PCA Pile-up and the Impact on the Energy Spectrum of GRO J1655-40

J.A. Tomsick, P. Kaaret
Department of Physics and Columbia Astrophysics Laboratory, Columbia University, 550 W. 120th Street, New York, NY 10027

1. Pile-up Correction

This section describes the method used to correct for pile-up in the PCA energy spectrum. We define A_i to be the PCA spectrum in counts per second after a correction for deadtime but with no correction for pile-up. The index i runs over the channels in the energy spectrum ($0 \leq i \leq 255$). B_i is the spectrum after correction for pile-up. The time window for the occurrence of pile-up is denoted by τ. For a given channel, the pile-up corrected spectrum can be written as,

$$B_i = A_i - \tau \sum_{k=1}^{i-1} A_k A_{i-k} + 2\tau A_i \sum_{k=0}^{255} A_k \tag{1}$$

where the second term in Equation 1 accounts for the the counts added to the spectrum due to pile-up and the third term accounts for those removed due to pile-up.

The following assumptions are made in the derivation of Equation 1:
1. Only the effect of single pile-up is considered (i.e. $\tau A_i << 1$).
2. We assume a linear energy scale (i.e. pile-up of signals at channels i and j give a count at channel $i + j$).
3. Due to signal decay between the first and second events, the pile-up peak will be smeared out by an amount that depends on the time constant for the decay and the time window for pile-up. We are neglecting this effect.

2. Testing the Pile-up Correction

The code used to calculate the pile-up correction has been tested by comparing the predicted pile-up count rate to the pile-up count rates reported in Jahoda et al. (1996) using test pulse measurements. Table 1 shows the pile-up rates and inferred values for τ from Jahoda et al. (1996). Table 2 shows the pile-up rates predicted by Equation 1 for specific input rates and values for τ. Using the same input rates as were used for the pulser tests, τ was adjusted to give the pile-up rates measured during the pulser tests. The values of τ found are close to those inferred from the pulser measurements, indicating that the pile-up rates predicted by Equation 1 are in agreement with the pulser measurements. The last two lines in Table 2 show the predicted pile-up rates when τ is set to 1.84 microseconds. From the predicted pile-up rates, we conclude that it should be adequate to use 1.84 microseconds for τ. Figure 1b shows the pile-up rate predicted by term 2 of Equation 1 for the input spectrum shown in Figure 1a.

The code has also been tested by checking that r, which is defined as $\tau(\sum_{k=0}^{255} A_k)^2$, is equal to the total count rate added to the spectrum to correct for pile-up. For the GRO J1655-40 spectrum measured by Anode 1R of PCU 0, Figure 2 shows the separate contributions to Equation 1 from terms 2 and 3. The total count rate on Anode 1R is about 3600 s^{-1} giving $r = 24$ for $\tau = 1.84$ microseconds. Term 3 of Equation 1 gives a total of 48 counts added to the spectrum, while term 2 of Equation 1 gives a total of

24 counts subtracted from the spectrum. Thus, the net number of counts added to the spectrum is 24, in agreement with the expected value for r.

3. Impact on the GRO J1655-40 Energy Spectrum

At times during its 1996 outburst, GRO J1655-40 produced a count rate of about 30,000 s^{-1} in the PCA (2-60 keV), corresponding to about 3200 s^{-1} on each layer 1 anode. After correcting for deadtime, this corresponds to about 3600 s^{-1} on each layer 1 anode. Figure 3a shows the PCA energy spectrum for GRO J1655-40 for one layer 1 anode after the deadtime correction is applied. The 129 channel PCA Standard 2 spectrum has been rebinned to 256 bins. Figure 3b shows the pile-up spectrum (i.e. the spectrum predicted by terms 2 and 3 of Equation 1) for the spectrum shown in Figure 3a. Figure 3c shows the ratio of the pile-up spectrum to the spectrum shown in Figure 3a. The ratio reaches a maximum of 5% near channel 50, indicating that pile-up may have a significant impact on the GRO J1655-40 spectrum.

Figure 4 shows a fit to the GRO J1655-40 energy spectrum before correcting for pile-up using a diskbb+bbody+powerlaw model. Previously published GRO J1655-40 energy spectra have been fit with a model consisting only of a diskbb+powerlaw model. However, for this spectrum, the bbody component is necessary to adequately fit the spectrum. For comparison, the positive part of the pile-up spectrum is shown. Although the contribution due to pile-up is similar in shape and energy to the bbody component, the pile-up spectrum is about a factor of 6 lower than the bbody component.

REFERENCES

Jahoda, K., Swank, J.H., Giles, A.B., Stark, M.J., Strohmayer, T., Zhang, W., Morgan, E.H. 1996, SPIE 2808, 59

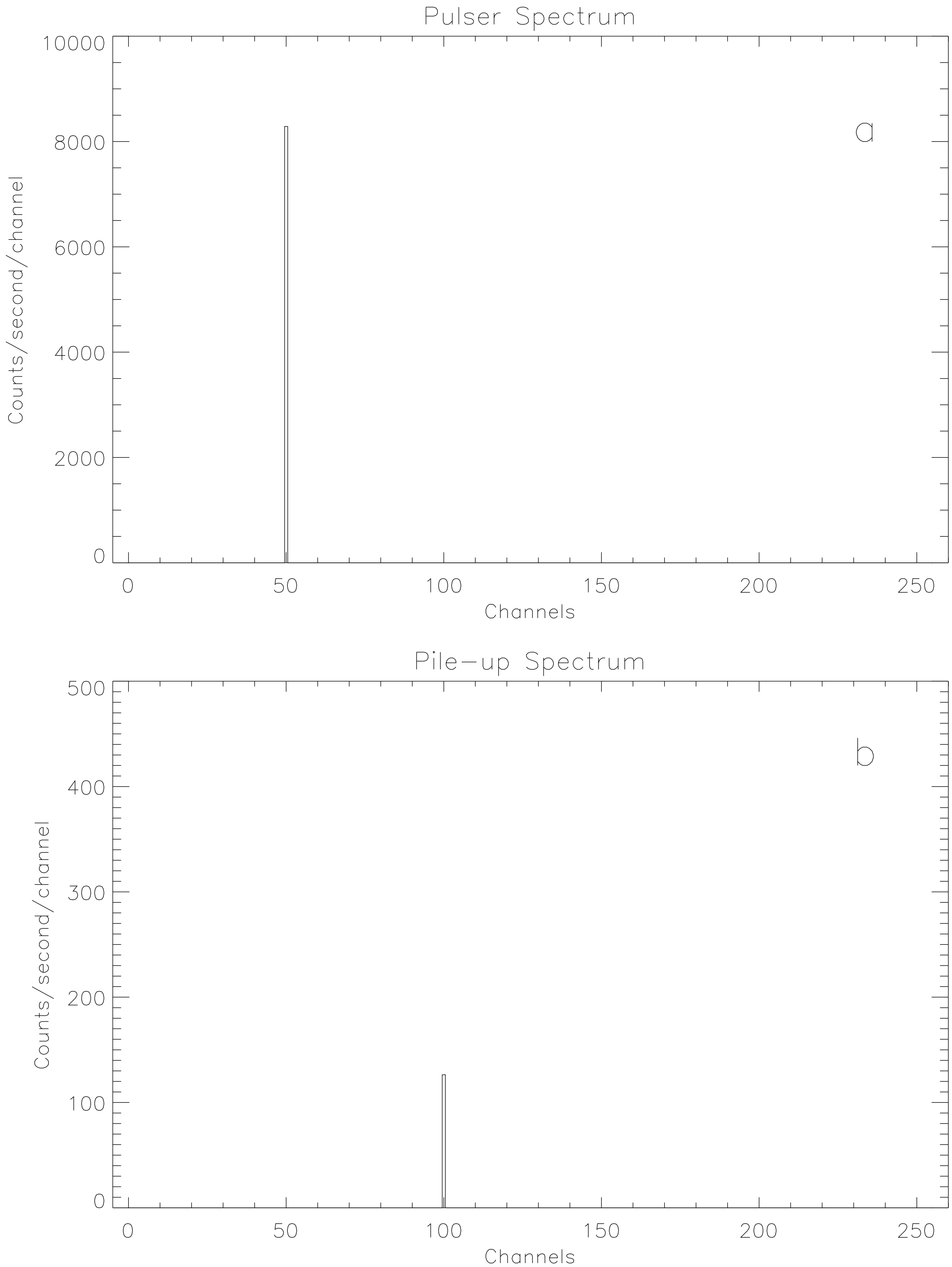

Fig. 1.— (b) shows the pile-up rate predicted by Equation 1 for the input spectrum shown in (a) and a pile-up time window (τ) of 1.84 microseconds.

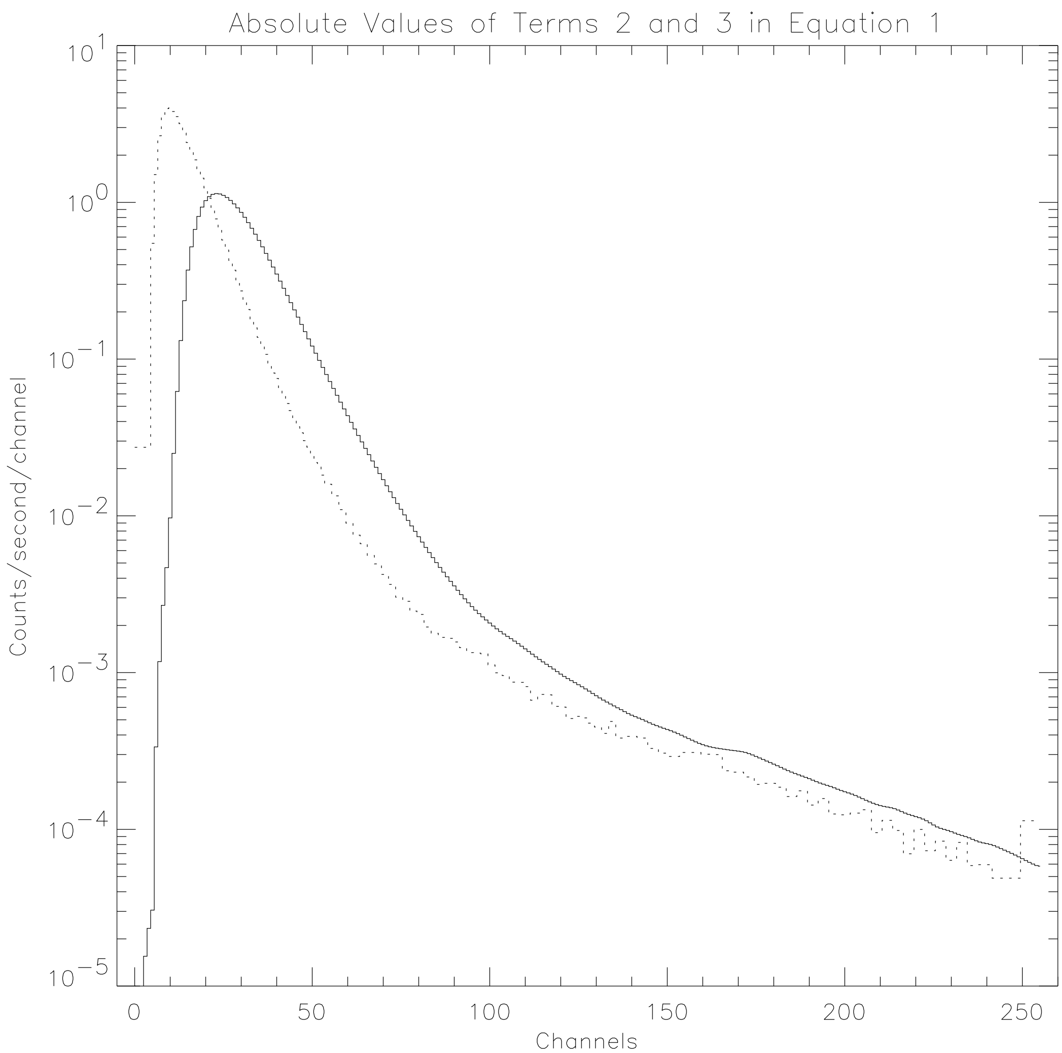

Fig. 2.— The contributions of terms 2 and 3 of Equation 1 for the GRO J1655-40 spectrum measured by Anode 1R of PCU 0. The dashed line is the spectrum predicted by term 3, and the solid line is the spectrum predicted by term 2.

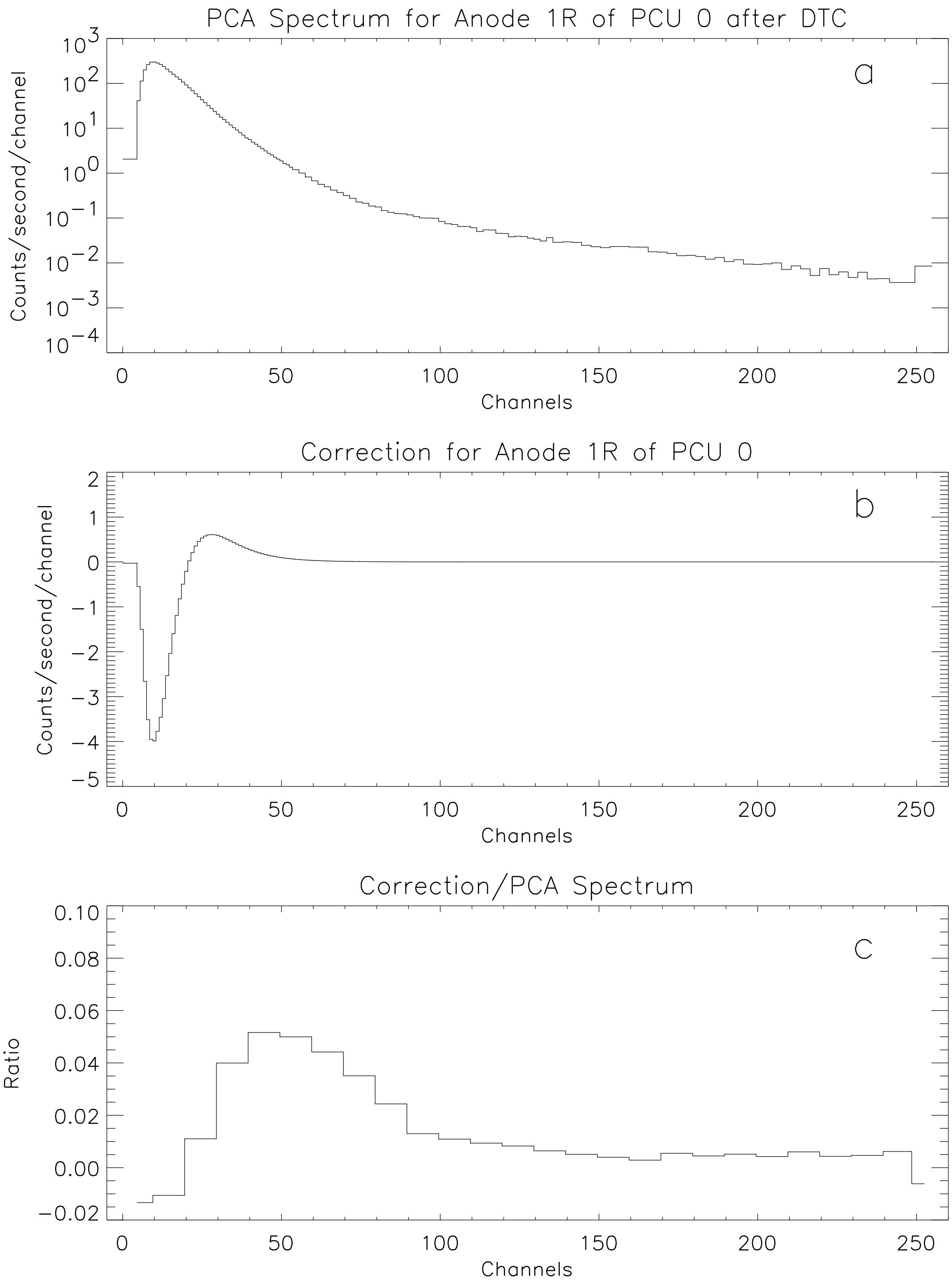

Fig. 3.— (a) The PCA spectrum for GRO J1655-40 after correcting for deadtime, (b) The pile-up spectrum predicted by Equation 1 for the spectrum shown in Figure 3a, (c) The ratio of the spectrum shown in Figure 3b to the spectrum shown in Figure 3a.

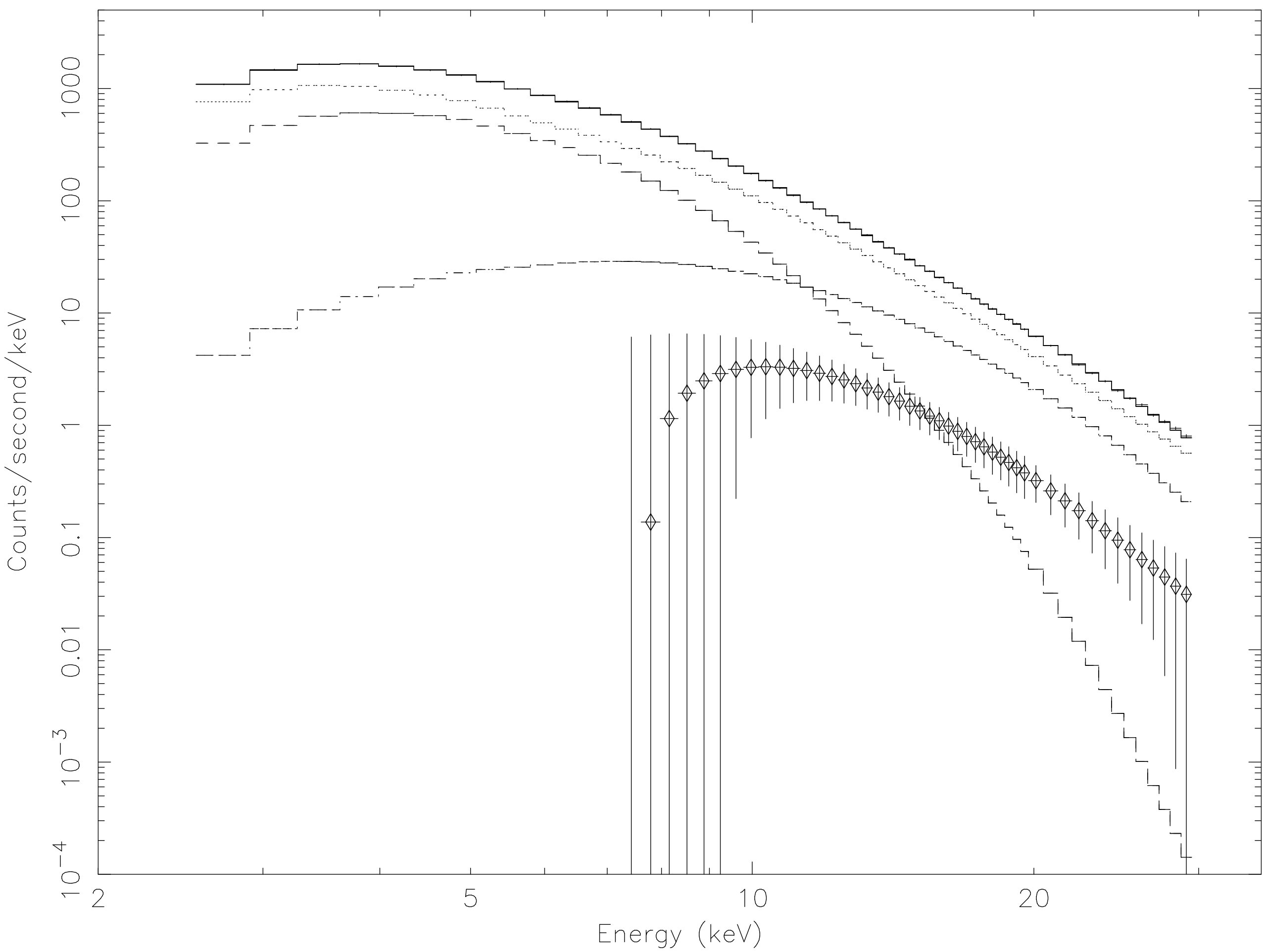

Fig. 4.— Fit to the GRO J1655-40 energy spectrum (before pile-up correction) with a diskbb+bbody+powerlaw model. The pile-up spectrum, marked with diamonds, is shown for comparison. Here, $\tau = 1.84$ microseconds is used.

Table 1. Results from Jahoda et al. (1996)

Anode	Input rate (Hz)	Pile-up rate (Hz)	τ (μs)
L1	8285	126	1.8
L1	2065	7.2	1.6
R1	2098	10.3	2.3

Table 2. Pile-up calculations using Equation 1

Input rate (Hz)	Pile-up rate (Hz)	τ (μs)
8285	126	1.84
2065	7.2	1.70
2098	10.3	2.34
2065	7.85	1.84
2098	8.10	1.84