MIT Kavli Institute **Chandra X-Ray Center**

MEMORANDUM
July 20, 2013

To:	Jonathan McDowell, SDS Group Leader
From:	Glenn Allen, SDS, and Miriam Krauss, CDO
Subject:	Randomizing the Values of ENERGY and PI in ACIS Event Data Files
Revision:	1.0
URL:	http://space.mit.edu/CXC/docs/docs.html#energy_pi
File:	/nfs/inconceivable/d0/SDS/SPECS/ENERGY_PI/energy_pi_spec_1.0.tex

1 The Problem

A problem has been reported for an ACIS PI spectrum of obsid 1996 (the Crab). The PI spectrum for a spatially-selected subset of the events exhibits semi-periodic jumps in the total number of counts per bin (fig. 1). (Please do not circulate this memo to non-CXC staff, since the data are proprietary.) This behavior is not evident in the corresponding PHA spectrum (fig. 2). After carefully investigating this issue, Miriam identified the problem: the values of ENERGY are discrete. There is a one-to-one mapping between the discrete values of PHA and the discrete values of ENERGY. As a result, when PI is calculated from ENERGY, sometimes a PI bin contains n discrete values of ENERGY and sometimes a PI bin contains $n+1$ values. That is, the width of the PI bins (14.6 eV) is not an integer multiple of the difference between consecutive values of ENERGY (ΔENERGY $\sim$ 4 eV). The proposed solution to this problem is to randomize the value of the ENERGY of an event within plus or minus one-half of a PHA bin. This randomization would yield a continuous range of values for ENERGY and hence a smooth transition from one PI bin to the next.

As a test of the proposed technique, the values of the ENERGY of the events for obsid 1996 have been randomized in a manner similar to the technique described in section 2. The corresponding values of PI were computed in the usual manner. The results are shown in figure 3. This figure shows part of the PI spectrum for obsid 1996. The red curve is the spectrum obtained before randomization and the black curve is the spectrum obtained after randomization. Unlike the results shown in figures 1 and 2, the results shown in figure 3 are for the entire source (i.e. several different 32×32 pixel regions). Since the results are averaged over the different gains (i.e. PHA to ENERGY mappings) of these regions, the effect is diminished with respect to the effect shown in figure 1, but still significant.

The histogram in figure 4 shows the difference between the two PI spectra in figure 3. The red and blue curves in figure 4 represent the square root of and 3% of the randomized spectrum of figure 3, respectively. Since the amplitude of the differences is significantly larger than the red curve over most of range of PI shown, the effect is very significant for this observation of a bright source.

Figure 5 shows the difference between the red and black spectra of figure 3 divided by the black spectrum of figure 3. The RMS deviation of the two spectra is 2.8% and appears to be a constant over the range of PIs shown. This behavior is consistent with the nature of the problem. Note that if a much smaller region were used to construct the PI spectra (i.e. if only one 32×32 pixel region were used), the amplitude of the differences would be larger. For example, the differences in figure 1 are about 20%, which is close to the maximum for the present binning of PHA (~ 4 eV channel^{-1}) and PI (14.6 eV channel^{-1}).

Since the problem with the quantization of ENERGY and the non-commensurate binning of PI and PHA seems to be well understood and since randomizing the values of ENERGY within one adu solves the problem, we propose to change the algorithm used by acis_process_events to compute the values of ENERGY. The proposed algorithm is described in section 2.

2 Revised Algorithm to Compute ENERGY and PI

1. Calculate the value of the ENERGY of an event that corresponds to the value of the PHA of the event using the vectors named ENERGY and PHA in the gain ARD file. Select the gain ARD file that is appropriate for the nominal temperature of the focal plane during the observation. Since the gain depends on the position of an event on a chip, the vectors ENERGY and PHA are tabulated in the gain ARD region-by-region for each chip. To compute the value of the ENERGY of an ACIS event:

   i. Find the vectors ENERGY and PHA of the row in the gain ARD file that satisfies the conditions that

$$\begin{aligned} \text{chip id} \quad &= \quad \text{CCD\_ID}, &(1)\\ \text{CHIPX\_MIN} \quad &\le \text{CHIPX} \le \quad \text{CHIPX\_MAX}, \text{ and} &(2)\\ \text{CHIPY\_MIN} \quad &\le \text{CHIPY} \le \quad \text{CHIPY\_MAX}, &(3)\end{aligned}$$

   where "chip id" is the chip on which the event was detected, CHIPX and CHIPY specify the location on the chip at which the event was detected, and CCD_ID, CHIPX_MIN, CHIPX_MAX, CHIPY_MIN, and CHIPY_MAX are the names of columns in the gain ARD file.

   ii. Find the two real values of PHA_i and PHA_{i+1} in the vector PHA such that

$$\text{PHA}_i \le \text{PHA} + \alpha < \text{PHA}_{i+1}, \tag{4}$$

   where PHA is the pulse height amplitude of the event and α is a uniform random deviate over the interval $[-0.5,0.5)$.

   iii. Set the ENERGY of the event to be

$$\text{ENERGY} = \frac{\text{PHA} + \alpha - \text{PHA}_i}{\text{PHA}_{i+1} - \text{PHA}_i}\left(\text{ENERGY}_{i+1} - \text{ENERGY}_i\right) + \text{ENERGY}_i, \tag{5}$$

   where ENERGY_i and ENERGY_{i+1} are the non-zero values in the vector ENERGY that correspond to the values of PHA_i and PHA_{i+1}, respectively. This formula is valid if the value of the PHA of the event satisfies

$$\text{PHA}_1 \le \text{PHA} + \alpha < \text{PHA}_n, \tag{6}$$

   where PHA_1 and PHA_n are the smallest and largest, respectively, non-zero values in the vector PHA. If $0 < \text{PHA} < \text{PHA}_1$,

$$\text{ENERGY} = \frac{\text{PHA} + \alpha - \text{PHA}_1}{\text{PHA}_2 - \text{PHA}_1}\left(\text{ENERGY}_2 - \text{ENERGY}_1\right) + \text{ENERGY}_1. \tag{7}$$

   If $\text{PHA} \ge \text{PHA}_n$,

$$\text{ENERGY} = \frac{\text{PHA} + \alpha - \text{PHA}_{n-1}}{\text{PHA}_n - \text{PHA}_{n-1}}\left(\text{ENERGY}_n - \text{ENERGY}_{n-1}\right) + \text{ENERGY}_{n-1}. \tag{8}$$

   If $\text{ENERGY} < 0$, set $\text{ENERGY} = 0$.

2. Compute the value of the PI of an event as follows.

$$\text{PI} = \text{integer part of} \left(\frac{\text{ENERGY}}{\text{pi\_bin\_width}} \right) + 1 \tag{9}$$

   For example, the values of PI = 1, 2, and 3 correspond to $0 \leq \text{ENERGY} < 14.6$ eV, $14.6 \leq \text{ENERGY} < 29.2$ eV, and $29.2 \leq \text{ENERGY} < 43.8$ eV, respectively, using the default value of pi_bin_width = 14.6 eV. If PI > pi_num_bins, set PI = pi_num_bins. The value of PI may have a value of zero in the special case that PHA has a value of zero. In this case, also set the value of ENERGY to zero. Otherwise, PI > 0.

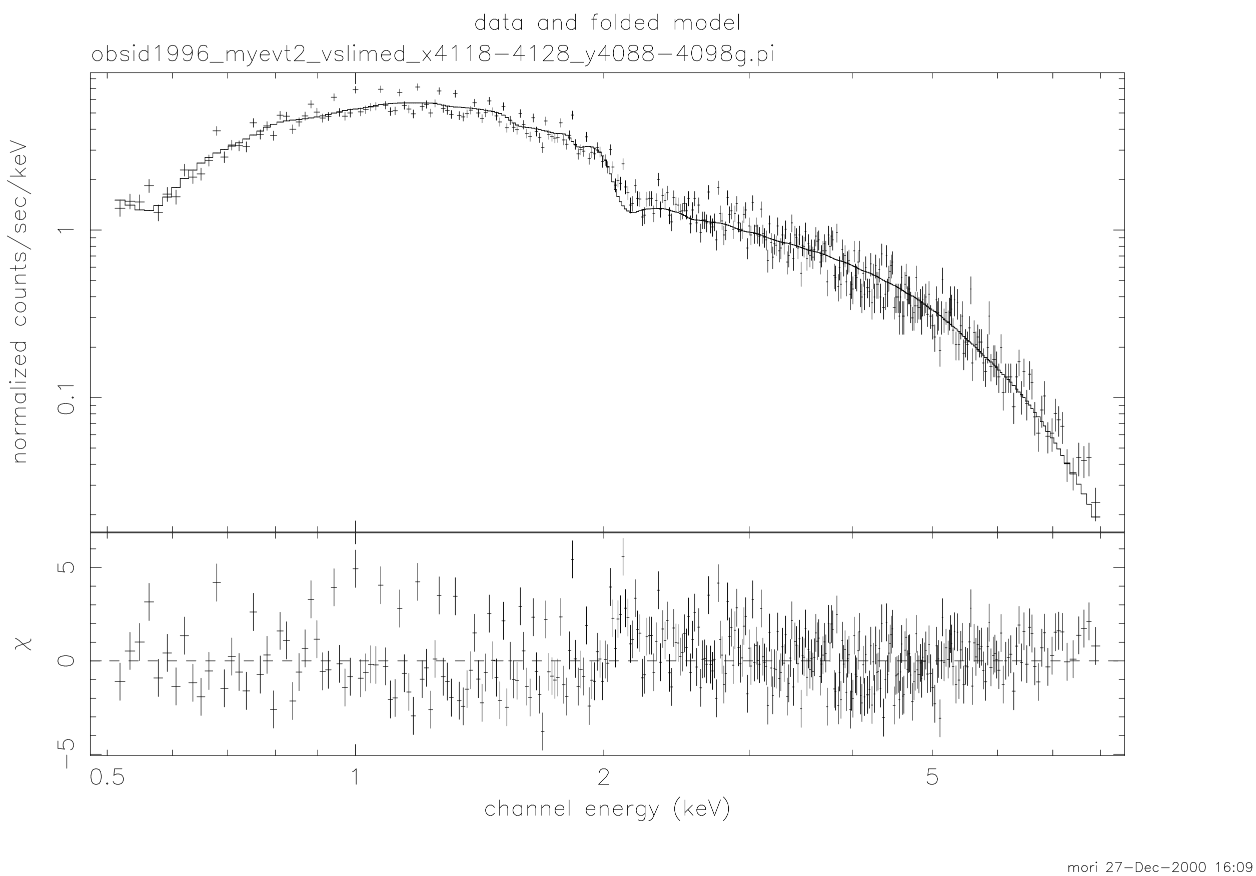

Figure 1: The ACIS PI spectrum of a spatially-selected subset of the events for obsid 1996. The count rate jumps every four or five bins. This jump is not evident in the corresponding PHA spectrum (see fig. 2).

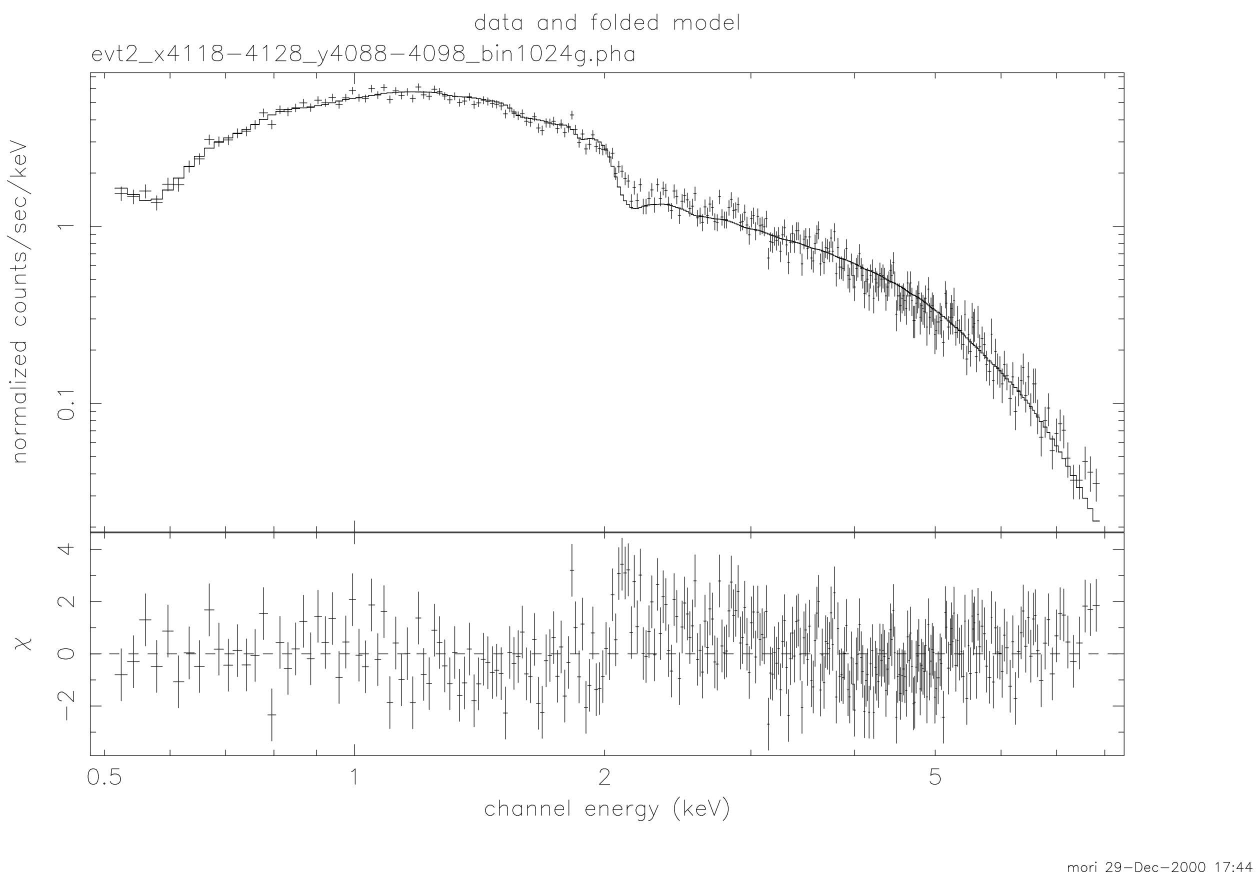

Figure 2: The ACIS PHA spectrum of a spatially-selected subset of the events for obsid 1996. This spectrum does not exhibit the count rate jumps observed in the corresponding PI spectrum (see fig. 1).

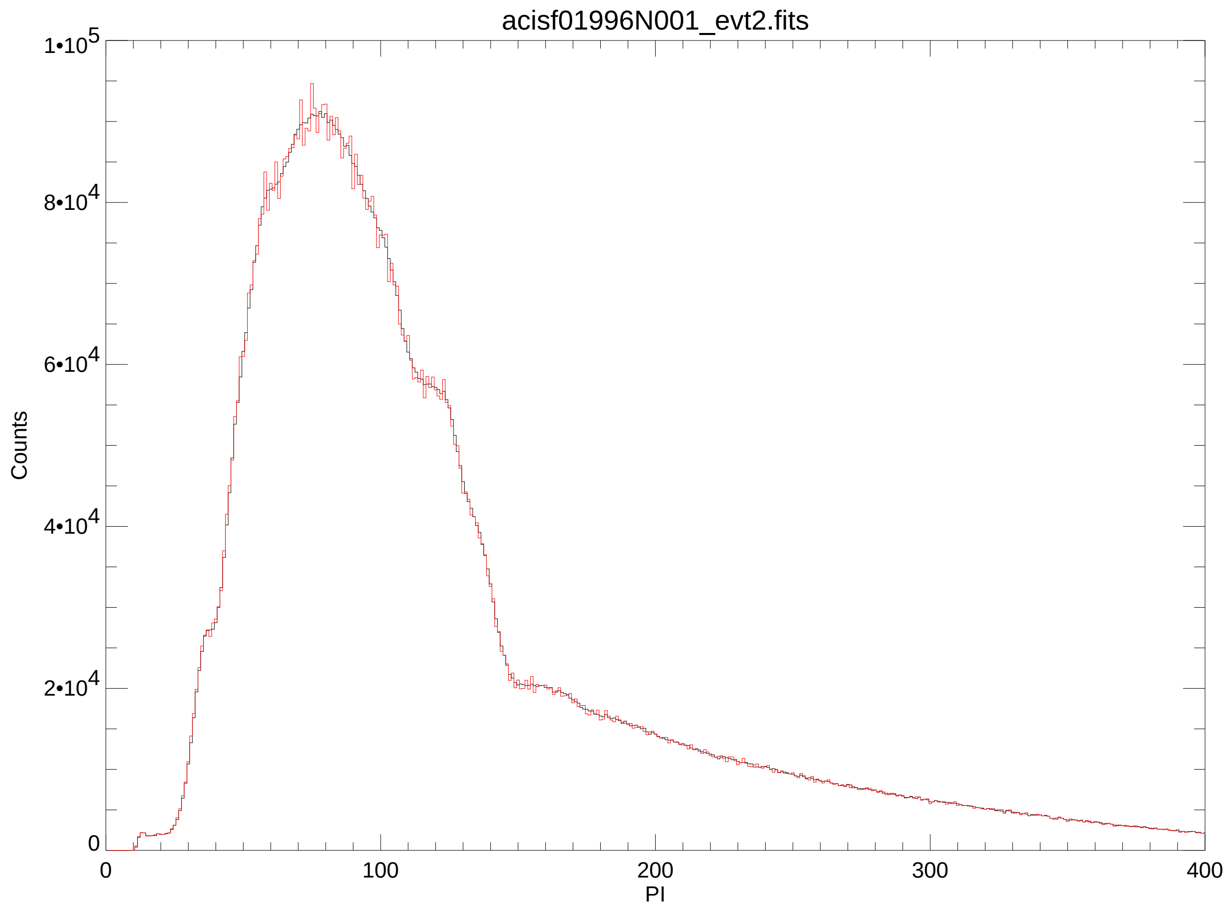

Figure 3: A portion of the PI spectrum of all Level 2 events for obsid 1996 before (red) and after (black) randomizing the values of ENERGY. Since the value of PI is computed from the value of ENERGY, randomizing the value of ENERGY within a range corresponding to one adu removes the count-rate jumps observed in figure 1.

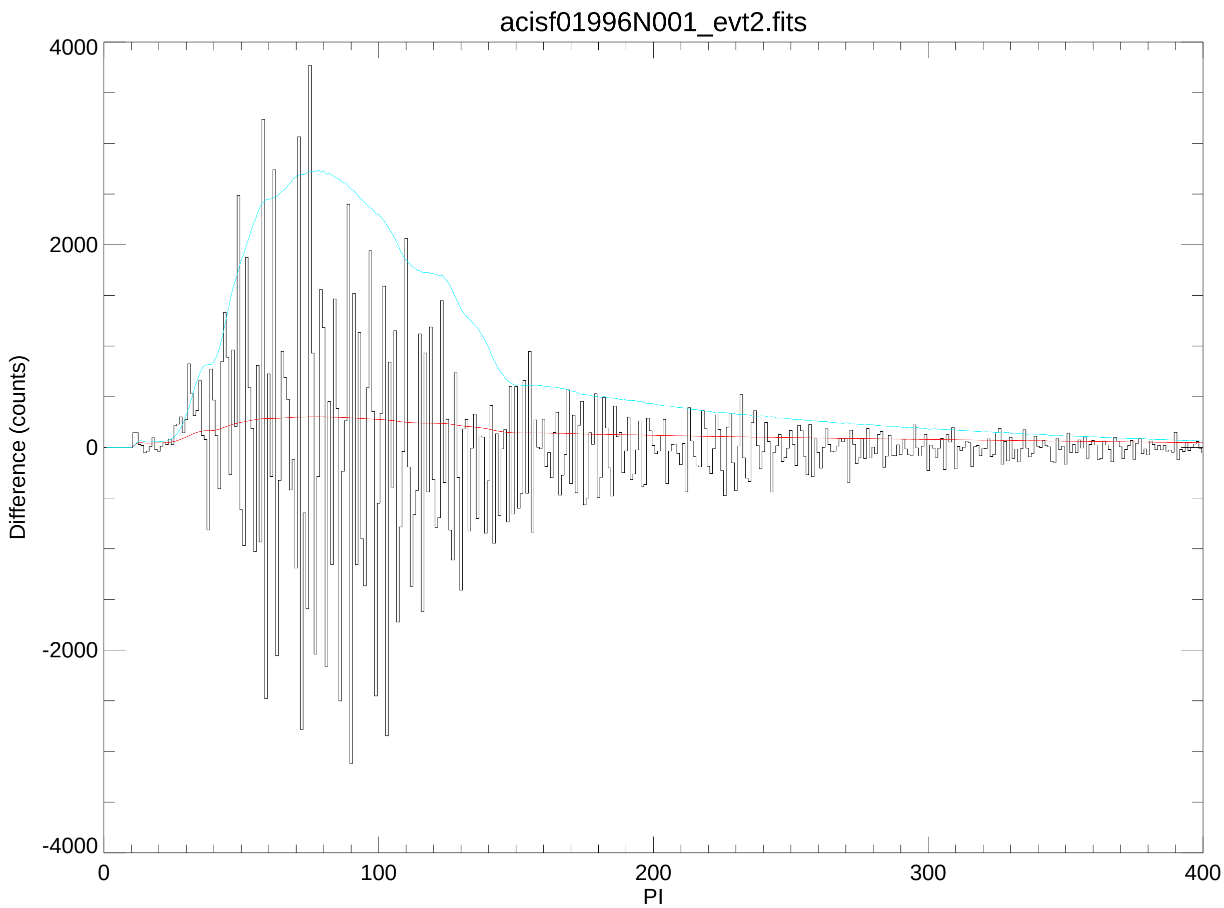

Figure 4: The difference between the red and black curves of figure 3 is shown as the black histogram. The red curve is the square root of the black spectrum of figure 3. The blue curve is the black spectrum of figure 3 multiplied by a factor of 0.03. The differences between the two spectra of figure 3 are significant.

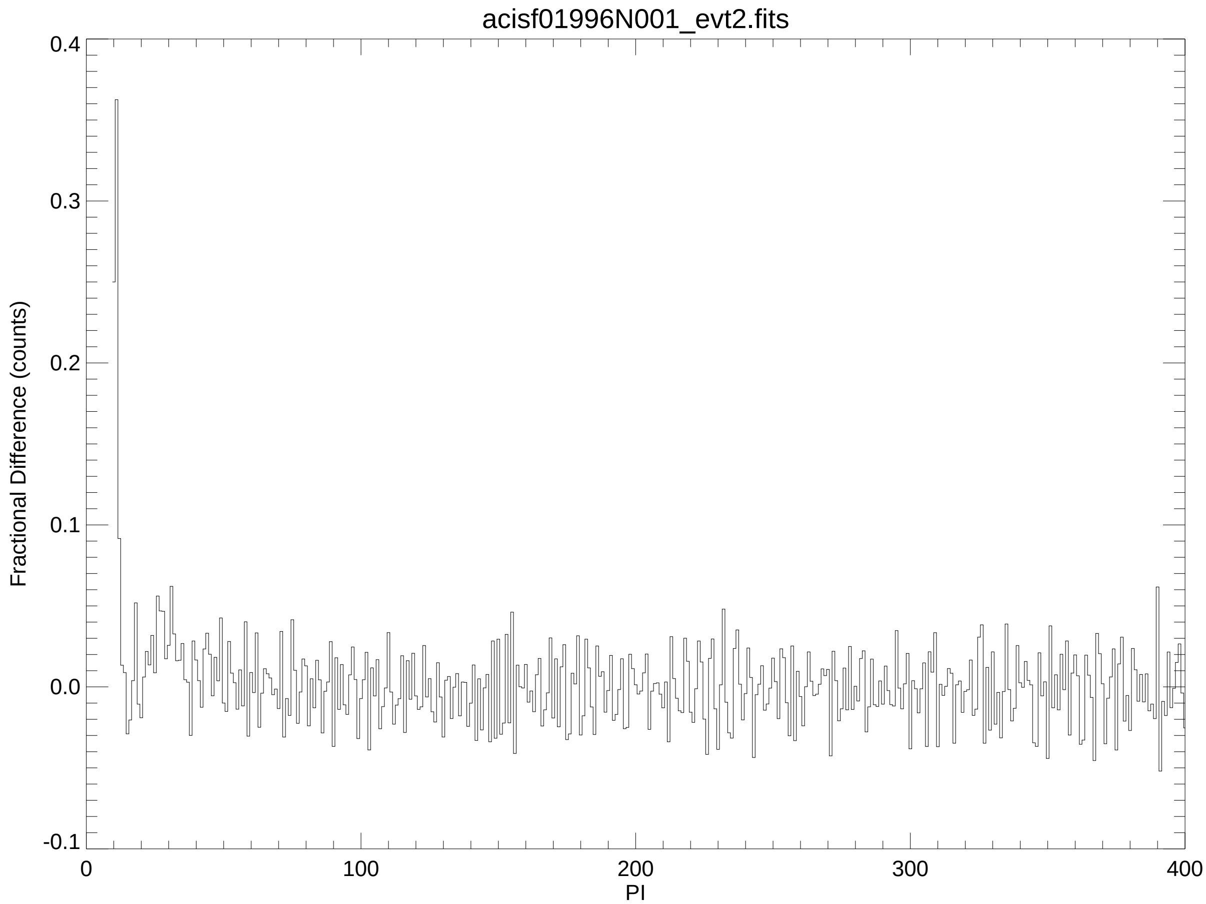

Figure 5: The difference between the red and black spectra of figure 3 divided by the black spectrum of figure 3. The RMS deviation is 2.8% and appears to be constant over the range of PI shown.