N87-21811

# A SEARCH FOR FAST VARIATIONS IN THE Fe XXI EMISSION DURING SOLAR FLARES

**Chung-Chieh Cheng**

E.O. Hulburt Center for Space Research
Naval Research Laboratory
Washington, DC 20375-5000

ABSTRACT. The main results are: 1) No periodic oscillation in Fe XXI emission detected. 2) The shortest timescale of rapid variation persistently present in the Fe XXI emission is about 20 sec. 3) Statistically significant isolated bursts of duration 3 to 5 sec are present in some of the flares.

## 1. INTRODUCTION

Observations have shown that the intensity of soft X-ray bursts from solar flares varies smoothly with a gradual rise and decay time profile. The timescales of soft X-ray burst variations range from minutes to hours. On the other hand, the impulsive hard X-ray bursts typically show fast variations and spiky time structures, with timescales as short as one tenth of a second (Hoyng et al., 1976; Kiplinger et al., 1983). Since the soft X-ray burst is generally regarded as the result of energy transfer from the hard X-ray electrons, either by direct heating or by the process of chromospheric evaporation, it is of interest to ask whether the fast variations observed in the impulsive hard X-ray burst are in any way reflected in soft X-ray bursts. Studies of the Fe XXV and Ca XIX emissions in solar flares obtained from the P78-1 (Doschek, Kreplin, and Feldman 1979, Doschek et al. 1980; Feldman et al. 1980) have shown that these emissions have a very smooth intensity profile, when observed with a time resolution of about 30 sec. During the SMM in 1980, many flares were observed in the UV line of Fe XXI at 1354 Å, which originates in plasmas with a temperature of about 10 million K. Examinations of high-time resolution Fe XXI observations generally show gradual rise and fall profiles, representative of typical soft X-ray bursts. However, these gradually varied time profiles do show intensity fluctuations. In this paper we make a quantitative study of the Fe XXI intensity variations, and assess whether the observed rapid fluctuations represent intrinsic variations in the emission or are just due to photon counting statistics.

## 2. DATA ANALYSIS

The Fe XXI observations were obtained with the Ultraviolet Spectrometer and Polarimeter (UVSP) on the SMM satellite. In order to study fast variations, we have chosen flares that were observed with a field of view of 30" x 30" and a slit size of 10" x 10". These 3 x 3 raster element images were taken every 1.215 seconds for a period of ten minutes. This time resolution was the highest observed by the UVSP in the Fe XXI mode. Out of 26 flares in the fast Fe XXI mode, 10 were observed from the beginning of the flare, and showed appreciable Fe XXI emission in the small field of view. These were chosen for analysis. Figure 1 (upper panel) shows an example of the time evolution of the Fe XXI emission in the 1 November 1980 flare at 1924 UT; the intensity is for the brightest pixel in the field of view (FOV).

Figure 1 shows there are large fluctuations superimposed on the generally gradual rise and fall profile. In all figures, the count rate is count per 0.063 sec. As is well known in photon detection and cosmic ray observations, such fluctuations are most often due to photon counting statistics rather than due to real signals. How does one determine whether the observed variation is

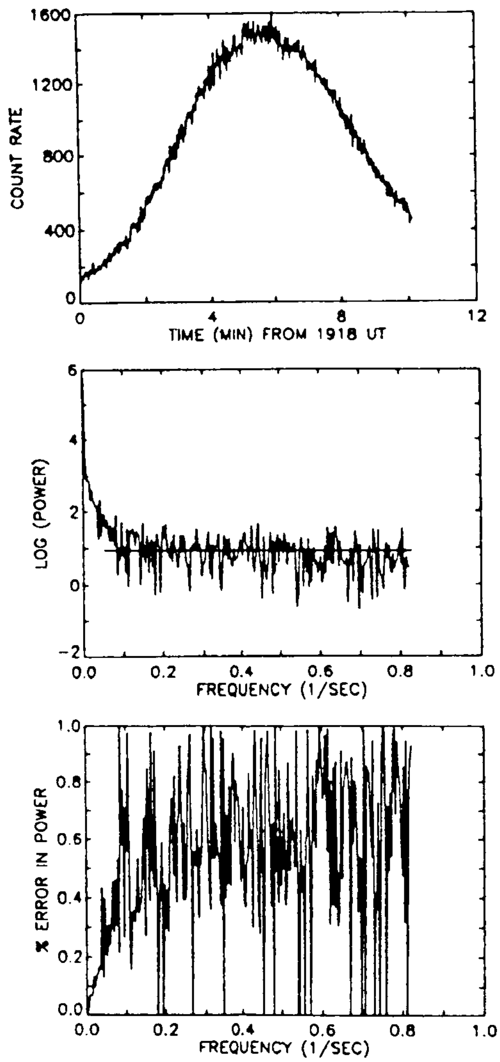

Figure 1

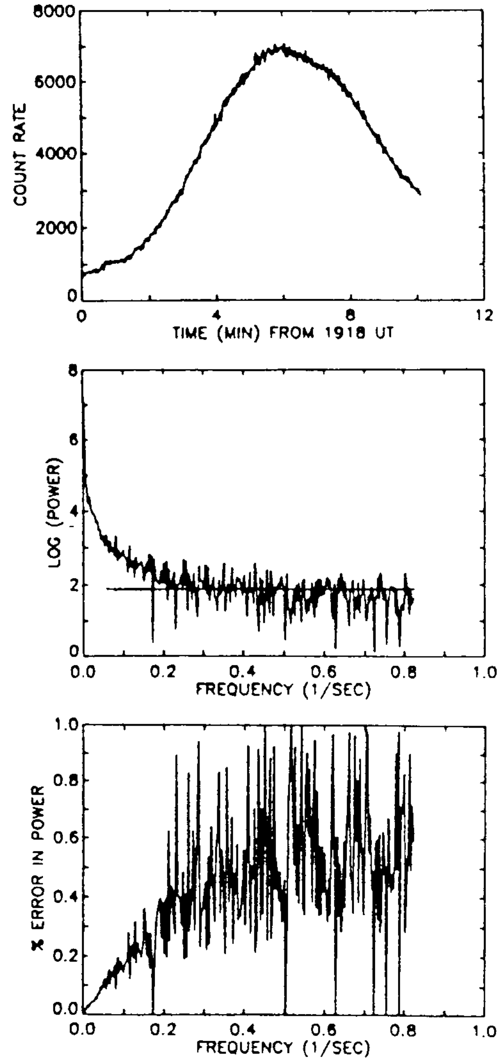

Figure 2

statistically significant in the inherently noisy data? If such fluctuation is real, what is its timescale? One technique to answer such questions is the use of Fourier power spectral analysis. This technique was used by Hoyng *et al.* (1976) and Brown, Loran, and MacKinnon (1985) to determine the shortest timescale present in solar impulsive hard X-ray bursts.

We have calculated the power spectra for the 10 flares selected for analysis, using a standard fast Fourier transform code. Since the analyses are the same for the flares we studied, we shall present calculations for three flares to illustrate the results.

In Figure 1 we have already shown the light curve for the brightest Fe XXI pixel in the FOV for the 1 November 1980 flare. The flare occurred in AR 2776 (NOVA designation), and is classified as a 1B in H$\alpha$ and M1 in soft X-ray. In H$\alpha$ the flare began at 1915 UT, reached maximum at 1922 UT, and ended at 1931 UT. The Fe XXI emission started to increase at 1918 UT and reached peak intensity at 1924 UT. Figure 1 also shows the power spectrum. As expected, the power spectra is dominated by the zero frequency component. The power decreases sharply towards higher frequencies and levels off at about the frequency $f = 0.2\ sec^{-1}$. The high frequency powers are dominated by random noises. Since the noise in the photon counting experiment generally obeys Poisson statistics, it is possible to calculate the expected level for the high frequency powers that are due to noise presented in the data. Hoyng (1976) has derived such an expression as well as calculated the relative error in a power spectrum for Poisson distribution. The horizontal line in the power spectrum graph is the calculated high frequency power expected from noise, and the relative error in the power spectrum as a function of frequency is shown in the lower panel of Figure 1. As can be seen, the power does not rise above the noise level until the frequency has decreased to below $f = 0.1\ sec^{-1}$. At $f = 0.1$ sec, the relative error in the power is about 30%, and the error approaches unity at high frequencies, again demonstrating the dominance of noise at high frequencies. Considering the errors involved in the power spectrum, it is only for $f < 0.05\ sec^{-1}$ do we see any appreciable power in the data. If we take $f = 0.05\ sec^{-1}$, where the error is relatively small, as the cut off frequency beyond which the power is due to noise, then the corresponding timescale is about 20 sec. We emphasize that this is the fluctuation timescale that is persistently present in the data that is not masked by noise. There are no isolated peaks in the power spectrum, indicating the absence of any periodic variations in the Fe XXI emission.

We also obtained the power spectrum for the total intensity of Fe XXI summed over the FOV. This is done to increase the count rate to improve its statistics. Figure 2 shows the total intensity variation, the power spectrum, and the relative error in the power spectrum. We see that the power spectrum rises above the noise level at the frequency about $f = 0.05\ sec^{-1}$ with relatively smaller error than that shown in Figure 1. This is because of the increased count rate and comparatively lower noise level. It is clear that for the 1 November flare, the shortest timescale persistently present in the data is about 20 sec. This timescale of variability is similar to those found for Fe XXV emission in some flares observed by the XRP instrument on *SMM* (Zarro, Strong, and Saba, 1985).

The detection of persistent variations in the Fe XXI emission by the Fourier analysis does not preclude the existence of isolated bursts that have timescales much shorter than those indicted by the Fourier Power spectrum. Close examination of the data shows there are isolated large changes; see Figures 1 and 2. To examine the reality of such isolated fast variations, we plotted the difference (absolute value) between the observed intensity and a calculated mean intensity (Figure 3). The calculated mean is obtained by a seventh power polynominal fitting of the observed data. Also plotted in the figure is the 3$\sigma$ level calculated from Poisson statistics for the observed data. Out of 500 intervals (a total time period of 10 minutes), there are about 22 intervals in which the observed intensities are above the 3$\sigma$ level. This represents a probability of 4.4% of occurrence of a signal that is above the mean. From the Poisson distribution, we know that the probabilty of occurrence of a 3$\sigma$ signal is 0.3% (Bevington, 1969). Therefore, the occurrence of a 3$\sigma$ signal above the mean in the observed data is 15 times greater than that indicated by the Poisson statistics. In other words, we would only expect less than 2 intervals in which the signal rises above the mean, if the 3$\sigma$ signals are purely random fluctuations. We can conclude that the observed fast variations, with large amplitudes, are statistically significant, and, to a reasonable degree of certainty, real. One particular isolated change with large variation can be seen in Figure 1 just before maximum intensity. The intensity jumps about 15% in about 4 sec. Other isolated bursts show similar timescales of fast variation. We emphasize that the existence of isolated fast bursts in our data should only be understood in the statistical sense.

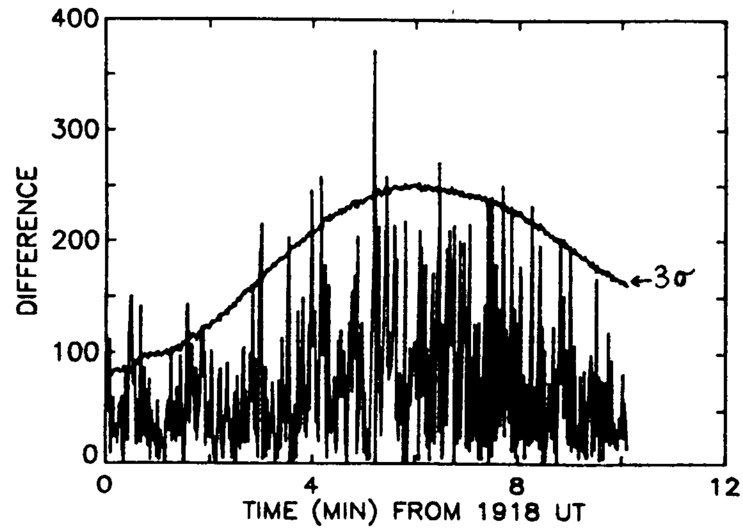


Figure 3

In Figure 4 we present the Fe XXI light curve for the whole raster as well as its power spectrum for the 6 November 1980 flare. This flare occurred in AR 2779 which in H$\alpha$ started at 1228, reached maximum at 1236, and ended at 1258 UT. The H$\alpha$ class is unknown but the X-ray class is M3. The Fe XXI observations started at 1232 UT and continued until 1233 UT. The FOV of the UVSP covered only part of the flare. The figure shows that the shortest timescale of fluctuations in the Fe XXI emission is about 20 sec, corresponding to a cutoff frequency of about 0.05 sec.

Another example of the Fourier analysis of the Fe XXI emission is the 11 November 1980 flare. This flare also occurred in AR 2779. It was a SN flare in H$\alpha$ , which started at 0625 UT, peaked at 0632 UT, and ended 0645 UT. In

X-ray, the flare was a M1. The Fe XXI observation started at 0628 UT and lasted for 10 minutes. This flare is interesting in that the FOV of the fast Fe XXI mode covered an area located at the top of the flaring loop (Cheng and Pallavicini, 1985). In Figure 5, we show the total Fe XXI intensity and its power spectrum. The power rises above the noise level at about f = 0.1 $sec^{-1}$, which gives a time scale of 10 sec. The relative error at f = 0.1 $sec^{-1}$ is about 10% (Figure 5). When the light curve of the brightest pixel is Fourier analyzed, as shown in Figure 6, the cutoff frequency that can be identified in the power spectrum is about f = 0.05 $sec^{-1}$, corresponding to a period of about 20 sec. For this flare there are 3 intervals out of 500 that are 3$\sigma$ above the mean. This is what is expected from the Poisson statistics, and therefore, we would not claim that the isolated large variations in the data are real.

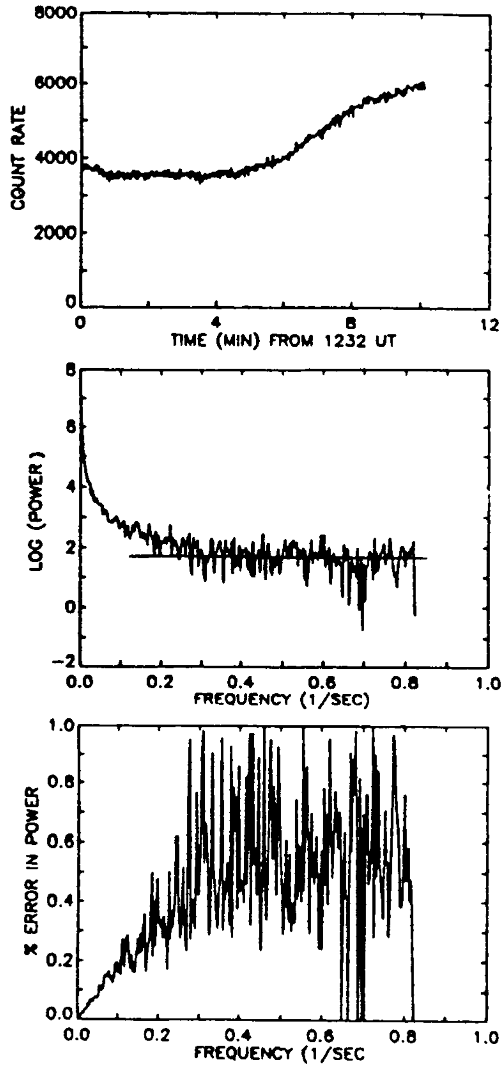


Figure 4

## 3. SUMMARY AND DISCUSSIONS

We have made a search for fast variations in the Fe XXI emission for ten flares using the Fourier analysis. Examples of three flares were described in the previous section. Here we summarize the main results:

1) We do not detect any periodic oscillation in the Fe XXI emission in any of the flares studied.

2) The shortest timescale of rapid variation, persistently present, in the Fe XXI emission is about 20 sec or longer.

3) Statistically significant isolated bursts of 3 to 5 sec duration are found in some of the flares. These isolated bursts, superimposed on the general gradual time profile of the Fe XXI emission, have an intensity variation from the mean by as much as 15%.

The main purpose of the paper is to find the shortest timescale, persistently present, in the Fe XXI emitting plasma. A timescale of about 20 sec in the Fe XXI emission is considerably greater than the subsecond variation found for the impulsive hard X-ray bursts (Kiplinger et al. 1983). If the heating of the Fe XXI emitting plasma or the soft X-ray emitting plasma is due to the energy deposition of the energetic electrons responsible for the impulsive hard X-ray burst, as is commonly assumed, then there might be some is due to the energy deposition of the energetic electrons responsible for the impulsive hard X-ray burst, as is commonly assumed, then there might be some

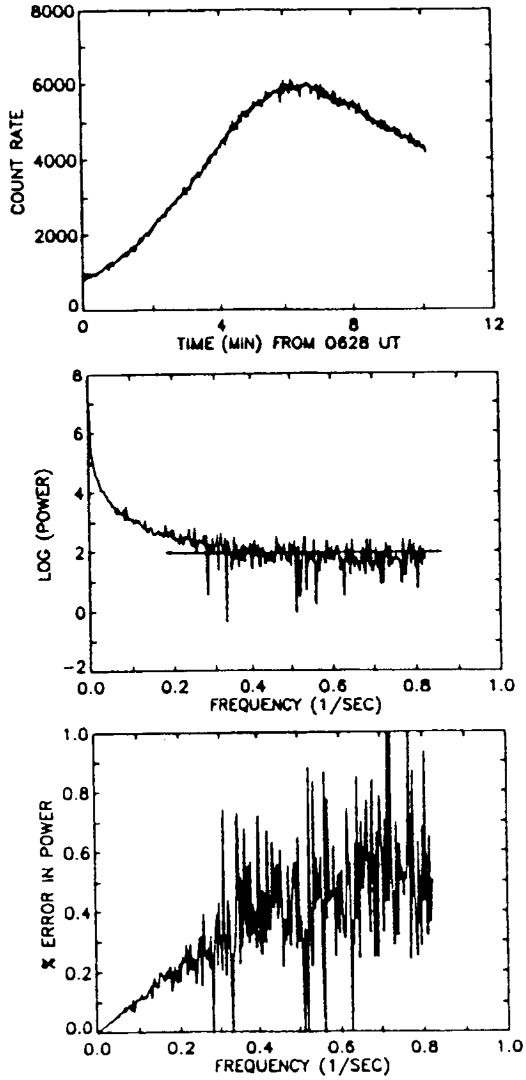


Figure 5

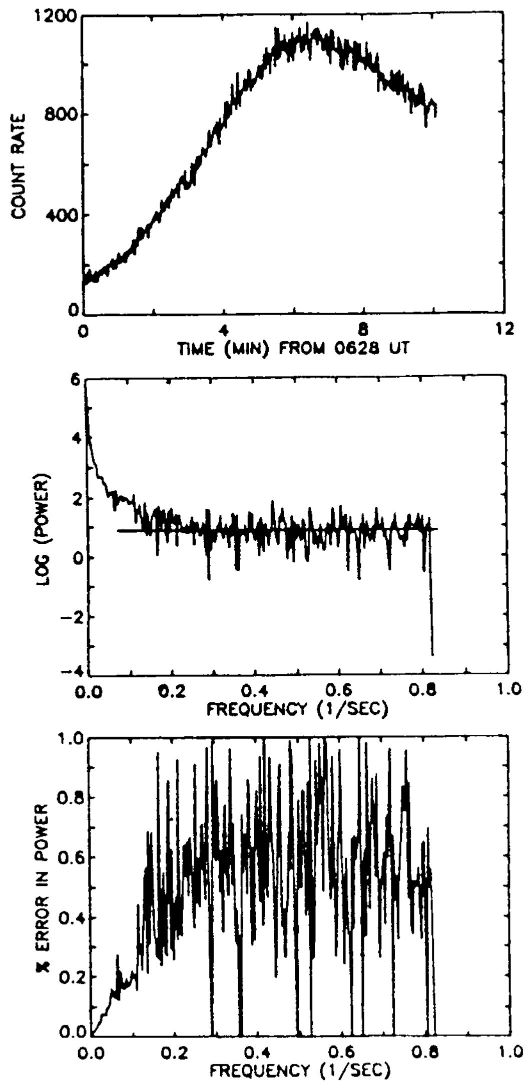


Figure 6

causal relationship between the time variations of the two components. We note that the chromospheric evaporation, which in the electron deposition model is the mechanism by which the soft X-ray bursts are powered, begins within seconds after the electron beam has heated the chromosphere (see, for example, Fisher et al. 1985; MacNeice et. al. 1984). If a variable electron beam is responsible for the fast variations in hard X-ray bursts, then we would also expect the thermal response of the chromosphere in the form of evaporation to vary accordingly, thereby manifested in the variations of the soft X-ray emissions. We then might expect to find intensity variation on the order of seconds in the Fe XXI emission. As we have seen, the shortest time scale of variation we found in our data is about 20 sec. Since the energy transfer process and the thermal response of the chromosphere are complicated and are not precisely known, it is difficult, at the present time, to conclude whether the timescales we found for the Fe XXI emitting plasma are due to variations in the electron energy depositions. A better understanding of the timing relationship between the various emission components in the electron energy deposition model has to wait for more realistic numerical calculations (see Canfield et al. 1986).

This work is supported in part by NASA under Contract DPR W-15367.

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