SWIFT-XRT-CALDB-12

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SWIFT XRT CALDB RELEASE NOTE SWIFT-XRT-CALDB-12: Response matrices and Ancillary Response Files

Table 1: Component files being a part of this release. The WT unbroadened kernel RMFs **swxwt0s0_20010101v011.rmf** and **swxwt0to2s0_20010101v011.rmf** should be used for WT data collected before 01-03-2007. The PC RMFs (**swxpc0s0_20010101v011.rmf** and **swxpc0to12s0_20010101v011.rmf**) and (**swxpc0s6_20010101v011.rmf** and **swxpc0to12s6_20010101v011.rmf**) should be used for PC data collected at $V_{ss} = 0$ & 6 V, respectively. The PC RMFs and the WT unbroadened kernel RMFs (**swxwt0s0_20010101v011.rmf** and **swxwt0to2s0_20010101v011.rmf**) have been described in the previous release note SWIFT-XRT-CALDB-11.

Filename	Mode	Grade	Substrate* voltage (V)	Start time°	End time°	Date
swxwt0to2s0_20070301v011.rmf	WT	0-2	0	01-03-2007	31-08-2007	07-04-2009
swxwt0to2s0_20070901v011.rmf†			0	01-09-2007		
swxwt0to2s6_20070301v011.rmf‡			6	01-03-2001	31-08-2007	
swxwt0to2s6_20070901v011.rmf			6	01-09-2007		
swxwt0s0_20070301v011.rmf	WT	0	0	01-03-2007	31-08-2007	07-04-2009
swxwt0s0_20070901v011.rmf†			0	01-09-2007		
swxwt0s6_20070301v011.rmf‡			6	01-03-2001	31-08-2007	
swxwt0s6_20070901v011.rmf			6	01-09-2007		

*The substrate voltage was permanently raised from $V_{ss} = 0$ V to $V_{ss} = 6$ V on 2007 August 30 (see Section 4).

° Start and end validity time when the PC and WT RMFs should be used.

† The $V_{ss} = 0$ V RMFs **swxwt0s0_20070901v011.rmf** and **swxwt0to2s0_20070901v011.rmf** are a copy of the $V_{ss} = 6$ V RMFs **swxwt0s6_20070901v011.rmf** and **swxwt0to2s6_20070901v011.rmf**.

‡ The $V_{ss} = 6$ V RMFs **swxwt0s6_20070301v011.rmf** and **swxwt0to2s6_20070301v011.rmf** are a copy of the $V_{ss} = 0$ V RMFs **swxwt0s0_20070301v011.rmf** and **swxwt0to2s0_20070301v011.rmf**.

1 Scope of Document

This note describes the release of the *Swift* XRT epoch-dependent redistribution matrix (RMF v011) (see Table 1). Files are released only for the Windowed Timing (WT) mode and two different grade selections (grade 0 and grades 0-2).

The XRT effective area is made by three main components: the mirror effective area, the CCD quantum efficiency (QE) and the filter transmission. The QE is included directly in the redistribution matrix files (RMFs). The auxillary response files (ARFs) contain the mirror effective area, the filter transmission, as well as the vignetting correction and the Point Spread Function (PSF) correction (which depends on the source location and of the size of the extraction region, as well as on defects on the CCD). Here we report on the CALDB RMF and ARF files which represent the effective area of the telescope for a nominal on-axis observation (no vignetting correction) and for an infinite region of interest (no correction for PSF losses). RMF files do not include the PSF correction and do not depend on the source position on the detector. The CCD soft energy response is sufficiently uniform within the central 200x200 pixels (see e.g. previous RMF release notes), therefore there is just one RMF file per mode and grade selection and per epoch. The ARF files, instead, need vignetting and PSF corrections and, therefore, need to be built for each observation. To produce the observation-specific ARF files, the XRTMKARF task (XRTDAS-HEADAS software) has been developed. This task corrects the nominal ARF file for the vignetting and, optionally (psfflag=yes), for PSF losses. This task includes corrections for CCD defects with the inclusion of an exposure map automatically generated by the data analysis pipeline (expofile=filename.img). The adopted calibration method implies that we include the residual correction of the CCD quantum efficiency in the CALDB ARF files, accounting for why the nominal ARF files are different for different grade selection.

Motivations of this release:

Radiation and high-energy proton damage on the CCD (the imaging area, the store frame area and the serial register) over time result in the build-up of charge traps (i.e. faults in the Si crystalline structure of the CCD). The deepest faults are responsible for the line FHWM degradation, the line shape then showing a more pronounced low energy wing (see Section 2 and Fig. 1(a)). The most serious of these charge traps can cause a loss of up to 350 eV from the incident X-ray energy.

In this release, the WT RMFs are newly computed files including an epoch-dependent broadened kernel handling the evolution of the line broadening over time (see below), while the PC unbroadened kernel RMFs and the WT & PC ARFs are the same as those issued in the previous release SWIFT-XRT-CALDB-11.

File naming scheme:

On 2007 August 30 (at 14:28UT), the CCD substrate voltage was raised from $V_{ss} = 0\,\mathrm{V}$ to $V_{ss} = 6\,\mathrm{V}$. The change was made in order to reduce the thermally induced dark current in the CCD, which allows the XRT to collect useful science data at slightly higher temperatures (3 to 4 C) than was possible before the change. The change in substrate voltage has made it necessary to release two sets of RMF/ARF files, now distinguished by the characters 's0' and 's6' in their file names. At the moment the $V_{ss} = 6\,\mathrm{V}$ files are placeholders and identical to the 0V files (see the previous release SWIFT-XRT-CALDB-11 and see Table 1).

To model the evolution of the XRT spectral response over time, we release three sets of WT RMFs (for both grade 0 and grades 0-2). The first set of WT RMFs (being the same as those issued in the previous release SWIFT-XRT-CALDB-11) should be used for data collected from launch to 2007 February 28 (**swxwt0to2s0_20010101v011.rmf** and **swxwt0s0_20010101v011.rmf**). The second and third sets of WT RMFs including an epoch-dependent broadened kernel should be used for data collected from 2007 March 1 to 2007 August 31 (**swxwt0to2s0_20070301v011.rmf** and **swxwt0s0_20070301v011.rmf**) and from 2007 September 1 onwards (**swxwt0to2s6_20070901v011.rmf** and **swxwt0s6_20070901v011.rmf**), respectively. (see Table 1 and Fig. 2). The PC RMFs are the same as those issued in the previous release SWIFT-XRT-CALDB-11 (**swxpc0s0_20010101v011.rmf**, **swxpc0s6_20010101v011.rmf** **swxpc0to12s0_20010101v011.rmf** and **swxpc0to12s6_20010101v011.rmf**).

2 RMF generation

The Response Matrix Files (RMFs) are created by a Monte-Carlo simulation code (Godet et al. 2009, A&A, 494, 775, Godet et al. 2007, SPIE, 6686, 6686OA1). This code models: transmission of the incident X-rays through the CCD electrode structure; photo-absorption in the active layers of the device; charge cloud generation, transportation and spreading; silicon fluorescence and its associated escape peak; surface loss effects; mapping of the resultant charge-cloud to the detector pixel array; charge transfer efficiency; addition of electronic read-out noise; event thresholding and classification according to the specific mode of operation.

Past improvements: In the release SWIFT-XRT-CALDB-08, in orbit observations of the soft calibration sources were used to refine the surface loss function in order to better match the spectral redistribution at low energies. While for heavily absorbed sources, the parameterisation of the redistribution of high energy X-rays down to low energies was improved for both PC and WT modes (using SNR G21.5, SGR 1900+14 & NGC 7172 for PC, and

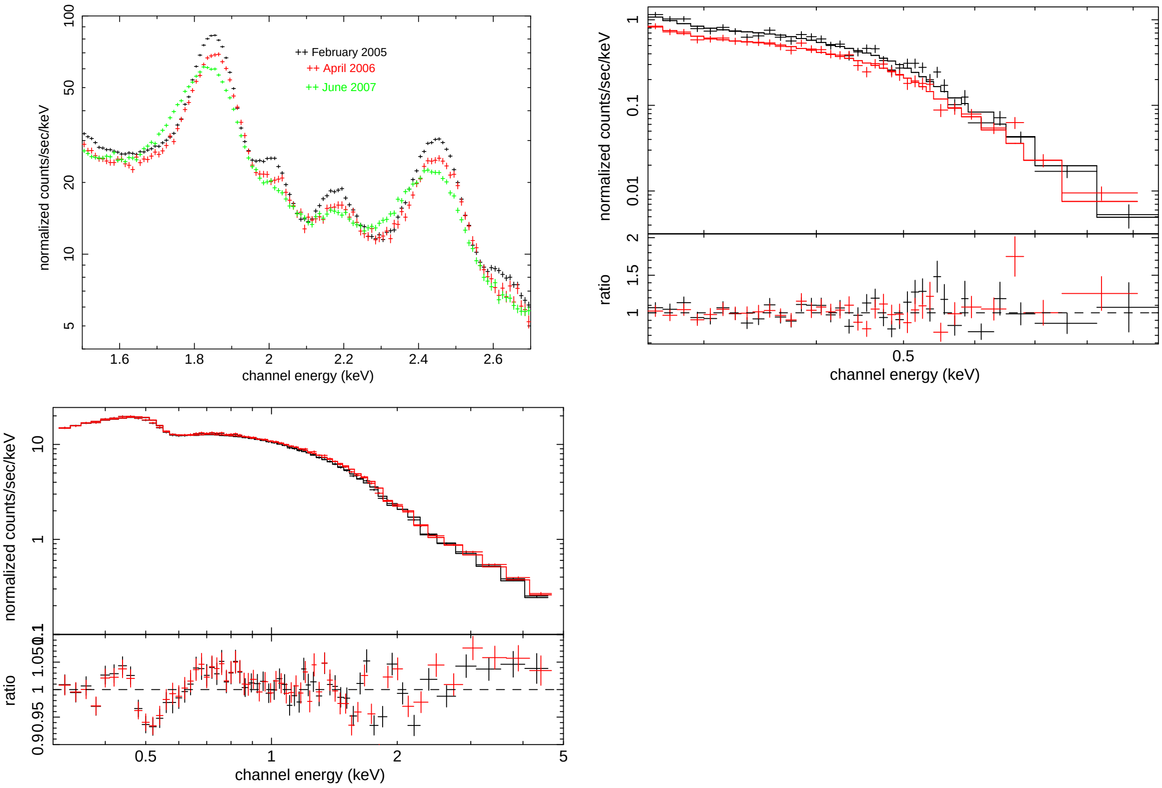

Figure 1: Effect due to the degradation of the FHWM over time is due to the build-up of charge traps on the CCD over time. **(a)** WT grade 0-2 spectra of the SNR Cas A (black crosses: from February 2005 data - red crosses: from April 2006 - green crosses: from June 2007 data. The energy resolution (FWHM) of the Si Kα lines increases from 105 eV in February 2005 to about 131 eV in June 2007. **(b)** Evolution of the PC grade 0 spectrum of the soft neutron star RX J1856.4-3754 over time: (red) data from February 2005 (a constant factor of 0.96 ± 0.03) and (black) data from June 2007 (a constant factor of 0.76 ± 0.03). The spectra were fitted using the unbroadened v011 RMF (**swxpc0s0_20010101v011.rmf**) and the model described in Beuermann et al. (2006, A&A, 458, 541). Only orbits of data when the source was not on the bad columns were used to make the spectra. When using the unbroadened v011 WT g0 RMF (**swxwt0s0_20010101v011.rmf**), a similar evolution is also observed in WT mode with a constant factor of 0.96 ± 0.03 from February 2005 data and 0.80 ± 0.03 from June 2007. The decrease of the spectral evolution is due to the build-up of charge traps on the CCD over time so that a fraction of low-energy events are lost below the on-board event threshold. **(c)** WT grade 0 (black) and 0-2 (red) spectra of Mkn 421 observed in March 2007 fitted using the unbroadened v011 WT response files (**swxwt0s0_20010101v011.rmf & swxwt0to2s0_20010101v011.rmf**). The spectra were fitted using an absorbed bended power-law i.e. WABS * exp[-α+β ln(E)] with the column density fixed at $N_H = 1.6 \times 10^{20}$ cm^{-2}. The WT spectra contain more than 2×10^5 counts.

GROJ1655-40, 4U1608-52, XTE J1701-462 & GX17+2 for WT) by including a correction to the loss-shelf (see the release note SWIFT-XRT-CALDB-10). For PC mode, a new charge-cloud spreading model was implemented following the theory of Pavlov & Nousek (1999 NIMA 428 348), which better accounts for sub-threshold losses seen in the more energetic multi-pixel events (see the release SWIFT-XRT-CALDB-10). In the release SWIFT-XRT-CALDB-11, a slight change in the loss function parameters between 1 keV and 2 keV in WT mode was implemented to suppress the 10% residuals around 0.9-1 keV only visible in high statistical spectra. A new set of PC and WT ARFs were also released along with the release of the WT gain file SWXWTGAINS0_20010101V008.FITS. For both modes, updated Charge Transfer Inefficiency (CTI) values were used, which are more appropriate for the CTI degradation suffered in orbit during the middle of 2006.

Improvements specific to this release:

We computed WT RMFs including an epoch-dependent broadened kernel enabling us to handle the line broadening seen over time. Indeed, we started observing a degradation of the energy resolution, from 146 eV at 5.9 keV in February 2005 to 210 eV in March 2007 (based on the on-board calibration Mn Kα and Kβ sources permanently illuminating the 4 corners of the CCD i.e. regions outside the CCD imaging area) due to the build-up of charge traps on the CCD due to radiation and high-energy proton damage (see panel (a) in Fig. 1 which illustrates the broadening in the line rich SNR Cas A). The broadening of lines is due to the energy scale shifting effect of traps in the pixels through which the charge has to be transported. The build-up of charge traps on the CCD also results in:

i) a loss of events at low-energy below the on-board energy threshold (see panel (b) in Fig. 1) implying a decrease of the apparent flux level by 15-20% from February 2005 to June 2007 when fitting the spectra of the soft neutron star RXJ1856.4-3754; ii) negative residuals (less than 10%) around the instrumental edges in featureless spectra which started to be clearly observed from March 2007 in high statistical quality PC & WT spectra (see panel (c) in Fig. 1).

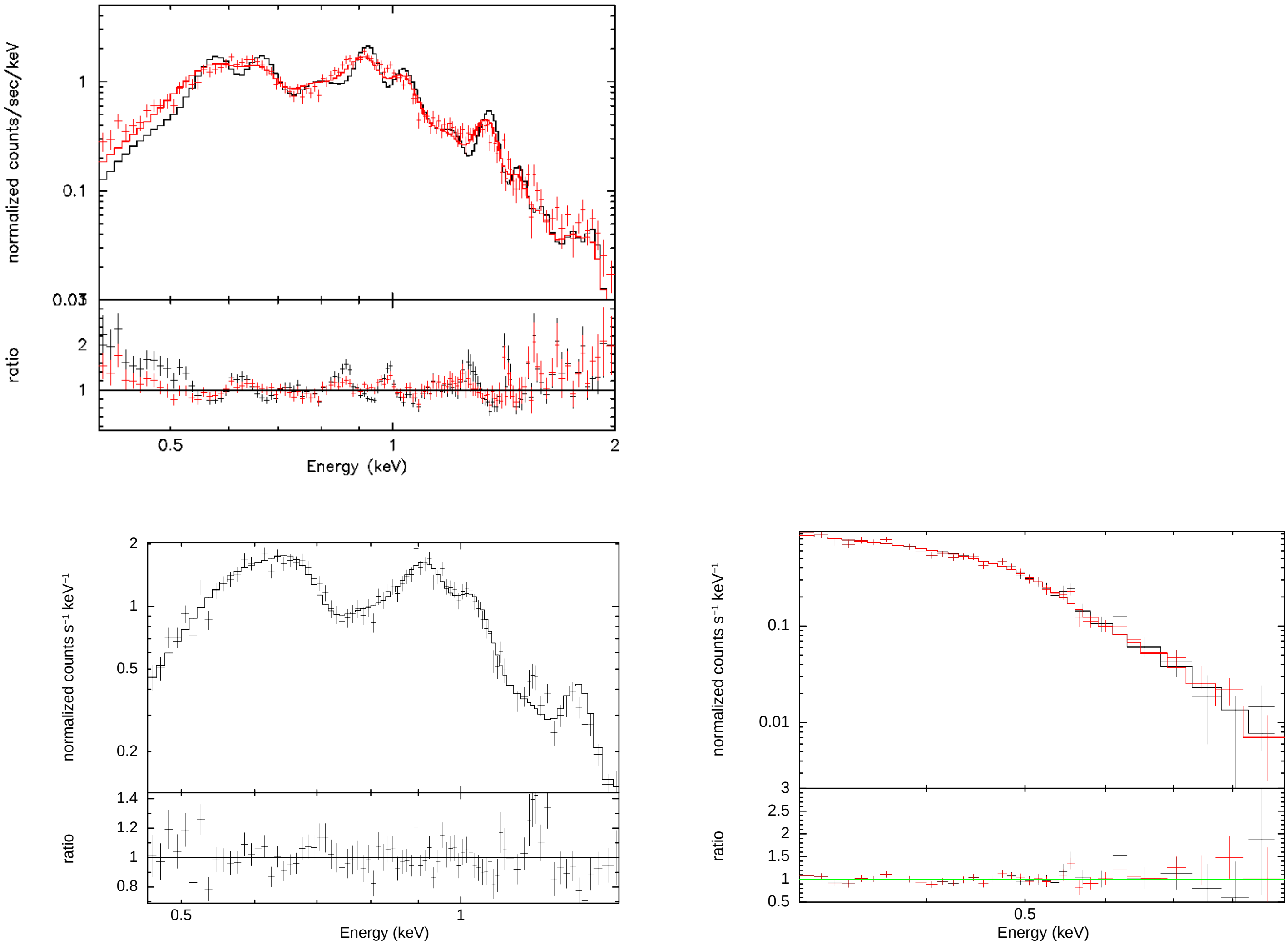

Figure 2: Top panel - SNR E0102-72.3 from June 2007 data (black: the current WT grade 0-2 RMF **swxwt0to2s0_20010101v011.rmf**; red: the new broadened WT grade 0-2 RMF **swxwt0to2s0_20070301v011.rmf**). The spectral model is based on an XMM/RGS-PN model (see Plucinsky et al. 2008, Proc. SPIE, arXiv0807:2176). Bottom left panel - SNR E0102-72.3 from August 2008 data fitted using the new broadened WT grade 0-2 RMF **swxwt0to2s6_20070901v011.rmf** and the XMM/RGS-PN model. The WT grade spectra contain more than 2×10^4 counts. In both cases, the spectra were extracted using data when the source was not located on the bad columns. Bottom right panel - RXJ 1856.4-3754 from July 2008 g0 (red) and g0-2 (black) data using the new broadened WT RMFs (**swxwt0s6_20070901v011.rmf**). The spectrum is fitted using the model described in Beuermann et al. (2006, A&A, 458, 541). The normalisation relative to that given in the Beuermann et al. model is $C = 0.92 \pm 0.02$; which is close to that derived using 2005-2006 data of RX J1856.4-3754 ($C = 0.96 \pm 0.03$).

To produce these new WT RMFs, we convolved each of the 2400 monochromatic line input spectra of the v011 WT RMFs (see Godet et al., 2009, A&A, 494, 775) with a function f. The profile of the function f should depend on several parameters related to the physical behaviour of charge traps on the CCD such as i) the position of the charge traps on the CCD; ii) their depth (i.e. their energy shifting effect); iii) the photon energy; iv) the CCD temperature which could affect the time relaxation of the trapped charges; v) the source count rates which, if too high, can fill completely the charge traps so that their effects on the spectral response are no longer visible. However, most of this information is unknown, and therefore it is not possible to work out the exact profile of the function f with energy. So, we defined an empirical function f, its energy-dependent width was calibrated using an iterative method based on fits of several datasets: Mkn421 (from March 2007 to February 2009), the SNR E0102-72.3 (from June 2007 to

August 2008), RX J1856.4-3754 (from June 2007 to August 2008). Fig. 2 shows a comparison of the performance of these new WT RMFs when compared with these obtained using the version 11 WT RMFs (designed for data collected before 2007 February 28). In all cases, the residuals are flattened. These new WT RMFs also enable to retrieve a value of the normalisation relative to that given in the Beuermann et al. (2006, A&A, 458, 541) model ($C = 0.92 \pm 0.02$ from July 2008) close to that derived using 2005-2006 data of RX J1856.4-3754 ($C = 0.96 \pm 0.03$), since the QE profile at low energy takes into account the fraction of events lost below the on-board threshold (see Fig. 3).

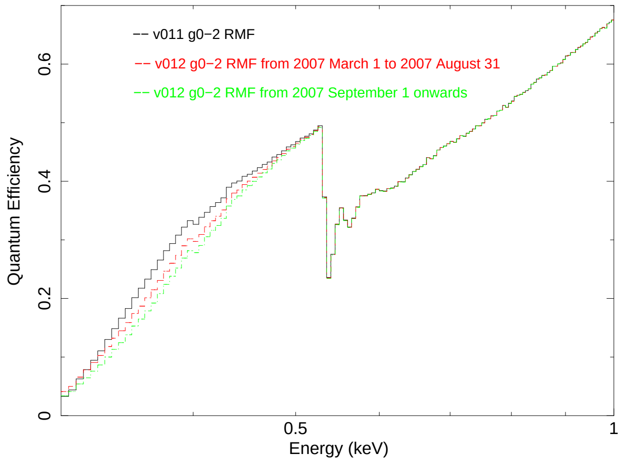

Figure 3: WT grade 0-2 QE curves in the 0.3-1 keV energy band: (black) v011 RMF, (red) v011 RMF to be used from 2007 March 1 to 2007 August 31; (green) v011 RMF from 2007 September 1 and onwards. The loss of QE at low energy in the v011 RMFs is due to the loss of events below the on-board central event threshold due to the build-up of charge traps.

3 Current limitations and future prospects

We recommend to fit the XRT WT spectra in the 0.3-10 keV energy range with these epoch-dependent XRT response files (version 11). The following considerations apply to both WT and PC mode observations:

- 10-15% spectral fit residuals in the 1.5-2 keV energy band can be visible in high statistical quality spectra (mostly in WT mode, because the sources observed are much brighter) using the v011 response files (also visible using previous versions). This is due to an overestimation of the effective area in that region induced by the change of the substrate voltage from 0 V to 6 V, which slightly reduced the depletion depth. The creation of both PC and WT RMFs including the effective area correction is under investigation and will be released as soon as possible.

- The v011 WT RMFs with a broadened kernel are designed to model the averaged behaviour of the line broadening in a given time interval. We have investigated the effects of source count rates (below 50 counts s^{-1}), CCD temperatures (from $-70°$C to $-50°$C) and location of the sources in the WT window (from column 200 to column 400) during the calibration of the v011 WT RMFs. Even if these latter parameters are in the ranges considered (and on the calibration sources considered they seem to have a second order effect), we cannot garantee that the broadening of the WT RMF kernel will be suitable in every case. In particular, the broadening scheme adopted in this release treats only the average behaviour of the increasing charge traps. Individual traps may affect specific datasets more strongly.

- The creation of PC RMFs with a broadened kernel is under investigation and will be released as soon as possible.

- Prospects to implement a column by column description of the bias correction in the ground software enabling to correct for the effects of traps are under investigation for PC and WT data after June 2007 (see Fig.4 in the release SWIFT-XRT-CALDB-11 and Godet et al. 2009, A&A, 494, 775).

- Even if the new WT broadened RMFs significantly improves the fitting residuals, there is still room for improvement.