The Effects of Pileup on RHESSI X-ray Imaging

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ABSTRACT

Pulse-pileup is a pervasive problem during periods of high counting rate during solar flares. When two photons lose energy in the detector within some short time window they create an energy loss equal to the sum of the two energies. That is pileup. The RHESSI time window is about 1 microsecond. The bulk of piling up photons are at low energy but they can combine with similar energies, higher energy flare photons, and even background unmodulated photons. The distortion created by pulse-pileup is non-linear, the fraction of mis-measured photons depends, to first order, on the square of the counting rate. Since RHESSI imaging depends upon modulation the problem becomes more difficult. So we must investigate the potential for hidden distortions caused by pileup when we attempt to make a series of images as a function of photon energy. We show a simulation of a single low energy coronal source and two high energy footpoints over a range of intensities in all three sources. We show the reconstructed images and extracted featured resolved spectra with no pileup and cases of low, moderate, and extreme pileup. This is a repeat of an earlier study and not yet optimized for September 2017 events.

FIGURE 1 Ground Test Spectrum with Pileup

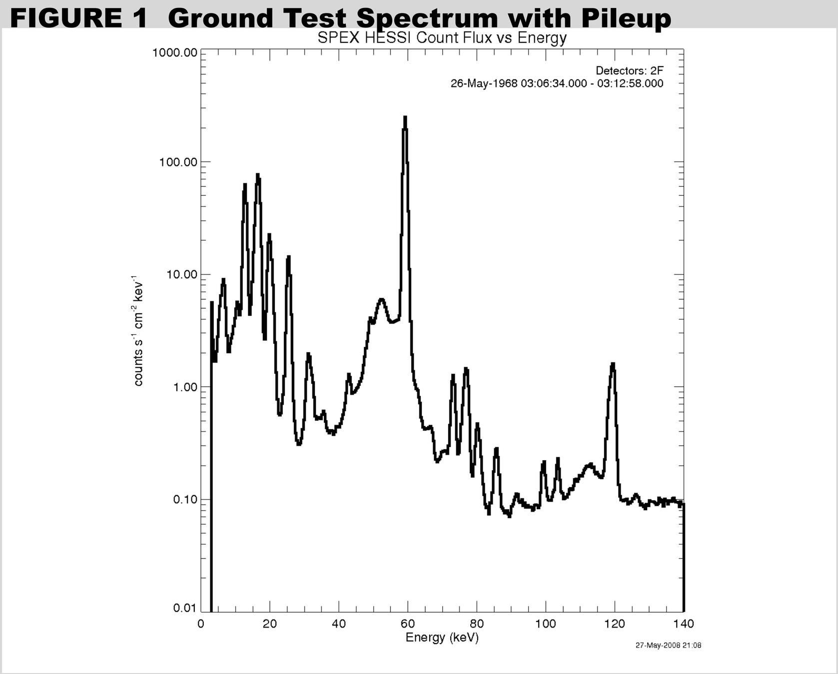

Fig 1 shows a RHESSI ground test spectrum of an Am241 radioisotope with xray lines from 12-20 keV and a strong nuclear line at 59.5 keV. The effect of pileup is clearly seen with the xray lines adding to the strong 59.5 keV line between 70 and 80 keV. The pileup of the strong line with itself is shown in the strong feature at 119 keV.

FIGURE 2 Source Maps

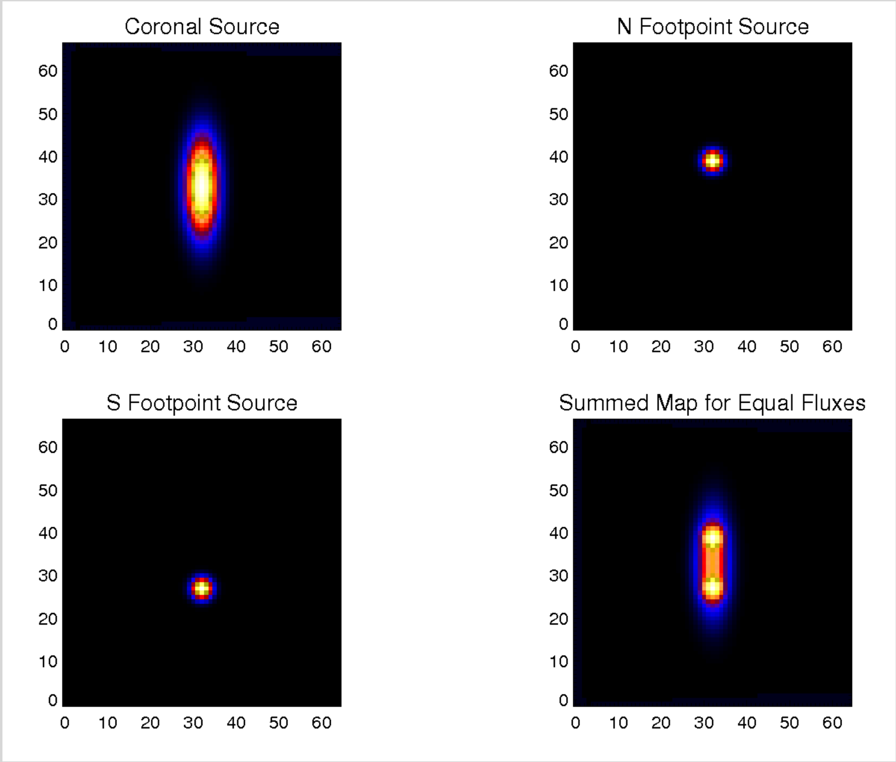

FIG 2 shows the source model used in these simulations. A thermal xray source that we call coronal is used to cover two non-thermal sources anchored on two footpoints on either side of the softer source. The three sources are summed in the bottom right with equal fluxes. At low energies the thermal source dominates and at higher energies above 20 keV the non-thermal sources dominate as is typical of the impulsive peaks of many flares.

Figure 3 Time Averaged Spectra Detector 8

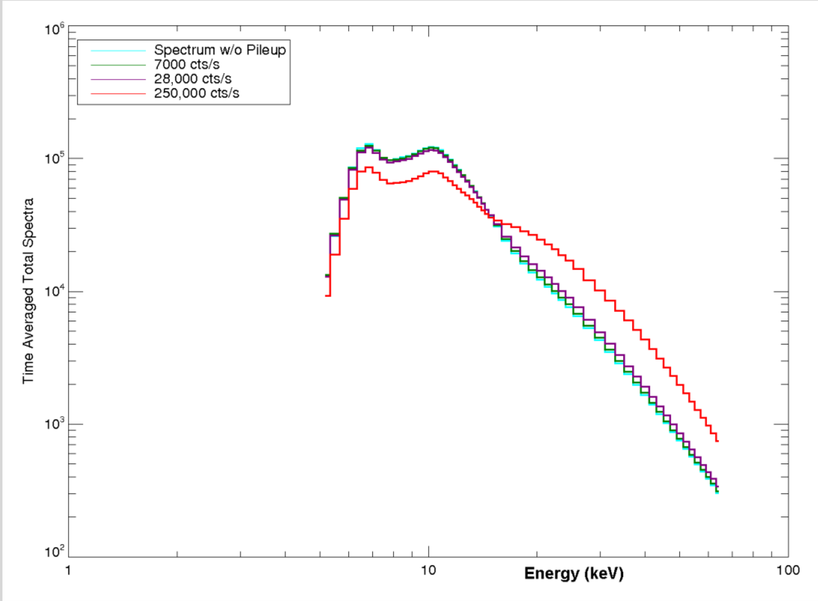

Fig 3 shows the simulated count rate spectra in RHESSI detector 8 with no pileup and with pileup for three total averaged detector count rates of 7000, 28,000, and 252,000 counts/sec. The thin attenuator is in. The spectra have been normalized to 7000 cts/s to show any pileup effects. Most flare rates are less than 20,000 cts/s/det.

Figure 4 Modulated Counts Detector 8 at 20.5 keV

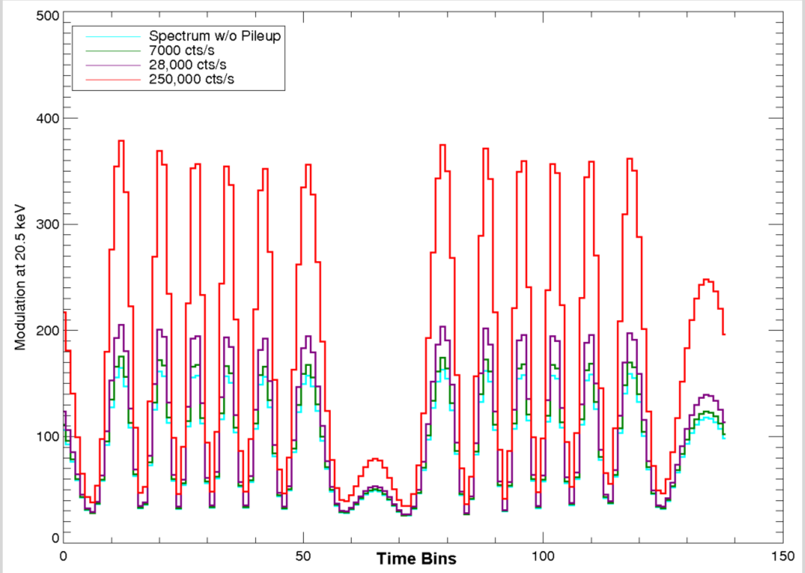

Fig 4 shows the simulated grid-modulated light curve at 20.5 keV in detector 8 with and without pileup. This energy is at about twice the peak of the count rate spectrum and is most sensitive to pileup. Pileup scales as the square of the count rate so is amplified at the peaks.

Figure 5 Modulated Counts Detector 8 at 7 keV

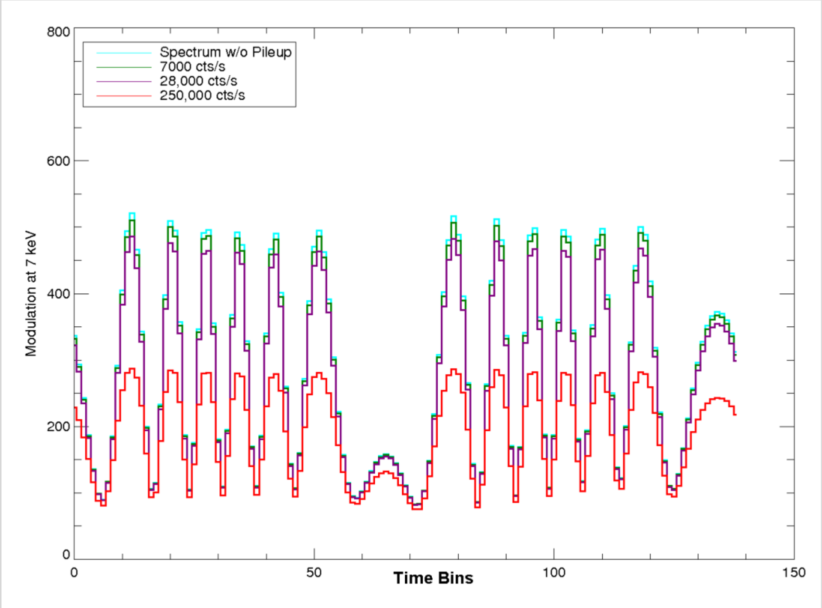

Fig 5 shows the simulated grid modulated light curve at 7 keV in detector 8 with and without pileup. This energy below the peak of the count rate spectrum so the effect of pileup is to depress the count rates as photons are promoted out of this band to higher energies.

Figures 6 & 7 Clean Maps with four levels of Pileup

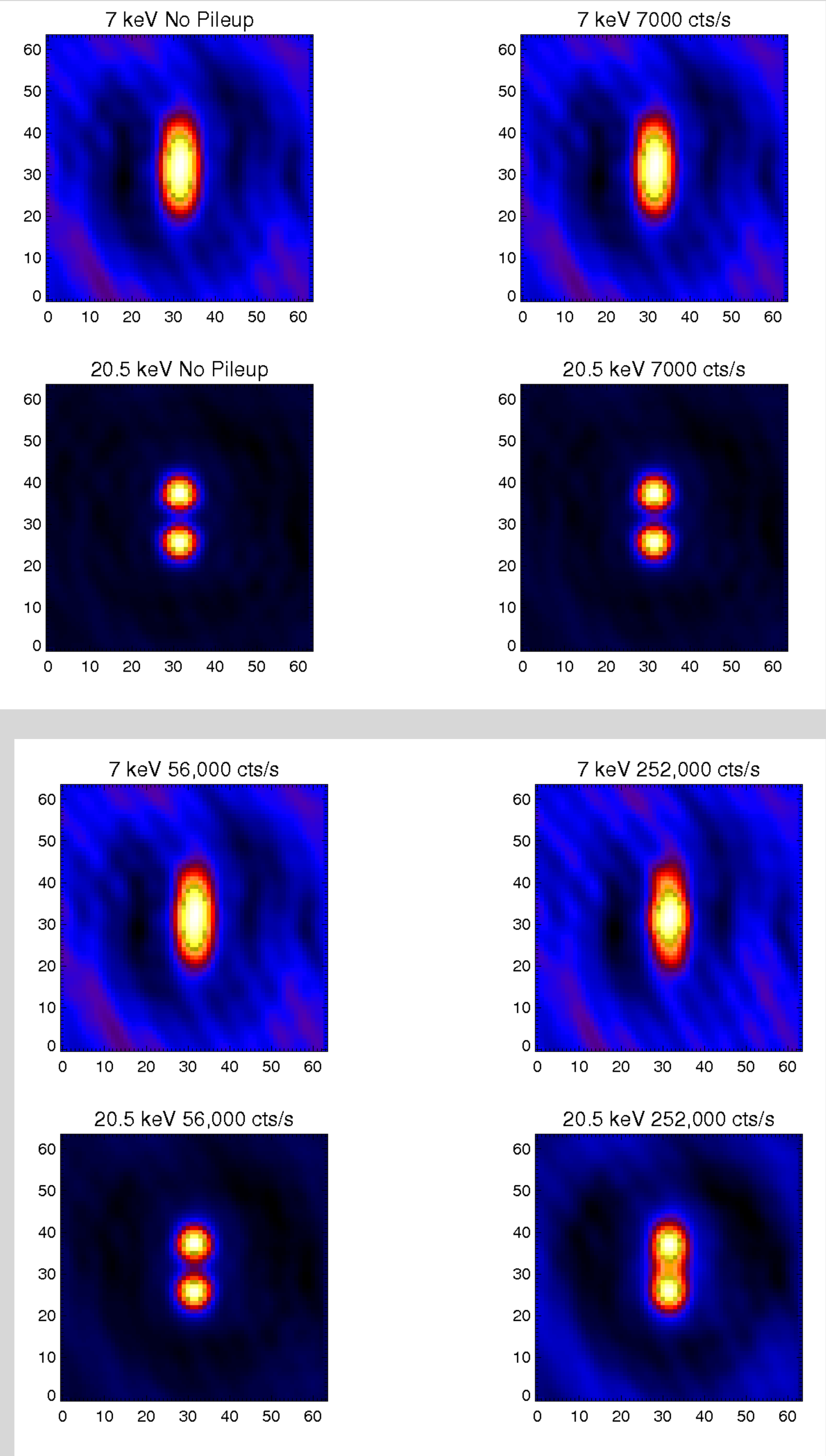

Fig 6&7 shows the maps at 7 and 20.5 keV generated using the standard RHESSI Clean algorithm using detectors 3-8. Even at average rates as high at 56,000 cts/sec there is little effect at 20.5 keV, where pileup is worst.

Figure 8 Footpoint Spectra from Clean Maps

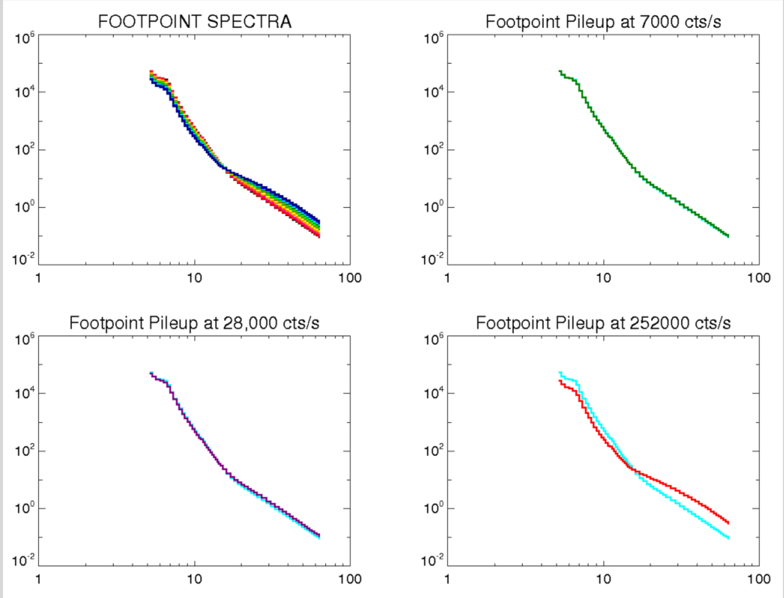

Fig 8 shows the spectra extracted from the map footpoints at all 60 energies used for all of our cases. The third figure for 28,000 cts/s shows a spectrum with only minor distortion for the typical worst case rate in a large flare. The extreme case in the bottom right has only occurred for a few minutes during the mission to date.

Figure 9 Spectral Deviations in Footpoints due to Pileup

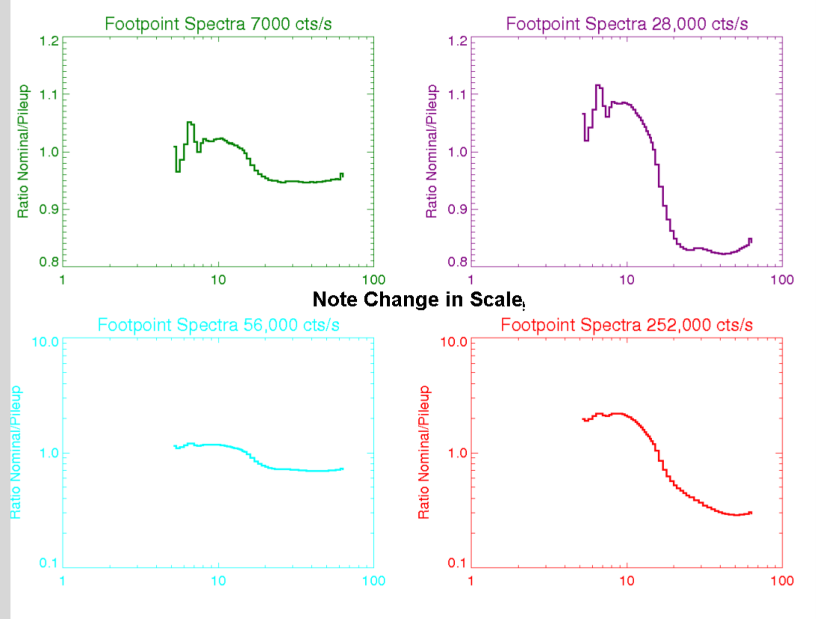

Fig 9 shows the deviation in the extracted footpoint spectra due to pileup for four averaged count rates. Note that the figure for 28,000 cts/s is shown with an expanded scale. The maximum spectral distortion occurs at about twice the peak of the counting rate as expected based on the probabilistic model of pileup. At higher energies the effect of pileup mainly enhances the flux but doesn't change the spectrum.

Summary and Conclusions

This simulation of pileup on imaging with RHESSI suggests some caution must be used in interpreting spectra extracted from images because of the possible effects of pileup. This is the first study, before there were no tools available to simulate the effects of pileup on region based imaging spectroscopy only on detector averaged spectroscopy. The good news is that the effect is only important when considering the detailed shape of the spectrum, and then only in a limited region below 20-30 keV. However, that is the most important energy range for many studies. Avoiding obvious degenerate cases where steep thermal fluxes produce ghost images because of no real photons, the effect on image morphology is usually small. In the future the tools developed for this study will be enhanced and made generally available and user-friendly.