Instrumentally-Induced Periodic Signal in IUE Images

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I. Introduction

It has been known for some time (see, e.g. Nichols-Bohlin 1988 and references therein) that images obtained with the *IUE* suffer from a periodic signal that is introduced by the instrument electronics, and is superimposed upon the science data. Nichols-Bohlin (1988) searched for these periodicities by performing fast Fourier transforms (FFTs) to a sum of many scan `lines` in UV-flood images. However, this approach assumes a pattern along the `sample` direction which is perfectly synchronized for each `line`, and it does not address the possibility of regular patterns along the `line` direction and patterns which are not rectilinear with respect to the raw image `samples` and `lines`. The approach adopted here is to perform 2-dimensional FFTs (2–D FFTs) to explore the possiblity of more complex periodicities in *IUE* images, and to determine their magnitude.

II. Methodology

Several UV-flood images for each camera were used, both singly and in sum (to yield higher signal-to-noise), to search for periodic signal. These images had been previously used to construct the intensity transfer functions (ITFs), and were selected for this study to ensure linearity and a fairly large number of counts in each pixel over essentially the entire image. The images were taken over a large interval in time and spanned a large range in temperature (THDA), and exposure level. While the effects of time and temperature on the registration of the periodic signal have not been studied explicitly, it might be expected to vary only in magnitude (i.e. to be fixed in raw space) if it is introduced by the readout electronics. This assumption will be discussed further in the next section.

A 512×512 subimage was extracted from the center (i.e. over the interval [128,128–639,639] inclusive) of each image. The subimage for each camera extended slightly beyond the target area (i.e. the corners did not contain data), but the dimensions of the subimages were an integer power of 2, which is necessary to apply the MIDAS routine `FFT/POWER`. This routine calculates a 2–D FFT and power spectrum of an input image.

III. Results and Interpretation

Each of the features in the 2–D FFTs were identified with the corresponding artifacts in the raw data images. The strongest signals in the FFT image are spikes (i.e. large signals with a width of one pixel) along both the first row and first column, which correspond to periodic signal that lies precisely along the **sample** and **line** directions in the raw images. Some non-rectilinear, low-amplitude, decaying sinusoidal pattern exists in the corners of all of the transformed images, however, which results solely from the rapid fall-off to zero DN of the data in the extreme corners of the raw sub-images. An additional artifact in all of the cameras manifests itself as a faint "cross-hatch" pattern on the raw UV-flood images. Although these grids are oriented differently for each camera (diagonally for the LWP and LWR, nearly rectilinearly for the SWP), they result from the way the fiber optics in the UV-converter are bundled. This grid manifests itself in the 2–D FFTs as a series of spikes (of 2–3 pixels in width) that decay in amplitude from the corners, and have exactly the same orientation as on the raw image.

These 2–D FFTs confirm the earlier results of Nichols-Bohlin (1988), in that they reveal strong two- and four-channel periodic signal along the `sample` direction, as shown in the lower half of Fig. 1. This pattern is also evident in a sum of many `lines` in a raw UV-Flood image. Eight-channel periodicity is also apparent in the SWP 2–D FFTs, although it is difficult to distinguish from the noise in single images. The 2–D FFTs also reveal a 2-channel periodicity in the `line` direction (i.e. orthogonal to the `sample` direction), as shown in the upper half of Fig. 1, which was somewhat unexpected.

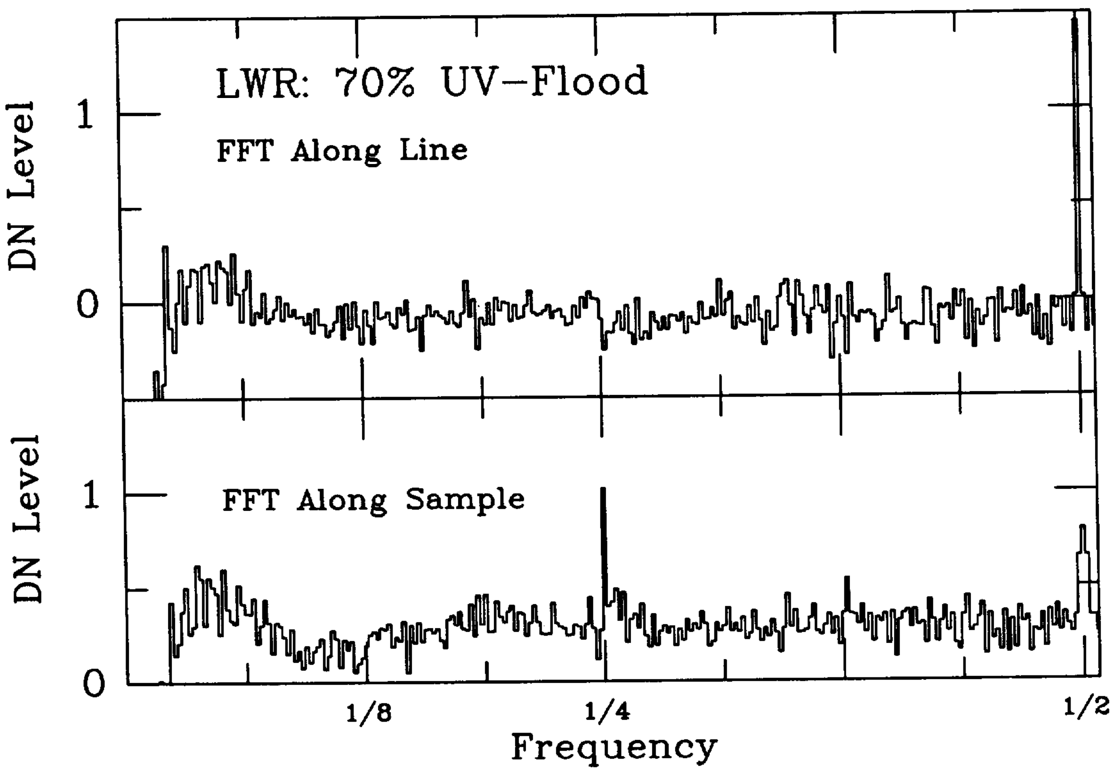

FIG. 1—Plot of the 2–D FFT of an LWR UV–Flood image along the first column (upper) and row, corresponding to the `line` and `sample` directions, respectively.

Despite using sums of many raw images in some of the experiments for each camera, the peaks in their FFTs are extremely sharp, and scale in strength roughly proportionately with the number of images used in the raw sum. Evidently, the periodic signal is well synchronized over a large range in both time and temperature, and is *independent of the geometric distortion.* Thus, if the signal is to be removed from an image, that image must be Fourier-filtered before any geometric or photometric correction can be applied.

IV. Amplitude of the Periodic Signal

The spikes corresponding to two- and four-channel periodic signal was filtered out of a 2–D FFT of a sum of LWR 60% UV-Floods and inverse transformed back to real space. The ratio of the filtered image to the unfiltered image, as Fig. 2 illustrates for one `sample` and `line` near the center of the image, showed that approximately 0.5 to 1.0 percent additional signal was introduced to these raw images at periodic intervals. Similar results were found for the 70% and 180% exposure levels for the LWR, implying that the periodic signal is multiplicative—i.e. that it is proportional to the DN level of the image.

In an effort to confirm the multiplicative nature of the phenomenon, the amplitude of the spikes in Fourier-space that correspond to two- and four-channel signal were measured for a series of summed images at varying exposure levels for all three cameras. The amplitude was measured relative to a "continuum" of nearby frequency bins, and it is linearly related to the magnitude of the periodic signal in real space. (It was these spikes that were removed when Fourier filtering.) If the periodic signal were strictly multiplicative, it should have a finite, though small, amplitude on null (i.e. zero-second exposure) images, owing to the small residual DN pedestal left by the camera preparation sequence. Figure 3 shows that the amplitude for both the `line` and `sample` directions increases linearly with the average DN level in LWR images (with some scatter, especially for the 180% UV-Floods which may suffer from some saturation). Curiously, the amplitude is *zero* in the `sample` direction for the null images for both the LWR and LWP cameras. However, when the *net* DN/pixel (i.e. the DN level above what the null pedestal contributes) is plotted for the `sample` direction in those cameras, as shown in Fig. 4 for the LWR, the correlations are much tighter. Although the amplitude for the SWP null images is non-zero in both the `line` and `sample` directions, it is not consistent with the linear relation defined by the other exposure levels. These results, together with the lack of correlation between the amplitude and number of summed images, show that the periodic signal is mostly multiplicative in nature, but that a small additive component may be present as well.

One final test was completed to confirm that the periodic signal is present in science images, and that it behaves as in UV-Flood images. A 512×512 subimage was extracted from both low- and high-dispersion exposures of a standard star

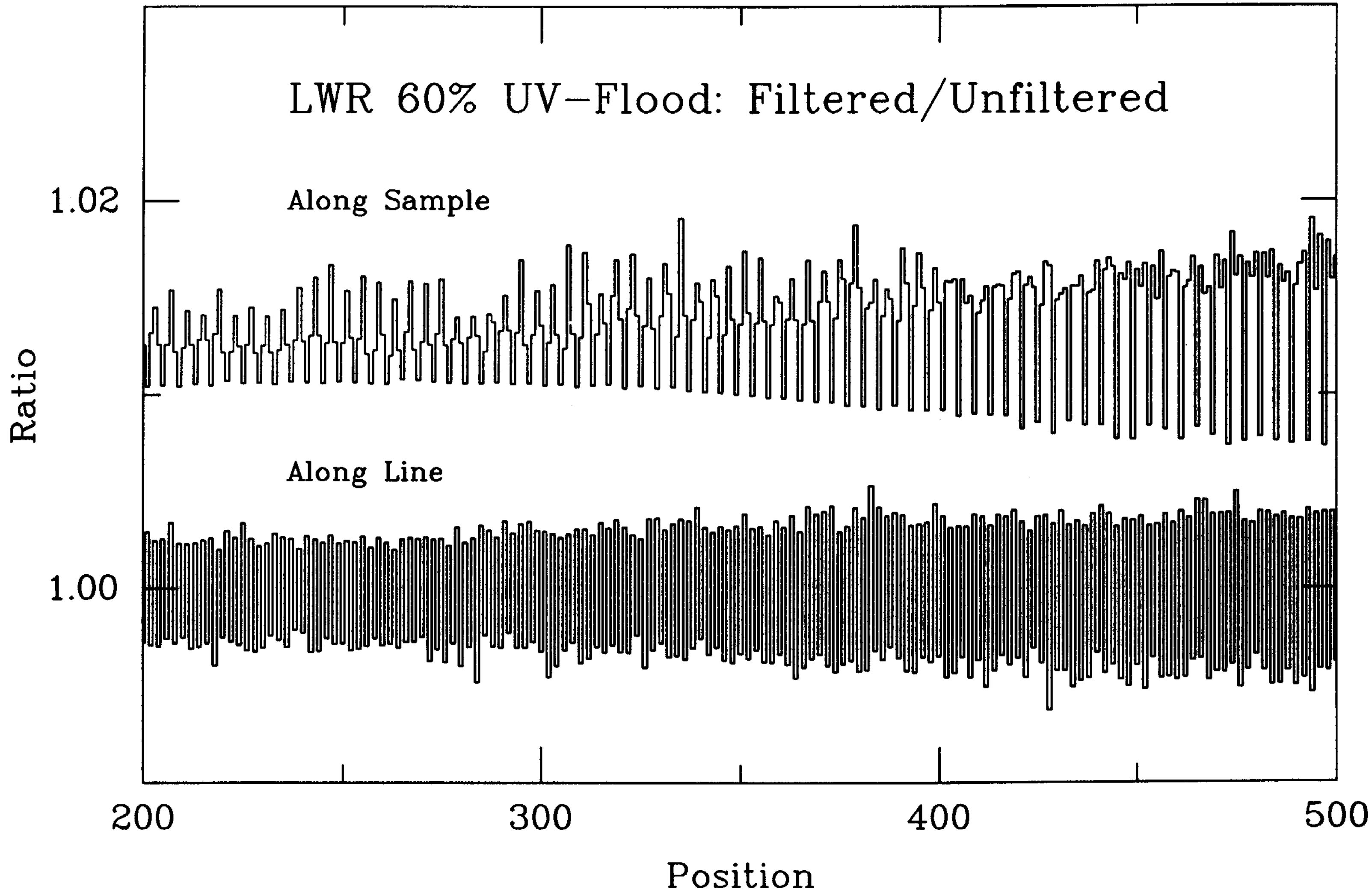

FIG. 2—Ratio of a Fourier-filtered to unfiltered LWR image along the `line` *(lower plot)* and `sample` *(upper plot)* directions. One percent has been added to the data in the upper plot for presentation.

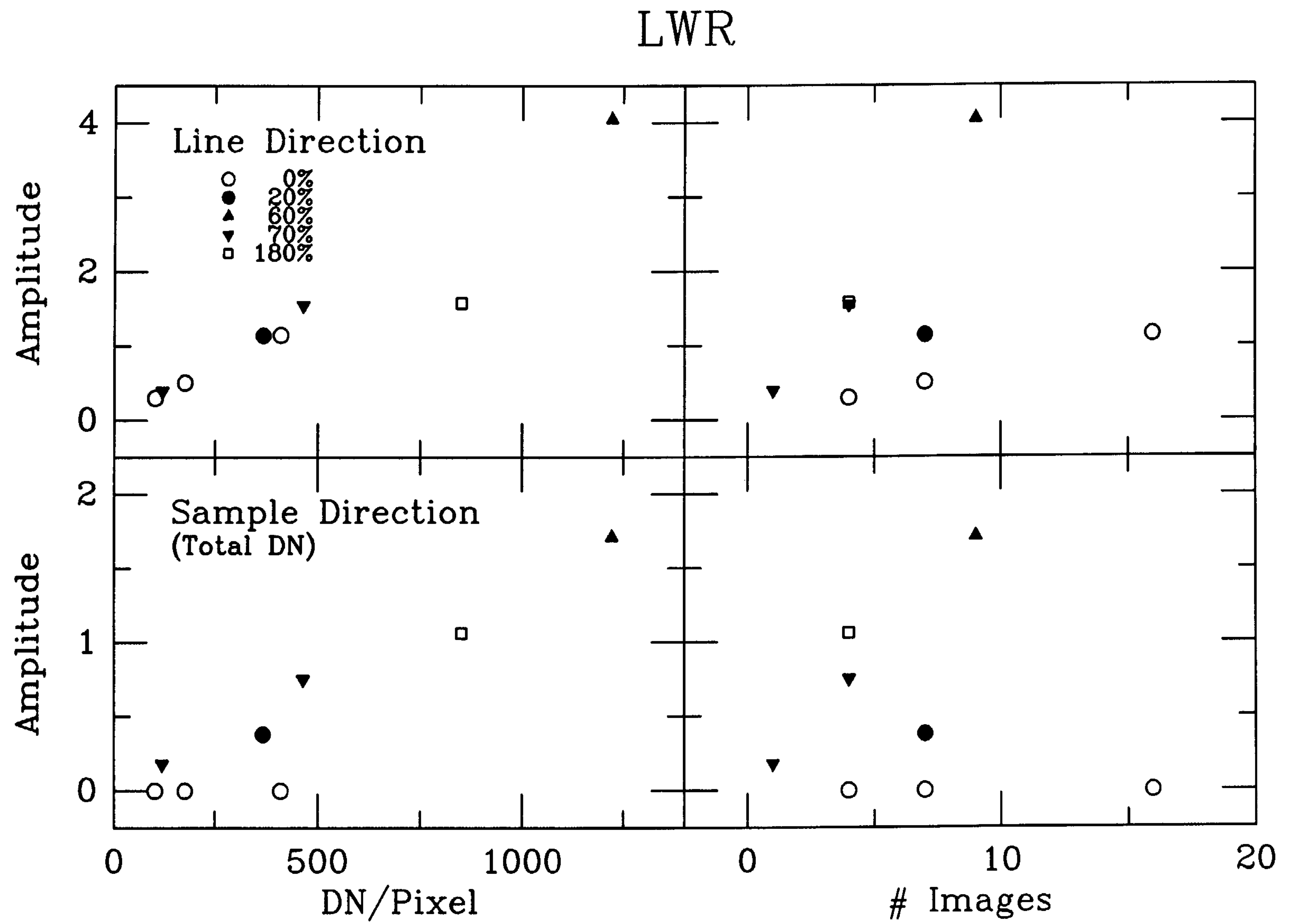

FIG. 3—Plot of the amplitude of the spikes in Fourier-space corresponding to two-point signal in the `line` direction *(upper plots)*, and four-point signal in the `sample` direction *(lower plots)*, *vs.* both the average DN per pixel *(left-hand plots)* and the number of raw LWR images summed before the transform *(right-hand plots)*.

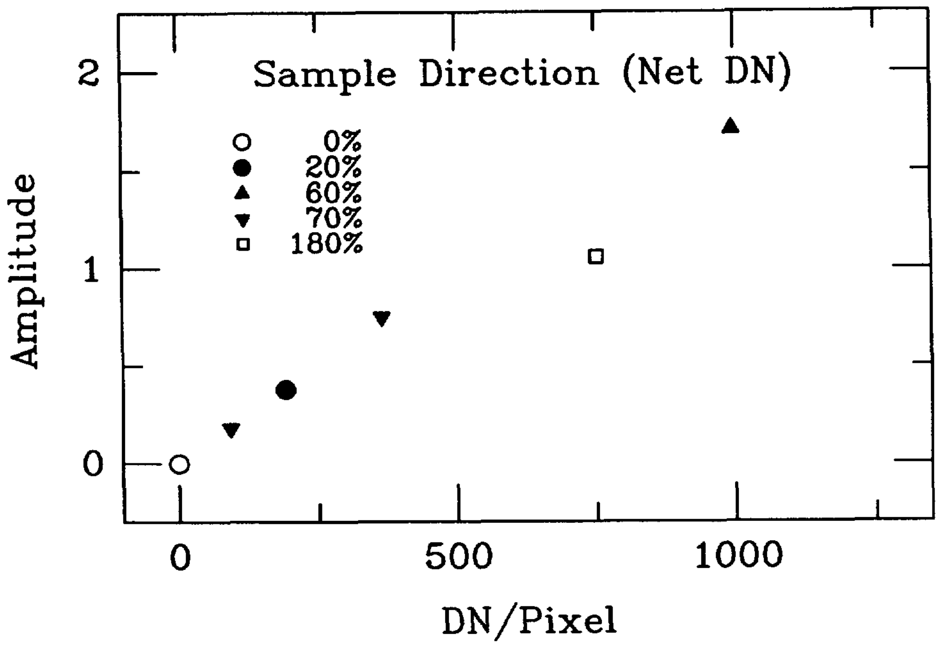

FIG. 4—Same as Fig. 3, except with *net* DN (i.e. DN/pixel above the contribution from the null pedistal).

(BD+28°4211) and Fourier transformed. The amplitudes of the two- and four-point spikes in the 2–D FFT are consistent with those expected from the mean DN levels of the standard star images and the linear relations found from the UV-Flood images.

V. Implications for Extracted Spectra

Several investigators, including Bohlin (1988), have shown that S/N in **extracted** spectra fails to increase with the square-root of the integration time, and that little improvement in S/N could be gained by adding more than about three or four *optimally exposed* spectra. Unfortunately, he was unable to address the question of whether the limiting S/N was encountered at a particular DN level (implying that the non-random noise is multiplicative) or after a certain number of spectra had been summed (implying additive noise). Bohlin's (1988) results suggest that the magnitude of a non-random component of the noise is $\sim 3\%$ (if it is multiplicative), which would indicate that the periodic signal is not the dominant source of noise.

In order to examine the nature of the non-random component(s) of the noise in *IUE* images, new *IUE* observations of a standard star have been arranged during upcoming engineering time; a total of 10 images at the 20% level and 5 images each at the 40% and 100% levels will be obtained. Summing the reduced spectra (separately for each exposure level) from the proposed observations should clarify whether the instrumentally induced periodic signal is an important limitation on the S/N in *IUE* data.

VI. Conclusions and Recommendations

It seems clear that two-, four-, and some eight-point periodic signal is present in all *IUE* images, and that it is instrumentally induced. The phase of the periodic signal is the same in all images, and it is constant in raw space. The signal is mostly multiplicative in nature, and is of order 1% of the signal in amplitude. While this amplitude is clearly not large enough to account for all of the non-random noise in *IUE* data, if the efforts to reduce other non-random components of noise are successful then periodic signal may become an important noise source. While periodic signal can easily be filtered from the images used to construct the ITFs for each camera, whether the amplitude of the periodic signal in science images can be determined sufficiently accurately for filtering will require further study.

Since the geometric correction for each of the ITF images is not in general the same, nor is that distortion necessarily the same between any ITF image and a science image, the ITFs should be reconstructed using Fourier-filtered images to avoid introducing additional non-random noise into the photometric correction of the science images.

References

Bohlin, R. 1988, *IUE Newsletter*, **34**, 10.

Nichols-Bohlin, J. 1988, *IUE Newsletter*, **34**, 57.