Swift XRT calibration note - energy scale offsets

XRT-LUX-CAL-112

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1 Introduction

Observational evidence has been obtained which suggests the CCD bias level, which is mode dependent and subtracted onboard during XRT observations, can vary considerably during a typical orbital snapshot on an astrophysical target. The variation seems to be at least partly related to changes in the CCD temperature and/or scattered optical light from the sunlit Earth, and it can affect both of the main science modes: windowed timing (WT) and photon counting (PC). When the bias changes during an observation, it can cause energy scale offsets which could give rise to spectral features (such as an edge at ~ 0.5 keV) in the observed spectra (for example, figure 1).

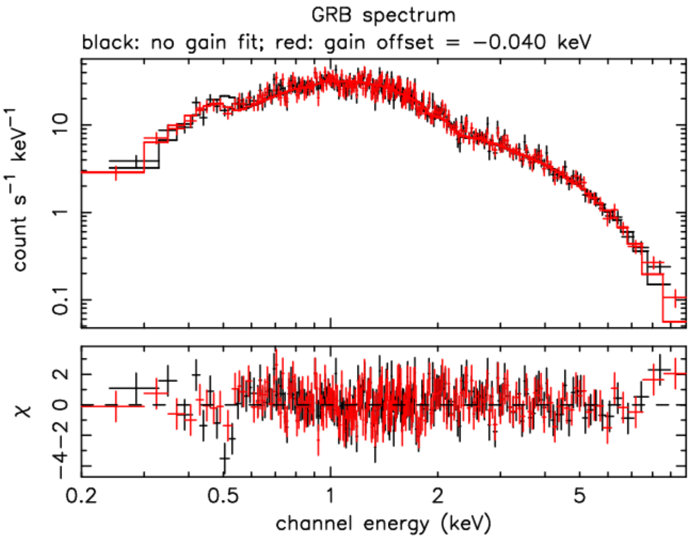

Figure 1: Example XRT WT spectrum of a GRB showing a feature at 0.5 keV (black) which can be removed with an energy scale offset of -0.040 keV (red).

2 Windowed Timing Mode

In WT mode, a bias row is accumulated as the spacecraft slews to a new target. The bias row is then subtracted onboard from all of the subsequently recorded WT events. Recent investigations suggest that the bias level can vary significantly throughout an orbit. Figure 2 (top panel) shows a plot of the bias level from the bias row, along with the bias value estimated from the median of the last 20 pixels, which are telemetered with each WT frame (but without bias subtraction). A 30 DN (where 1 DN is approximately 2.6 eV) difference in the bias level is apparent from the start to the end of this particular orbit of data, which results in a shift of the CCD energy scale as the observation progresses. In this example, the maxium bias deviation occurs towards the the end of the orbit when the BR_EARTH angle is low (figure 2, bottom), suggesting scattered optical light is the cause. Other data reveal there is sometimes a correlation between the CCD temperature and overall bias level measured by the last 20 pixels.

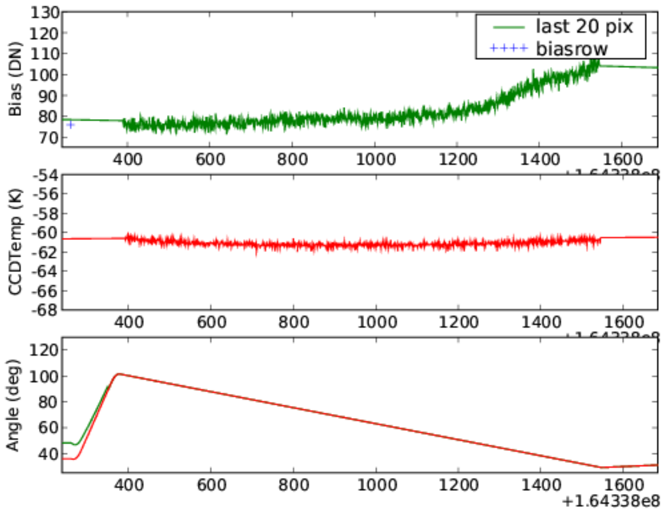

Figure 2: The top panel shows the bias level obtained from the WT bias row (blue cross) accumulated during the slew to a source, and the bias level estimated from the last 20 pixels telemetered with every CCD frame (green curve). A 30 DN (~ 80 eV) shift in the bias level is apparent from the start to the end of the orbit. The middle panel plots the CCD temperature, while the bottom panel plots the BR_EARTH (green) and ELV (red) angles. The x-axis in this figure has units of spacecraft clock time (seconds).

The FTOOL *xrtpipeline* (presently *Swift* software version 2.4) has a command-line option *wtbiasdiff* which, when invoked, uses the last 20 pixel data to make adjustments to the bias level for each frame of WT data. By default, this bias correction is not applied. The input parameter to *wtbiasdiff* is a threshold value (in DN). A bias correction is only made when the last 20 pixel bias estimate differs from the bias row obtained during the slew by more than the threshold value. For example, setting *wtbiasdiff* = 2 would apply a bias adjustment if the difference between the two bias estimates was greater than 2 DN. The actual implementation of the algorithm will be subject to change in a future release of the *Swift* software.

Figure 3 shows an example of the energy scale shifts which can be obtained when data are processed with and without the *wtbiasdiff* command. The spectra used in this example were obtained during the same time interval as the bias variation shown in figure 2. The default processing (i.e. no *wtbiasdiff*) is shown in black, while data processed with *wtbiasdiff* set to 5 and 2 DN are shown in red and blue, respectively. In this example, both *wtbiasdiff* processings shift the spectrum to lower energies by about 0.05 keV, though there appears to be no significant difference between the spectra for the two different threshold values.
We recommend that people analysing XRT WT data should process observations with and without the *wtbiasdiff* option in order to gauge the systematic uncertainties associated with the bias correction. The WT bias row is calculated onboard using a running mean algorithm. Until 2006 May 2, the running mean length (RML), which is used by the algorithm, was set to 3. The typical rms scatter in the bias row during this time was around 4 or 5 DN. In an attempt to reduce the pixel-pixel noise in the bias row the RML was changed to 10 on 2006 May 2nd resulting in a typical rms of 2 DN. The RML was further changed to 50 on 2006 June 29 resulting in an rms scatter of around 1 DN. There appears to be little benefit reducing the *wtbiasdiff* threshold below these typical rms values when performing the correction, That is, *wtbiasdiff* threshold values of between 1 to 5 DN seem to be appropriate for most observations.

Users should be aware that the last 20 pixel correction may not always be applicable if the source is near the right hand side of the WT window (in detector coordinates) so that it contaminates the frame-by-frame bias measurements with real source X-rays, though an event threshold is applied to discard potentially real X-ray events from the bias estimation. A typical WT source will have a PSF profile which extends to ~ 30 pixels in radius and, therefore, should ideally be

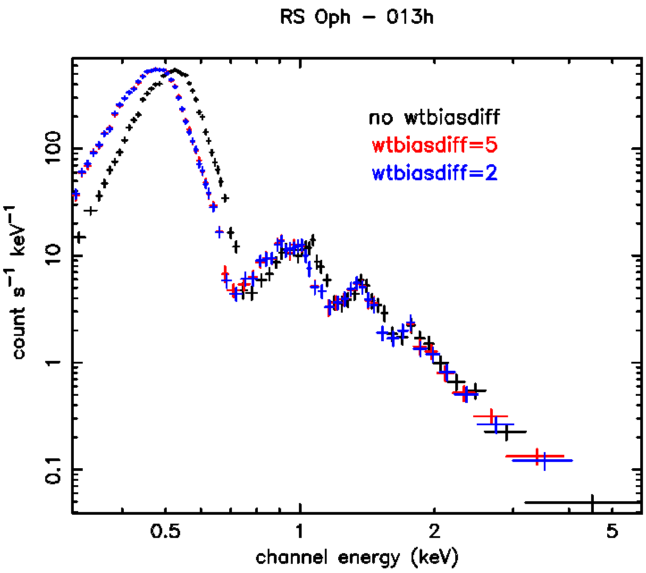

Figure 3: Spectra from a single orbit of WT data on the recurrent nova RS Oph, which were obtained by processing the data without *wtbiasdiff* (black), and with *wtbiasdiff* set to 5 (red) and 2 (blue) DN, respectively. The spectrum of this source is shifted to lower energies by approximately 0.05 keV when *wtbiasdiff* is used, though there is little difference between the individual spectra obtained for *wtbiasdiff* = 2 or 5 DN.

placed at a detector X coordinate DETX< 350 when *wtbiasdiff* is used. If the source is badly placed then the systematic effects associated with the energy scale offsets may have to be dealt with by other means — for example, the *gain* command in XSPEC.

Energy scale offsets most readily result in significant spectral fit residuals at low energies. In extreme cases, low energy count rates can be affected also.

3 Photon Counting Mode

Like the bias row in WT mode, the PC mode bias frame is updated as *Swift* slews onto a new target and it is then subtracted from all subsequent PC frames onboard. The PC mode bias level is, also, susceptible to changes in the CCD temperature and scattered optical light levels, which means the automatically subtracted bias map can be inappropriate at later times as the observation on a target progresses.

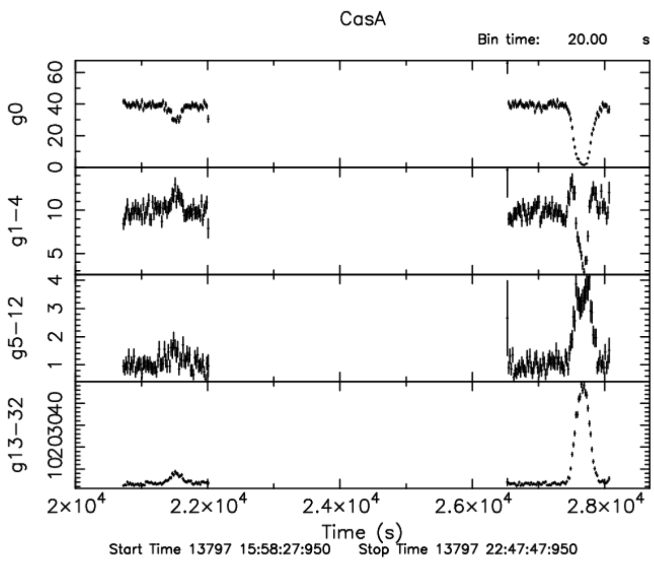

Figure 4: Light curves obtained during a PC mode observation of the SNR Cas A, illustrating a dramatic grade migration to larger event sizes at 2.767×10^4 s into the observation. The top to bottom panels show light curves in grades 0, $1-4$, $5-12$, and $13-32$, respectively. The effect is also visible, though to a lesser extent, in the previous orbit at 2.150×10^4 s.

The effect this can have on PC mode data was dramatically illustrated during a routine calibration observation of the supernova remnant Cas A. During this observation, a broad dip was seen in the grade 0 light curve from this constant source, and the event grade distribution was found to migrate towards larger event sizes (see figure 4). A detector coordinate image created during the dip revealed that scattered optical light contaminated the data at this time (figure 5).

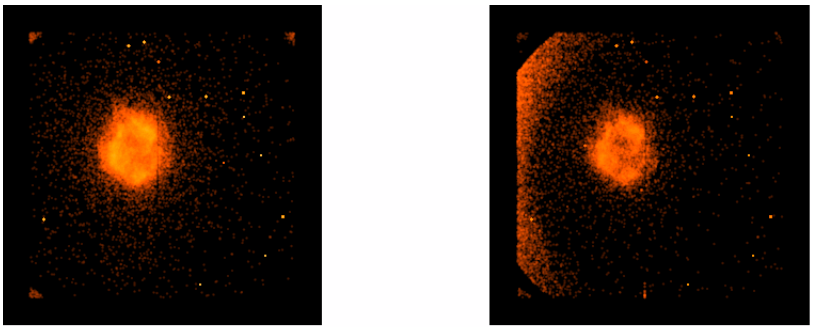

Figure 5: Detector coordinate images obtained during the light curve pre-dip (left) and dip intervals (right) from figure 4, which show scattered optical light contaminating the latter.

PC mode bias level variations of this type can give rise to energy scale offsets in a manner analagous to the ones seen in the WT data shown above. For example, figure 6 shows spectra obtained during the pre-dip and dip time intervals of figure 4. We see the Si-Kα and S-Kα lines are shifted in energy by $\sim 100\,\mathrm{eV}$ during the period of scattered optical light contamination.

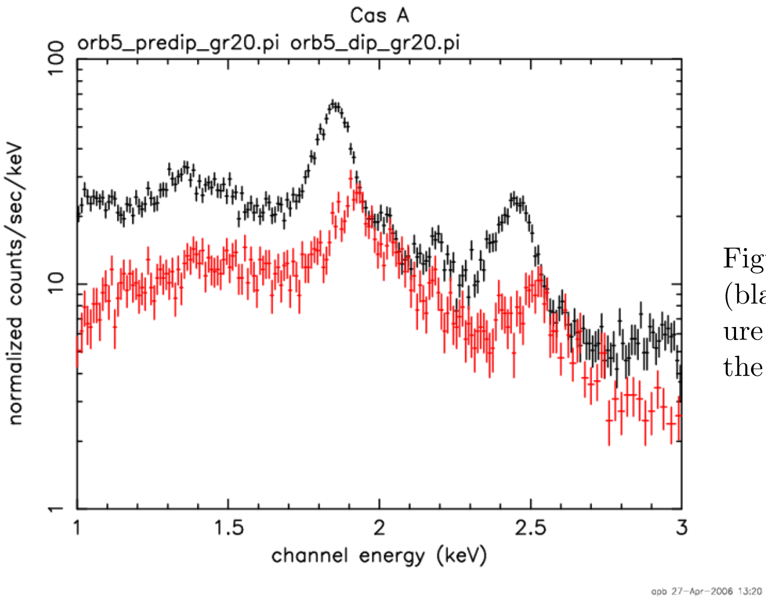

Figure 6: Spectra from the pre-dip (black) and dip (red) intervals of figure 4, showing a shift of $\sim 100\,\mathrm{eV}$ in the energy scale during the latter.

At present, there is no automatic procedure available to correct PC mode data for these effects, though one is planned for a future release of the *Swift* XRT software tools.[1]

We can only warn users to be aware that such problems can exist, and, if necessary, exclude time intervals of affected data from further analysis.

[1]When a valid X-ray event is identified on-board in PC mode the central pixel event energy is telemetered, along with the values in the surrounding 8 pixels. It is possible to use the mean of the corner pixel values for grade 0 events to track the bias level in a frame. This information can then be used to correct the original event array for bias level deviations before reprocessing the data fully (including re-grading the events).