Studying the HRC-I Uniformity with Observations of the Vela SNR

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Abstract

The current QE uniformity (QEU) map of the HRC-I, constructed from subassembly calibration (SAC) data taken at six discrete energies, suggests that above ~183 eV the quantum efficiency is uniform across the detector to within $^{+2}_{-10}$% (with an uncertainty of 0.7% per square arcminute), independent of energy. However, repeated observations of the white dwarf HZ 43 (a characteristic blackbody with temperature $\sim$ 60 eV) show that at $+10'$ off-axis the QE is roughly 20% less than expected from the current QEU map.

To investigate this, we have used two observations of the Vela SNR taken with the HRC-I at opposite roll angles to create a ratio map that is a relative measure of the detector response. This map indicate s that the detector is flat to within $\pm$10%, in good agreement with the nominal QEU map. The depression at $+10'$ off-axis is not seen in the ratio map, indicating that it does not affect the detector's performance above 150 eV.

Analysis

The two HRC-I Vela observations used in our analysis are ObsID 3451, taken in April 2002 at a roll angle of 265°, and ObsID 3713, taken in October 2003 at a roll angle of 87° (178° from the original).

Our first step in creating the ratio map was to filter each event list to remove time intervals affected by flaring or telemetry saturation. We next binned the cleaned event lists into images, then registered the second image (Oct 03) to the first image (Apr 02) in sky coordinates. Finally, we divided the first image by the second (registered) image to create a ratio map, which we smoothed and normalized to the mean value in its central third. This is shown in Figure 1.

Since the observations were taken at nearly opposite roll angles, any non-uniformity in the detector should show up in the ratio map as a pair of opposite features rotated $\sim 180°$ around the aimpoint. For example, the 20% depression in the quantum efficiency seen by HZ 43 at $+10'$ off-axis at the roll angle of the original Vela observation would appear as a 20% depression (i.e. values of 0.8) in the bottom of the ratio map and a 25% excess (i.e. values of 1.25) at an opposite position at the top of the map. These locations are marked with arrows in Figure 1, and we find no such features present. Instead, the map implies that the detector is uniform to within $\pm$ 10%.

A histogram of pixel values in the ratio map is shown in Figure 2 with the best-fit Gaussian ($\mu = 1.02$, $\sigma = 0.03$) over-plotted. Note that we ignored trailing values (below 0.92) when finding the best-fit Gaussian, as these values represent the fall-off at the perimeter of the detector (shown in red in Figure 1). Figure 3 shows the Poisson error map for the ratio map. The values in the error map range from $\sim$0.04 to 0.06, with a median of 0.05, suggesting a $\sim$ 5% uncertainty for relative QE values implied by the Vela ratio map.

We suspect that particle background may be contributing to the overall gradient in the ratio map (i.e. the higher values in the upper-right of Figure 1). We are currently exploring the possibility of modeling and removing this component using particle background images developed by Mike Juda (see M. Juda et al. 2002, "Characteristics of the On-Orbit Background of the Chandra X-ray Observatory High Resolution Camera", SPIE Proc. 4851, 112). However, we are confident that this refinement will not affect our general conclusion about the validity of the current QEU map.

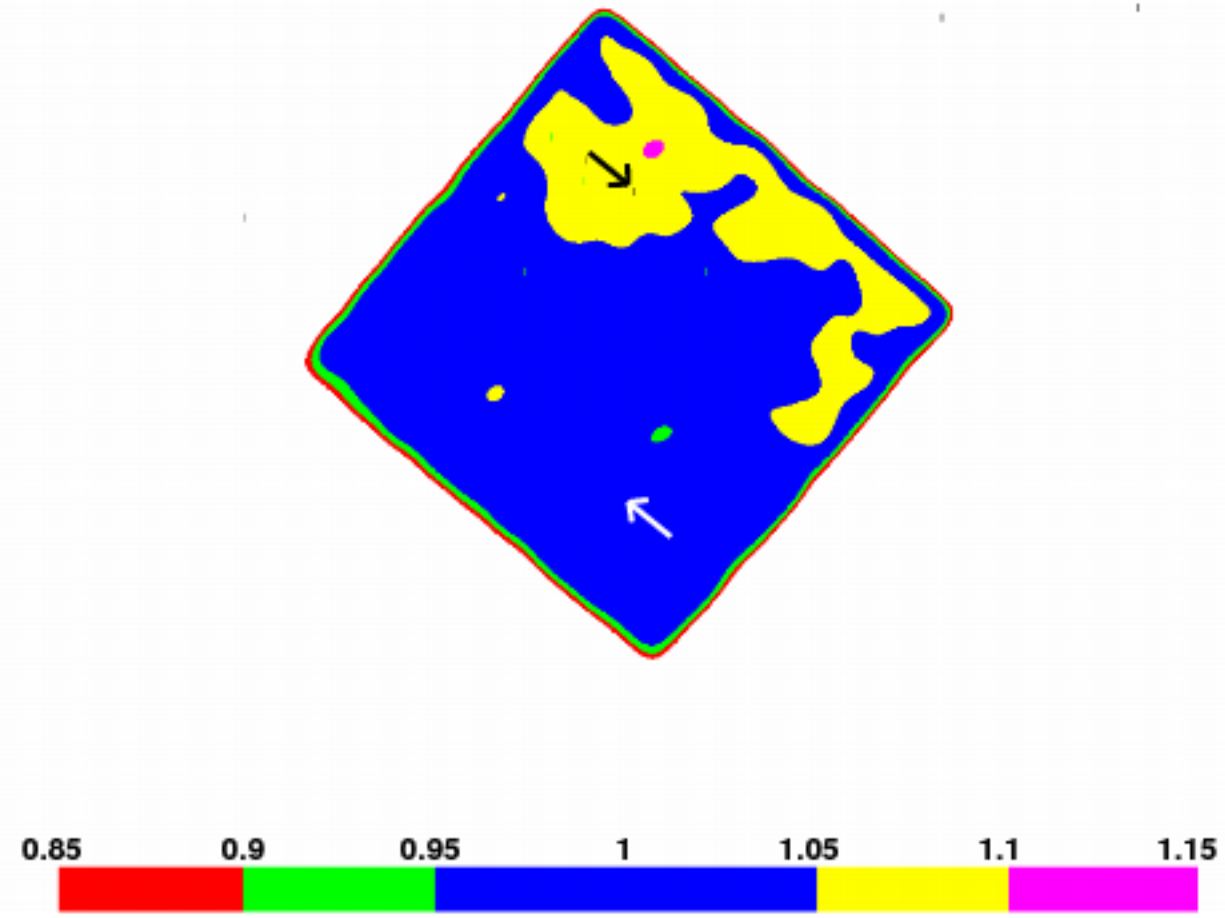

Figure 1: Ratio map with linear scale ranging from 0.85 to 1.15. Blue represents $1 \pm 1\sigma$.

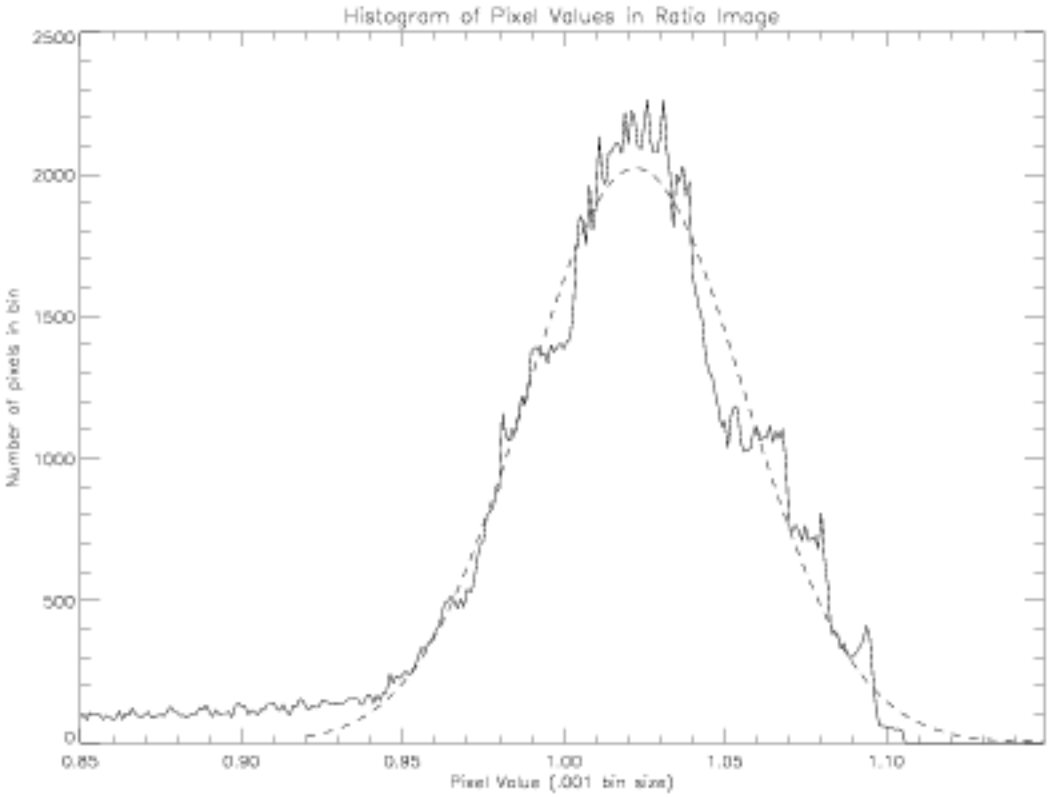

Figure 2: Histogram of pixel values in ratio image, with best-fit Gaussian overplotted.

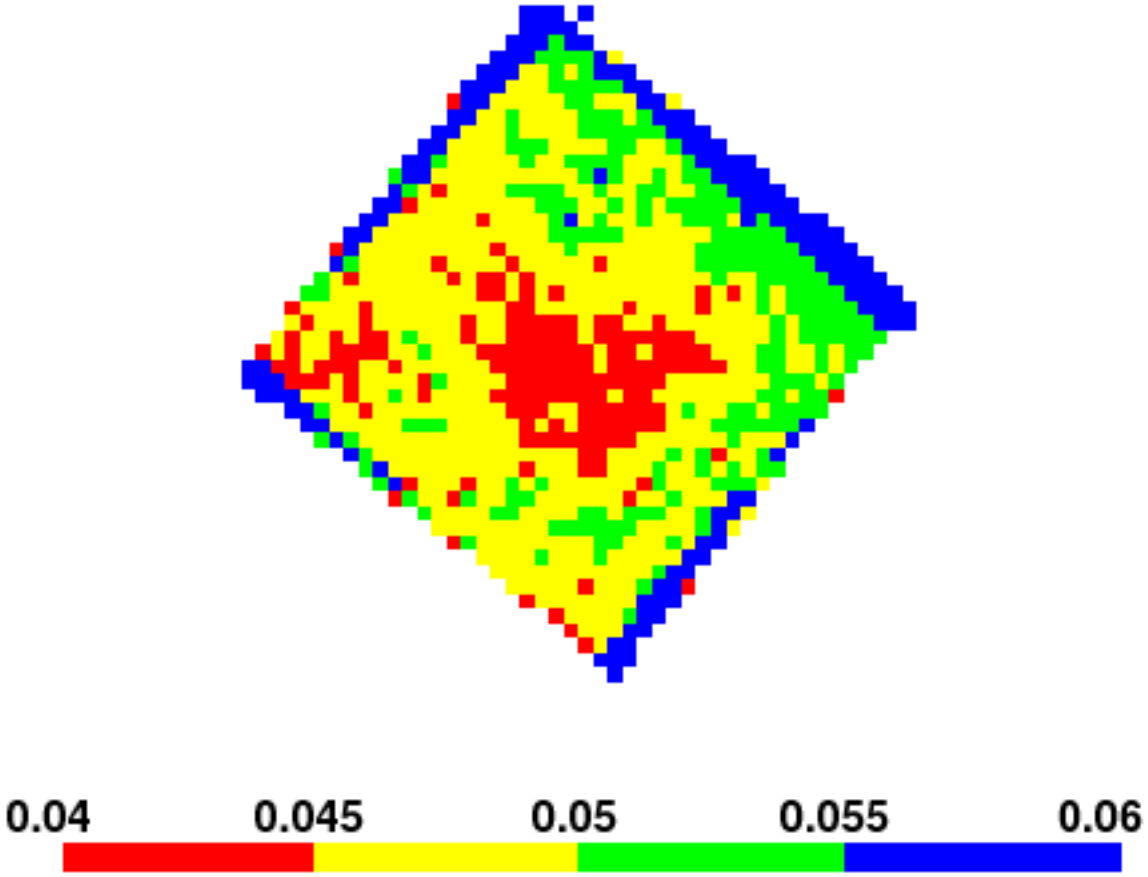

Figure 3: Poisson error map for ratio map - linear scale.

Conclusions and Future Work

By dividing two images of the Vela SNR taken with the HRC-I at nearly opposite roll angles, we have investigated the uniformity of the detector. We find that it is flat to within $\pm 10\%$ with a statistical error of $\sim 5\%$ on scales of 1 square arcminute.

Since the bulk of the emission from Vela is above $\sim$150 eV (see spectrum in Figure 4), the relative flatness of our ratio map means that the HRC -I is uniform above this energy, in agreement with the current QEU map constructed from SAC data above 183 eV. From repeated observations of HZ 43 (brightest around 60 eV) we know there is a non-u niformity at $+10'$ off-axis, with the quantum efficiency here $\sim$20% lower than expected. However, we do not know at exactly what energy between 60 and 150 eV this depression is revealed. The spatial extent of the non-uniformity is also unknown.

This issue could affect science done with the HRC-I. For example, users observing diffuse, soft x-ray sources may find that measured count rates in this area are depressed relative to theoretical predictions or to observations done with other instruments.

One possible way to investigate the non-uniformity of the HRC-I at low energies would be to take a series of calibration observations with HZ 43 to map out the uniformity of the detector. In this way, we could constrain the spatial extent of the problem and offer more specific guidance to users whose observations may be affected.

The current QEU map was created from ground-based pre-launch data taken at the detector's original voltage setting. Since then, the voltage has been lowered and the detector has had over five years of in-flight use, so it is not unreasonable to suppose that the uniformity may have changed. However, our analysis with Vela indicates that the SAC map is still valid. In the future, it may be worthwhile to repeat this study with longer exposure times for the Vela observations to obtain better statistics and allow for a more rigorous check of the SAC map. We do not suggest that the Vela ratio map presented here be considered as a replacement for the current QEU map, primarily because of its much larger statistical uncertainty ($\sim 5\%$ in our map compared to 0.7% in t he SAC map).

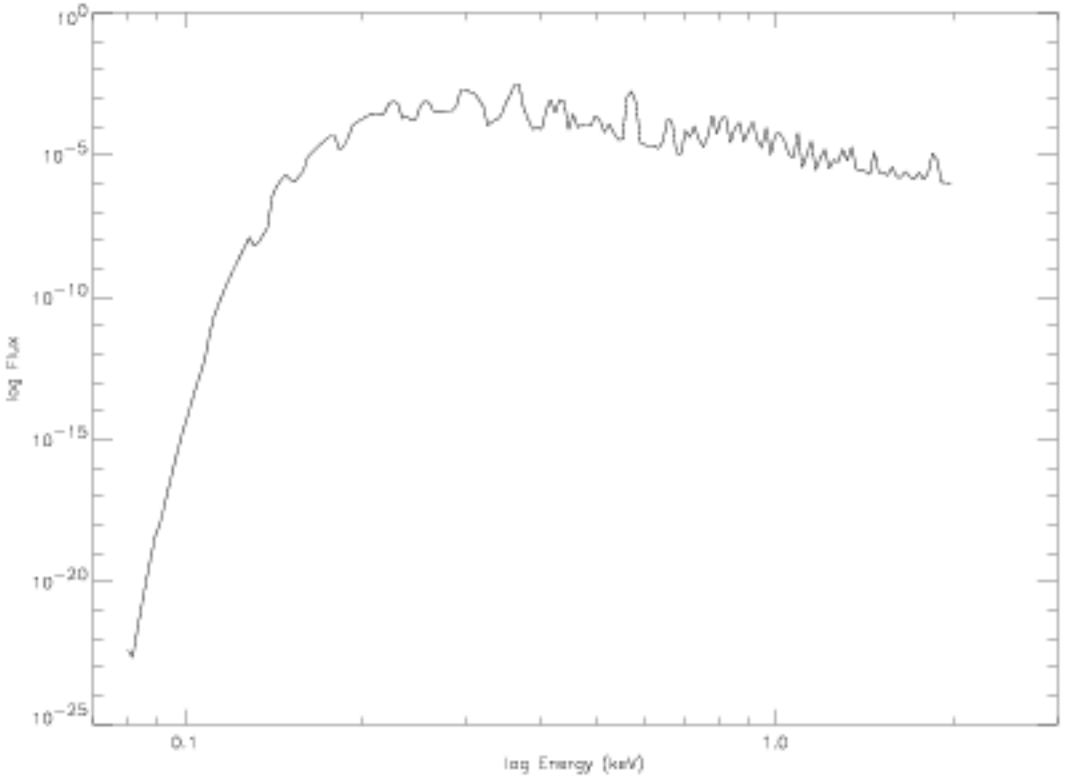

Figure 4: Spectrum of Vela SNR derived from a ROSAT PSPC observation.