Swift XRT ancillary response files v3.0

XRT-I-CAL-1-2005
Release version: ARF-3.0
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1. Introduction

This note describes release 3.0 of the Swift XRT ancillary response files. Ancillary Response Files (ARF) are released for each XRT mode (Photon Counting, PC, Window Timing, WT, and Low Rate PhotoDiode, LRPD) and for two/three different grade selections for each mode[1].
The XRT effective area is made by three main components: the mirror effective area, the CCD quantum efficiency (QE) and the filter transmission. In XRT the QE is included directly in the redistribution matrix (rmf). In the ARF files are instead included the mirror effective area and filter transmission, as well as the vignetting correction and the Point Spread Function correction, as a function of the source location and on the size of the extraction region.
Here we report on the CALDB ARF files which represent the effective area of the telescope for a nominal on-axis observation (no vignetting correction) and for a infinite region of interest (no correction for Point Spread Function, PSF, losses). To produce the observation specific ARF files, the xrtmkarf task (headas software) has been developed. This task corrects the nominal ARF file (here described) for the vignetting and, optionally (default=yes), for PSF losses.

2. ARF generation

In testing the XRT efficiency we make use of the latest rmf matrices (now v7.0, see XRT-LUX-CAL-108) and tune the different ARF files on celestial sources. This method is a macroscopic one since it does not try to start from basic physical processes (which might be too difficult given the large parameter space to be explored) but simply hide our ignorance of the global process (mirror reflectivity, photon detection, signal reconstruction, etc.) relying on well known, stable astrophysical sources.
Crab-like supernova remnants are sources characterized by well known energy spectral distributions, stable with time. Thanks to these characteristics these objects are the best candidates for in-flight calibration of the global effective area of X-ray telescopes.
Crab nebula and PSR B0540-69 have been used to calibrate the XRT effective area for the three XRT observing modes at this stage.

- To calibrated the LRPD ancillary files we started from the ancillary files generated from on-ground calibrations and apply a procedure of ARF optimization in order to have a good

[1] Note fort the skilled readers: The adopted calibration method implies that in the CALDB ARF files we include the residual correction of the CCD quantum efficiency. This explains why the nominal ARF files are different for different grade selection.

description of the Crab data with the very well known spectral model parameters reported in the literature.

The idea behind this approach is that the XRT spectrum is compared and forced (modelling the existent residuals) to be consistent with the observed one.

This procedure allows to produce a final LRPD ARF file that applied to Crab data reproduce its spectral energy distribution with best fit parameters consistent with those reported in previous works performed with data from other satellites (BeppoSAX: Massaro et al. 2001, A&A 361, 695; RXTE: Pravdo et al. 1997, ApJ, 491, 808).

We consider a 6742 s exposure, resulting in 5.5 10^6 counts (0.5-10 keV, due to the high absorption in the Crab nebula we can not calibrate the spectrum below 0.5 keV for the moment). In Figure 1 we show the residuals obtained fitting the LRPD Crab data with an absorbed power law, after correcting the ARF file. This has been done using a 0-5 grade selection (according to XMM-Newton nomenclature). The reduced χ^2 is 1.5 (919 degrees of freedom, dof), formally yet not acceptable, but enourmously improved with respect to ground matrices. We estimate a systematic uncertainty at the level of 5% for all LRPD ARF matrices in the 0.5-10 keV energy range. The strongest features are an absorption feature around 5 keV and an excess above 8 keV.

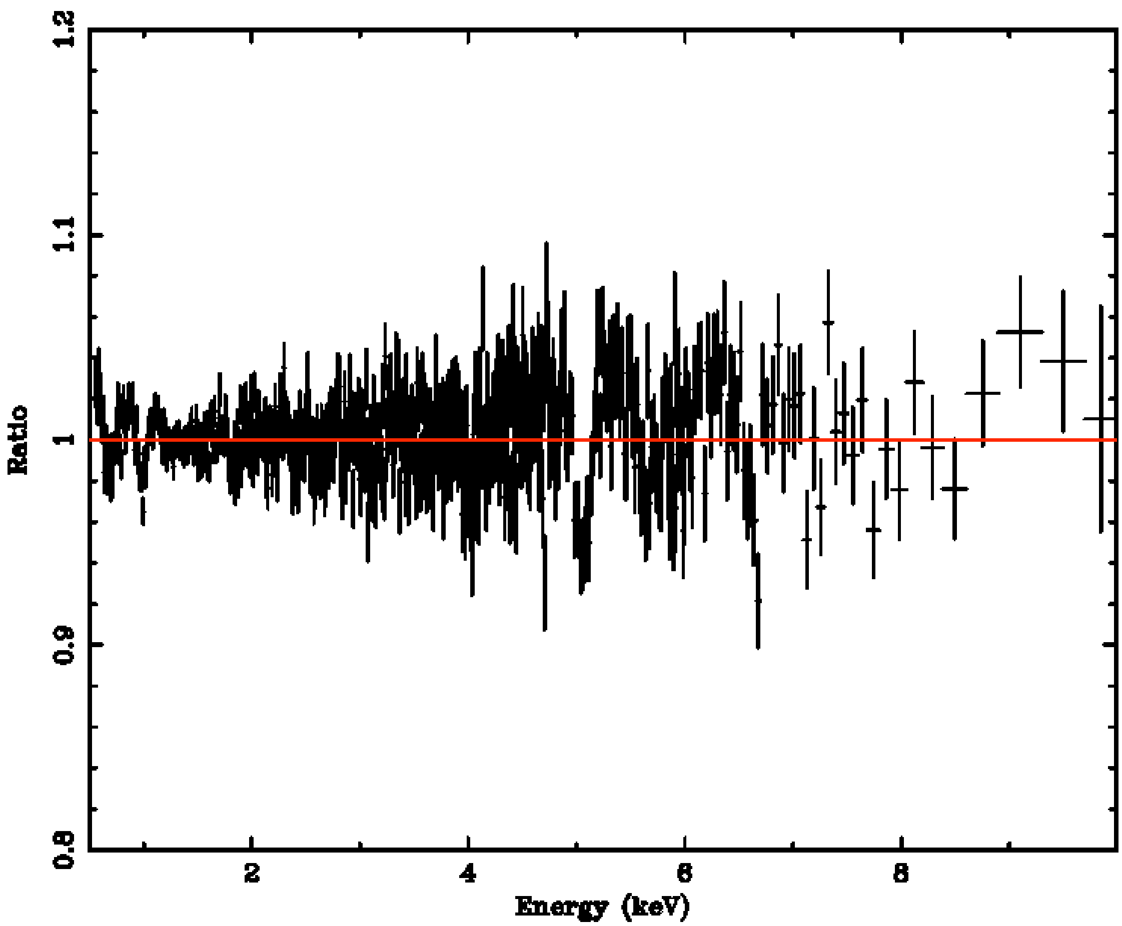

Figure 1: Residuals of the Crab spectrum in LRPD mode (grade 0-5).

• In the case of the WT mode we still used the Crab nebula as calibrator but in this case we have to deal with a moderate pile-up in the Crab. The observation has a 4373 s exposure. We consider the outer region of the nebula (rejecting the central part) in order to reduce (but not completely eliminate) pile-up effects, resulting in 2.2 10^6 counts (0.5-10.0 keV).

Figure 2 shows the residuals obtained by fitting the outer region of the Crab nebulae with an absorbed power law. We consider as spectrum of the Crab Nebula that reported in Massaro et al. 2001, even if there are hints of a relatively softer spectrum in the outskirts of the nebula. The fit is relatively good with χ^2 is 1.4 (943 degrees of freedom, dof). We estimate a systematic uncertainty at a level of 5% for all grades and in the 0.5-10 keV energy range. The strongest features are an emission line around 0.6 keV and an absorption feature around 0.5 keV.

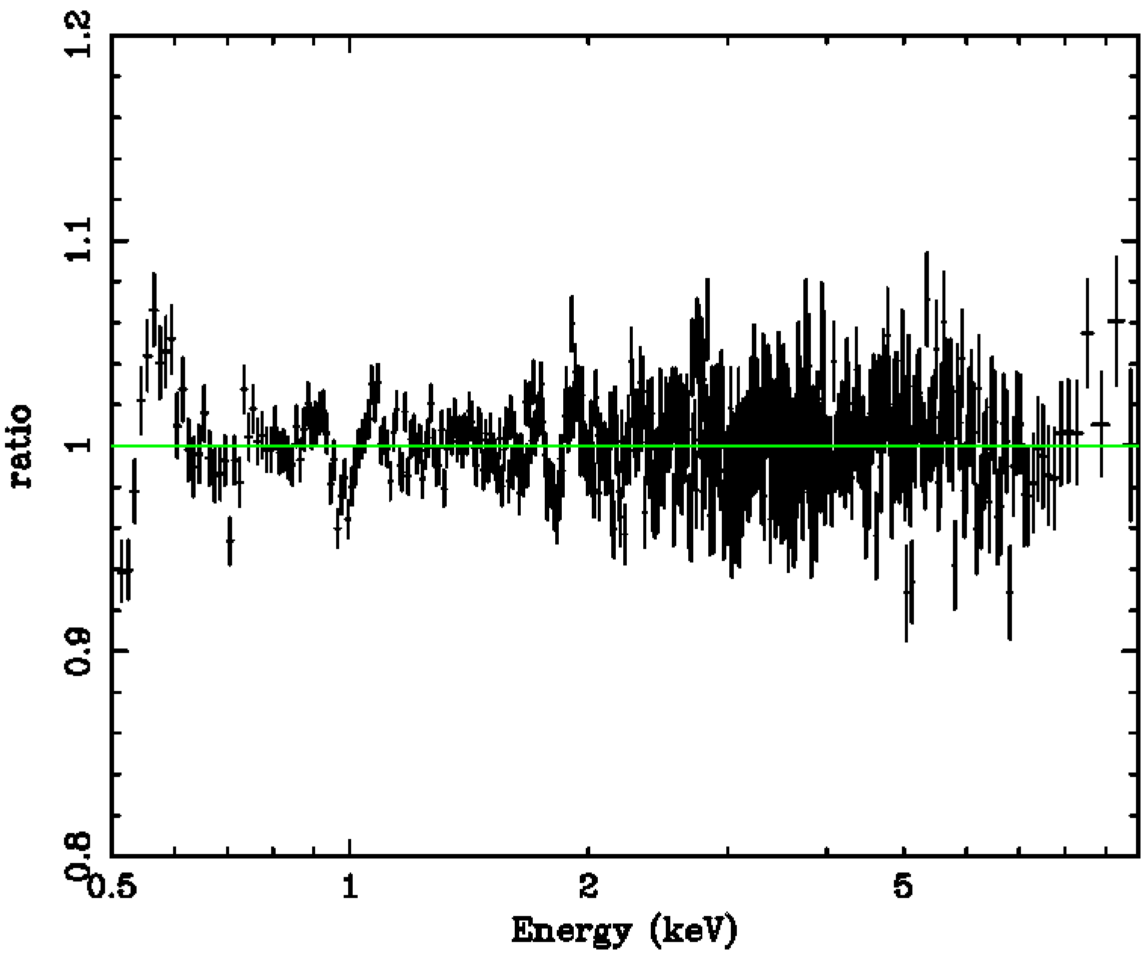

Figure 2: WT residuals of the Crab spectrum (grade 0-2).

• In PC mode the ancillary files have been calibrated with the Crab-like plerion PSR B0540-69. The source is well suited for calibrating the PC mode with a count rate of about 0.7 counts s^{-1}, and its moderate nebular extension, about 10-15 arcseconds, do not cause pile-up in the PC frame time of 2.5 seconds. Calibration was performed on a data set of 32 ks of XRT exposure with a statistics of 22400 counts in 0.2-10 keV energy band. As for the Crab in LRPD and WT mode, the ancillary files were calibrated by modifying the on-ground ARF files in order to reproduce the PSR B0540-69 best fit parameters reported in literature from previous X-ray missions (ROSAT PSPC, BeppoSAX MECS and XMM-Newton).

Figure 3 shows data, best fit model and the fit residuals obtained with the in-flight PC ARF file that we derived with the above procedure. The plerion parameters are well known as for the Crab and this induces some more scatter in the final result. The χ^2 is 1.3 (340 dof). The statistical uncertainty on the final ARF matrices in PC mode is higher than for the other modes and is at the moment estimated at 10% level in the 0.5-10 keV energy range, however due to high asborption we cannot probe direcly the spectrum below 0.5 keV hiding larger uncertainties. A strong and broad emission feature is present around 0.6 keV.

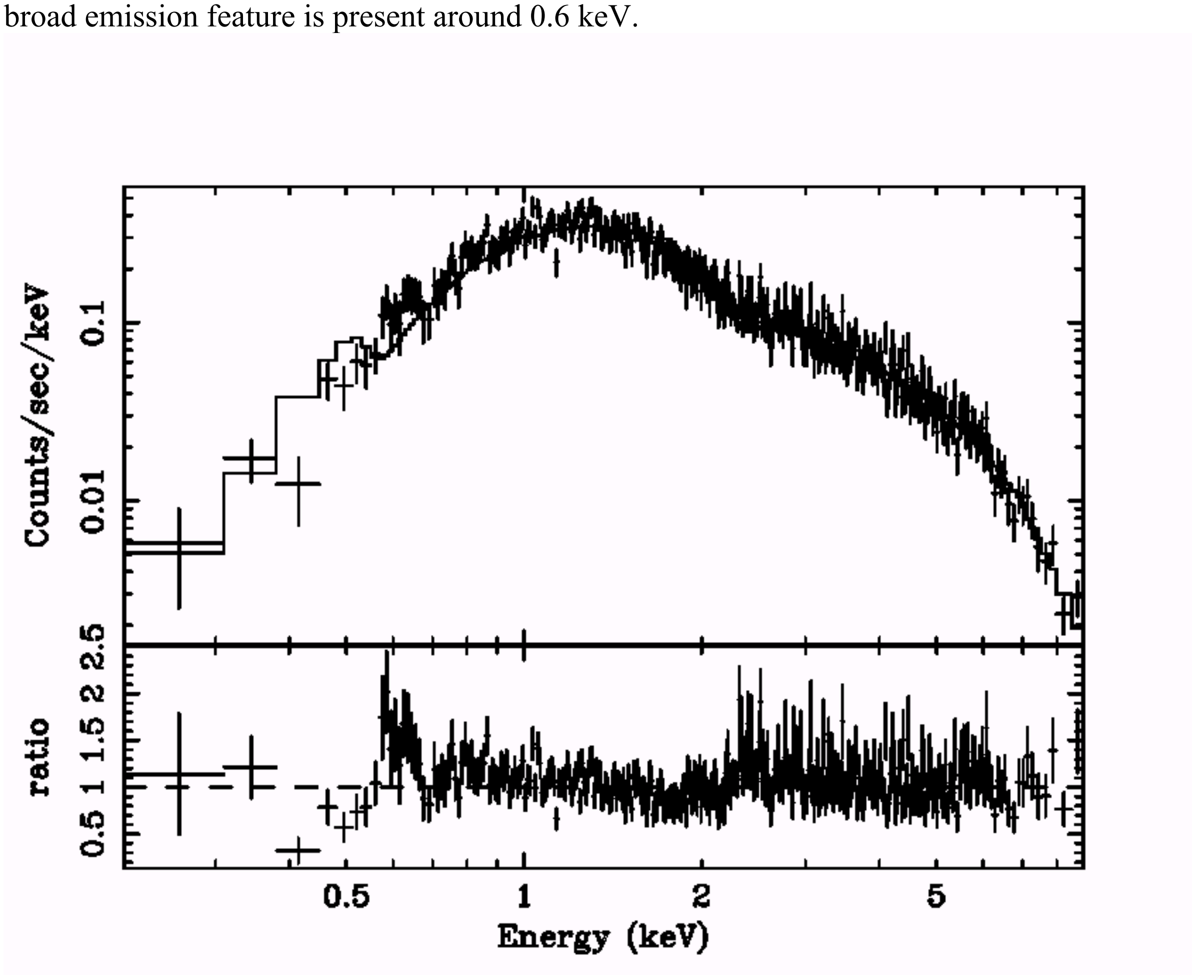

Figure 3: XRT spectrum (grade 0-12) of PSR B0540-69 in PC mode (upper panel) together with its residuals (lower panel).

3. Future prospects

We are working on further improvement in the ARF matrices, especially at the low energy part of the spectrum. We plan to improve the response of WT and PC modes down to 0.3 keV using soft calibrators. A cross-calibration campaign with XMM-Newton is going to take plane in June 2005, allowing us to further improve WT and PC ARF files.

4. Vignetting

The XRT mirrors suffers for a reduction of the-off axis collecting area called vignetting.
We adopted a vignetting function $V(\theta)$ of the type (with θ the off-axis angle)

$$V(\theta) = 1 - C\,\theta^2$$

where the coefficient C is expressed as a function of energy by:

$$C(E) = P_0 \times E^{P_1} + P_2$$

(with P_0, P_1 and P_2 parameters to be confirmed observationally and the energy measured in keV). The XRT vignetting parameters have been tested by fitting Crab data observed at different off-axis pointings from 3' up to 7.5' off-axis angles. The best fit parameters are reported in Table 3.

Table 3: Fit at different off-axis angles.

Off-axis (arcmin)	N_H (10^{22} cm^{-2})	Photon index	Norm	χ^2_{red}
2.9	0.361±0.002	2.105±0.004	9.61±0.05	1.2
4.9	0.397±0.01	2.19±0.02	10.6±0.2	0.97
5.8	0.354±0.002	2.074±0.005	8.680.05	1.1
7.5	0.384±0.007	2.14±0.01	10.2±0.2	0.98

5. XRT-BAT intercalibration

To accurately inter-calibrate XRT with BAT we used the phase resolved Crab nebula emission. In fact, the Crab emission is made up of two distinct components: the pulsar emission and the nebular emission. Phase resolved spectroscopy has shown that the pulsar emission is harder than the nebula emission and the relative contribution of the two components changes, therefore, with the energy. Moreover, only the nebular component shows a spectral distribution modelled by a power law with a constant photon index between 0.1-300 keV energy band (Massaro et al. 2001). The nebular emission from Crab was fitted by an absorbed power law plus a constant factor to take into account the differences in the absolute flux determination between the two instruments.

The constant factor for XRT was fixed to 1. The BAT inter-calibration factor (using the 27 March 2005 release matrix) relative to the XRT results to be about 0.82±0.05.