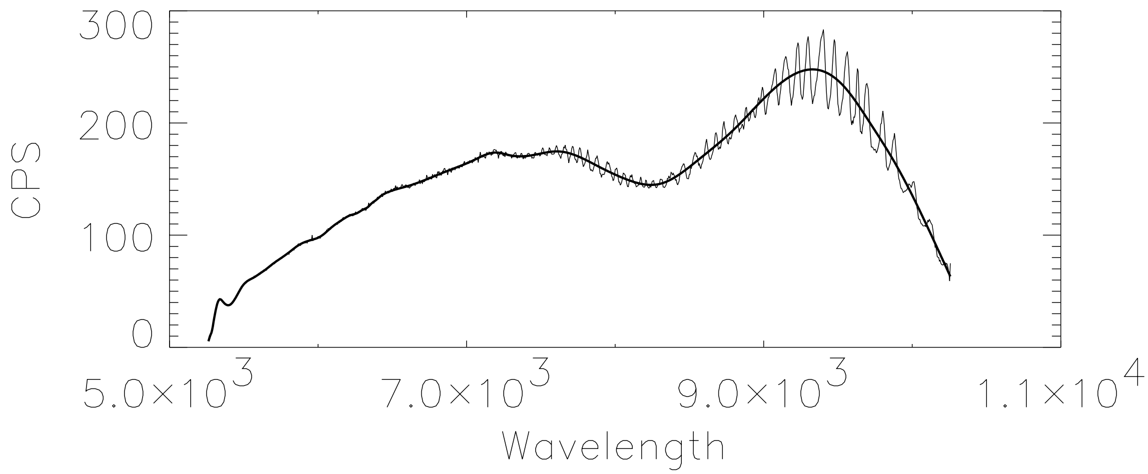

Figure 1. A single row of an unprocessed tungsten lamp observation (thin line) and the result of the spline fit (thick line, see section 2.2).

it can actually increase the amount of fringing. If possible, we always recommend taking a contemporaneous flat field with your observations.

2. Making the Flat Field

Assuming you have no flat field observation taken with your data, where should you start? Numerous long slit flat fields have been taken that are public data; a search of the Hubble Data Archive will find them (excellent software such as STARVIEW is available for searching the archive—use proposal ID 7642, 7063 or 7095 to find some of the tungsten lamp observations). A good example is observation O3TT42030, taken on May 21, 1997. This is a well-exposed tungsten lamp observation using the 52x0.1 arcsecond slit, and is what we use below as our example.

However, take care! Not all flats are the same. Unfortunately, two observations with even slightly different central wavelengths will have fringe patterns that do not shift identically. Grabbing any old tungsten lamp observation to make a flat field will not necessarily work, and *may make the situation worse.* The fringes *must* line up well with your observation, or else you might wind up dividing by fringes that are off by half a phase, making your problem twice as bad. Luckily, there is a relatively straightforward, if tedious, solution: download as many long slit tungsten lamp observations as you can find in the archive (at the time of this writing there are perhaps twenty), and cross correlate the fringes in each one with the fringes in your observation. You want the minimum shift, of course, but you must still be careful: a shift of more than 3 pixels means the tungsten lamp flat will not do a good job removing the fringing, even if the flat is shifted to compensate. Due to the limited number of tungsten lamp observations, however, you may not have a choice. If at all possible, you should take a contemporaneous tungsten lamp observation, and should also use a slit that is concentric with the slit used for your target observation. This ensures the central wavelength will not shift by very much.

Once a long slit lamp observation is obtained, some processing must be done to prepare it. Besides the usual processing, the lamp observation must be normalized to remove instrumental effects, which includes fitting the lamp function and removing scattered light, if necessary. When finished, the final flat field should contain the fringing pattern and the pixel–to–pixel variations, but not any of the broader STIS response patterns. It should also be normalized to unity.

2.1. Initial Processing

We recommend doing the initial processing of the tungsten lamp observation in the usual way; removing the cosmic rays and the dark and bias frames in your favorite manner. Some tungsten lamp observations have multiple readouts making cosmic ray removal easier. Divide the image by the clear aperture camera mode flat field to remove blemishes and other CCD related variations in the image; we do not want to fit these features. After the image has the lamp function removed, the camera flat will be multiplied back in. Hot pixels are a different issue from cosmic rays; the CALSTIS pipeline will remove known hot pixels, but the effects of "cooler" pixels may not be removed, and they can adversely affect the removal of the lamp function. For display purposes, we find that dividing the image by the boxcar smoothed image makes the remaining hot pixels stand out well. For our processing we replaced these pixels with the median value of a small box centered on the pixel in question.

2.2. Lamp Function

The lamp function is the response of STIS to the lamp versus wavelength, and removing it is the most difficult and tedious step of this processing. The lamp function can be seen in Figure 1 as the broad-ahumped shape of the plot. To remove it, we made a low-frequency spline fit to each row of the observation, which was then divided into the observation; in a sense flattening the observation. Care must be taken to fit all the broad features of the observation (including the large amplitude bump at the extreme blue end caused by the order blocker), but not the fringes or the pixel-to-pixel variations, which of course must remain for the image to be useful as a flat field. That is why the cooler hot pixels must be carefully removed—the spline fit will produce large amplitude ringing around any hot pixels remaining in the image. The sensitivity curves for STIS (Collins & Bohlin 1997) have the STIS response built into them, and will take care of the broader features.

We were able to produce excellent fits using a second order spline with about 50 nodes. The large number of nodes is needed to accurately sample the relatively rapid variations in the lamp function at the blue end of the observation. At the red end, nodes were placed much farther apart, so that the broad features, and not the fringes themselves, were fitted. Figure 2 shows the results of this processing along one of the rows. Note that the slit-occulting bars will not be fitted well, but these areas of the image will not normally be used in the processing of spectra anyway, so the poor fit is not important. When this processing step is done, multiply the image by the clear aperture camera mode flat field, to put the blemishes and other detector features back into the image.

2.3. Scattered Light

A point source spectrum will not usually have scattered light in it, but the long slit tungsten lamp observation will. The CCD has a substantial halo towards the red end, and light from one row of the chip will "leak" into adjacent rows. This adds a pedestal to the lamp observation which must be removed to model a point source flat field. For an extended target, it may be beneficial to leave this scatter in the flat field, but be warned that the scattering is wavelength dependent, and the tungsten lamp is not likely to have the same flux distribution as the source.

The lamp observation (normalized to unity by the removal of the lamp function) is a combination of wavelength-dependent features (i.e., the fringing) and wavelength-independent features (i.e., the pixel-to-pixel variations). The wavelength-independent fea-

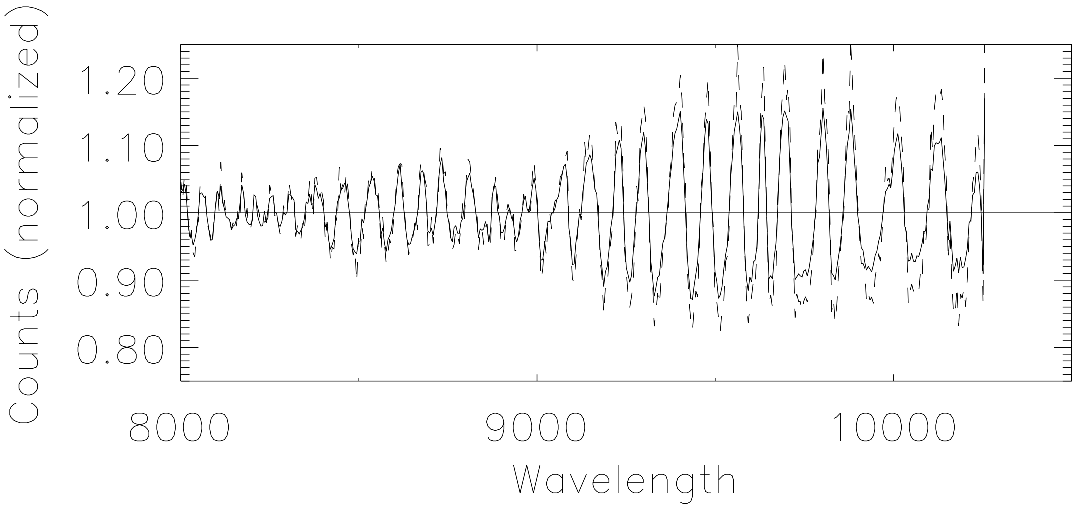

Figure 2. A single row of a processed tungsten lamp observation (solid line) and the same row with scattered light removed (dashed line, see Section 2.3).

tures may be more properly called "wavelength-averaged features" since the camera mode image will average the tungsten lamp spectrum over the detector's spectral range. The observation can then be represented mathematically as

$$F_{obs} \;=\; SL \;\times\; F_{cam} \;+\; (1-SL) \;\times\; F_{\lambda} \tag{1}$$

where F_{obs} is the observed tungsten lamp image, SL is the scattered light profile, F_{cam} is an image containing the wavelength independent features (that is, the clear aperture camera mode flat field, also available from the Data Archive), and F_{λ}—the final flat field and the goal of this whole process—is the image with the wavelength dependent features. The scattered light profile can be determined roughly by taking a cut across the lamp observation behind the slit's two occulting bars, normalized to cuts taken just above and below the occulting bars. We found that the scattered light profile was very similar in both bars, so we recommend simply averaging them to increase the signal-to-noise. As a test, we used different multiplicative constants on the scattered light function to check if we were under- or overestimating the profile, but found that simply taking a cut across the bars worked quite well.

The results of this operation can be seen in Figure 2, where a row from processed flat field is compared to the same row after scattered light removal. Note that after removing the scattered light, the amplitude of the fringes *increases.* This is because the pedestal has been removed, so the ratio of the amplitude goes up (a 10 count amplitude, for example, is negligible compared to a spectrum with 10000 counts per pixel, but is large if the spectrum has only 100 counts).

The final flat field, F_{λ}, should now contain only the fringing, pixel-to-pixel variations and blemish maps. Congratulations! You are ready to flat field your observation.

3. Applying Your New Flat, With An Example

To flat field the image, simply apply the flat as you normally would any flat field. The fringes in the flat may not line up perfectly with the fringes in the target observation, so it

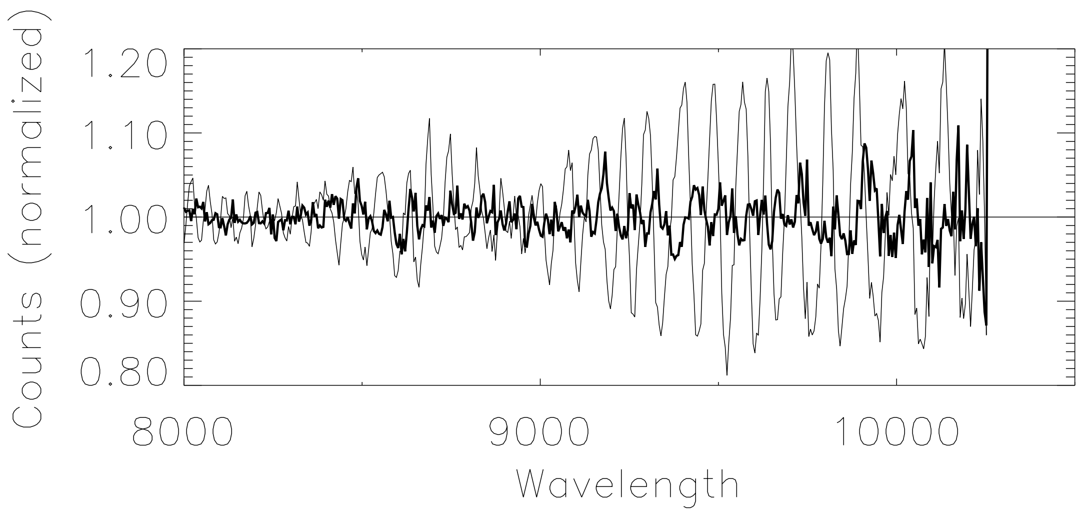

Figure 3. The un-flattened calibrated spectrum of GD153 (thin line) and the corresponding flattened spectrum (thick line).

is helpful to process the target observation with and without the flat field applied, to see just how well the fringes were removed.

You may find that you need to shift the flat field a bit to get the fringes to line up. A cross correlation of the fringes between your target and the processed flat field should yield an accurate shift (remember to keep it to 3 pixels or less). However, shifting the fringes also shifts any blemishes in the camera mode flat as well. Before shifting, divide by the camera mode flat, shift, then multiply the camera mode flat back in to keep the blemishes in the same place.

Using the method outlined above, we processed the flat field O3TT42030 to produce a fringe flat and applied it to the observation O3TT48040, a G750L spectrum of the photometric standard star GD153 (the same star used by Collins & Bohlin 1997 to determine the STIS sensitivity). Figure 3 shows the normalized spectrum of the star with and without the processed fringe flat field applied. The fringe amplitude dropped from an rms of 8% (from 7000 to 9000 Å) to ∼1.5% after flat fielding.

Note that the fringe removal is not complete, and adds some systematic noise to the spectrum. By comparing the spectrum calibrated without the flat field to the spectrum that did use the flat field, it is not hard to see what features arise from misaligned fringes. We strongly recommend making this comparison as a check on this.

4. Conclusions

A long slit tungsten lamp observation can be converted into a flat field that reduces the rms fringing in a STIS G750L observation from 8% to $\sim 1.5\%$. There are several pros and cons to this method:

PROS:

- Many tungsten lamp observations are available for processing.
- Multiple targets can be flat fielded simultaneously.
- Scattered light can be removed adequately for point source targets.
- This method is a reasonable substitute if no contemporaneous flat field was taken (although again we stress that a contemporaneous flat field should be taken if at all possible).

CONS:

- There may not be a tungsten lamp observation that matches your target observation fringe pattern.
- A shifting mismatch will make the fringing worse.
- Even a good match will leave some residuals that look like spectral features. A comparison between using the flat and using no flat is **strongly** recommended to identify such features.
- The processing needs to be meticulous and can be very time-consuming.

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References

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