Updated HRC-I Degapping Correction

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Abstract

Event positions within the HRC detectors are determined using a 3-tap algorithm, centroiding on three signals per axis. Due to the loss of information in using only three signals, a correction to the centroids must be made to eliminate gaps which would otherwise appear in images. This degapping correction is applied in standard processing of the HRC data. We recently completed an analysis of the data from a series of on-orbit observations of Capella that were designed to provide improved degapping corrections for the HRC-I. Capella was observed on-axis for forty 5ks pointings but between each observation the Science Instrument Module (SIM) was translated so that the image was placed on a different location along the HRC-I diagonal. The combination of the SIM translations and the spacecraft dither resulted in nearly complete coverage of all HRC-I detector locations along each axis with X-ray events of "known" location. We have used these data to produce an update to the HRC-I degapping corrections. The new corrections provide a major improvement in the CRSU = 12-13 region and smaller improvements elsewhere.

"3-Tap Algorithm"

Unlike the ACIS CCDs the HRC does not have discrete hardware pixels. In the HRC event positions are deteremined by centroiding the charge cloud generated by the microchannel plates on three signals per detector axis which are selected about a coarse location having the largest signal. There is an inherent loss of information when using only three signals that is most readily apparent when one considers an event that occurs half-way between two coarse positions: The two signals on either side of the event location will be roughly equal while the third signal is not matched by a roughly equivalent fourth signal. This missing information biases the centroided position away from the actual position toward the central coarse position, creating gaps in reconstructed images. A degapping correction is applied in standard processing in order to minimize this bias from the event positions.

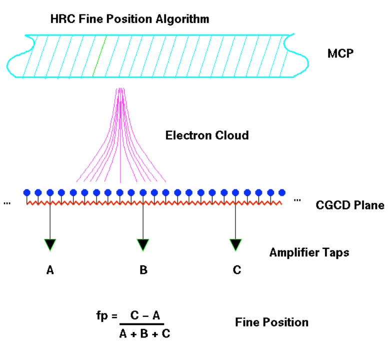

Figure 1: Schmatic representation of the HRC 3-tap fine-position algorithm

Capella Observations

In order to derive updated degapping corrections a set of dedicated observations of Capella were made. The observations were performed with different Science Instrument Module (SIM) translation offsets so that the dithered, on-axis source image would sample different regions along the HRC-I diagonal. The spacing between the offsets was selected so that the projection of the dither pattern along the detector axes would overlap by roughly 1/3 the total dither range (see figure 2).

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Iterate using the following steps:

1. For each observation:
   (a) Determine the mean SKY (x,y) position of the source
   (b) Select events within an 8-pixel radius of the mean position
   (c) Using the mean SKY position determine the mean offset from the nominal on-axis position
   (d) Using the mean offset position determined above and the nominal roll angle of the observation (ROLL_NOM from the aspect file header) determine the radial offset and position-angle of the mean offset position
   (e) Use the radial offset and position angle of the mean offset position and the geometry that describes the alignment of the HRC axes with the spacecraft to determine the location relative to the nominal HRC U,V position for the nominal SIM-Z position for the detector
   (f) Adjust the U,V position determined above for any offset of the SIM from its nominal translation position to determine the location of the source relative to the nominal U,V position
   (g) Use the time history of the RA and Dec in the aspect solution and the nominal RA and Dec to determine a time history of the RA and Dec offsets from the nominal direction.
   (h) Use the time history of the Roll from the aspect solution and the geometry that describes the alignment of the HRC axes with the spacecraft to determine the time history of the rotation of the RA and Dec offsets relative to the HRC axes
   (i) Use the time histories of RA and Dec offsets and their rotation angle relative to the HRC axes to determine the path of the nominal pointing direction in HRC U,V
   (j) Add the location of the source relative to the nominal U,V position to the time history of the path of the nominal pointing direction in HRC U,V to get the predicted source location on the HRC
   (k) Use the derived time history of the predicted source location on the HRC to determine the U,V for the time of each of the selected events (Figure 3).
2. Combining the events from all the observations
   (a) Sort events based on their AMP_SF, CRSU (or CRSV), and predicted U (or V) position and for each AMP_SF, CRSU[V], U[V] collection determine the mean RAW position, RAWX[Y], and deviation of the mean RAW position from the integerized, predicted position (Figure 4)
   (b) For a given CRS position and AMP_SF range select the predicted position bins that lie in the nominal CRS position range and which have more that a specified minimum number of events (minimum number = 5)
   (c) From the selected predicted position bins use the mean RAW position at each bin and the mean deviation of the RAW position from the predicted position, smooth over a specified number of samples in the RAW position (smoothing number = 5), and interpolate the correction into integer RAW position bins within the nominal CRS position range
   (d) If there are inadequate statistics or coverage for the CRS-position - AMP_SF combination use the existing correction
3. At low and high CRS position the statistics on AMP_SF = 3 are low. If the AMP_SF = 1 and 2 corrections are different from the prior version but the AMP_SF = 3 are not then update the AMP_SF = 3 correction with the average of the AMP_SF 1 and 2 corrections.

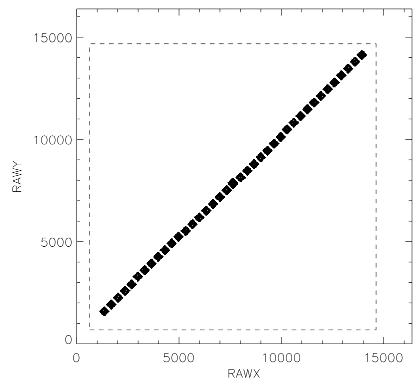

Figure 2: Capella events from all forty observations, in RAW coordinates, used in the derivation of the updated degapping corrections. Capella was observed on-axis and the science instrument module translated among the observations so that the source dither would cover different RAW coordinates. The dashed box delineates the "good" region of the HRC-I.

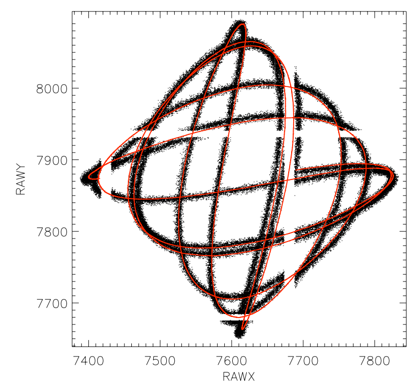

Figure 3: Dither pattern of Capella source events plotted in RAW coordinates with the aspect-derived source location over-plotted in red. The gaps in the RAW coordinates from the loss of information in the 3-tap algorithm are clearly visible.

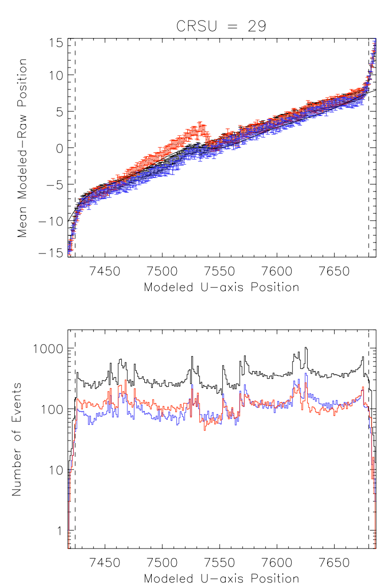

Figure 4:) **Top:** Observed deviation of the RAW position from the modeled source location for one HRC-I tap. The three colors indicate the result for each of the three AMP_SF values (Blue=1, Black=2, and Red=3). **Bottom:** Number of source events at the modeled source location used in deriving the offset above. Color labeling is the same.

Derivation Iterations

Updated degapping corrections were used to re-process the Capella observations and then the steps to derive degapping corrections repeated. A total of ten iterations were performed. Figure 5 shows the evolution of a measure of the size of the source at the various SIM-Z offsets as the iterations proceeded. The size was determined by first finding the best center via iteratively-clipped centroiding, using the *CIAO* tool *dmstat* to calculate the standard deviation in x and y of the events within a 20-pixel radius of that center, and taking the square-root of the sum of their squares. The large peak in the initial iteration at a SIM-Z offset of ~40 mm was due to a particularly bad set of degapping corrections around CRSU = 12, that we have unknowingly been using since the start of the mission. The poor degap correction was evident in the initial processing of the Capella observation, ObsID 8358, which shows a jet-like extension. Most of the size improvement occurs within the first two or three iterations; however, there is an overall continuing small improvement with additional iterations. The reason for the larger size in the SIM-Z Offset ranges of -15 to -5 mm and 50 to 60 mm is not clear at this time but note that 1 pixel is ~0.132 arcseconds..

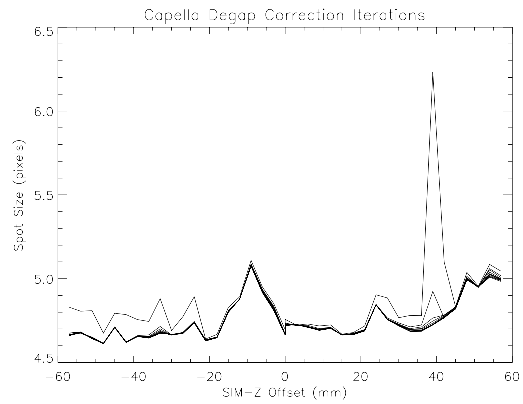

Figure 5: Reduction in on-axis spot size with multiple iterations. Spot size is the standard-deviation of all events within a 20-pixel radius of a center that was determined by iteratively-clipped centroiding.

Performance Improvement

As the plot in figure 5 suggests for the nominal SIM position (SIM-Z offset = 0) the updated degapping corrections provide a negligible improvement over the CALDB 3.3.0 version. This is not a surprise as the earlier version were derived from mostly the same data using a similar technique; most of the improvement came going from the CALDB 3.2.1 version to 3.3.0. The greatest improvement is in the SIM-Z offset = ~40 mm region. This SIM-Z offset corresponds to having the on-axis source dither around the CRSU and CRSV = 12 to 13 region of the HRC-I. On occasion the HRC-I has been positioned with SIM-Z offsets in this area so as to observe bright X-ray sources without over-dosing the nominal detector center with events; ObsID 8225, an observation of Cyg X-2 is an example of such an occasion. The left panel of figure 6 shows the resulting image from standard processing of the observation using CALDB version 3.3.0, the one available at the time of the observation. The right panel shows the resulting image when re-processing using the degapping corrections from the final iteration. The pronounced image artifact due to the extremely poor degapping correction in the CRSU = 12 region has been removed.

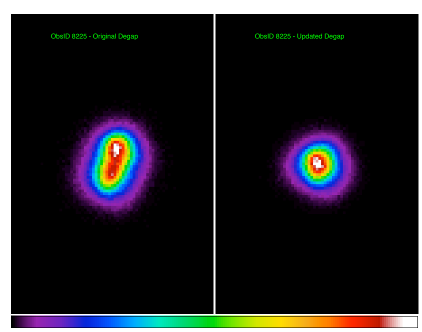

Figure 6: Comparison of the improvement provided by the updated degapping corrections around CRSU = 12. The left panel shows the image of Cyg X-2 from ObsID 8225 processed using CALDB version 3.3.0 of the depagging correction. The right pannel shows the same data processed using the final iteration of the degapping correction (now in CALDB version 3.4.1).

Concluding Remarks

The updated degapping corrections described here provide a major improvement to the corrections in the CRSU = 12-13 region and smaller improvements elsewhere on the HRC-I. These corrections are now part of standard data processing and are included in CALDB version 3.4.1. The updated corrections can be applied by running the *CIAO* tool *hrc_process_events* on the Level 1 event list as described in the analysis thread "HRC-I Degap Correction" (http://asc.harvard.edu/ciao/threads/hrci_degap/).

Using a similar method of deriving degapping corrections on the HRC-S is much more difficult. The main problem lies in the fact that the SIM translation direction is aligned with the short axis of the HRC-S not along the diagonal as with the HRC-I. Sampling locations along the long axis of the HRC-S requires off-axis pointings which will produce larger point-spread functions, limiting the range that can be probed. Bright spectral lines might provide an equivalent function to the "on-axis" source but care must be taken in understanding the impact that line-blends and the local continuum.will have on the derived corrections.