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Title: Reproducibility of the HXD-PIN Non X-ray Background
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Author: T. Mizuno et al.
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Reproducibility of the HXD-PIN Non X-ray Background

T. Mizuno, H. Takahashi, K. Nakazawa, Y. Terada, M. Ushio,
H. Shirai, T. Yamasaki, T. Yasuda, M. Sasada, N. Isobe, A. Bamba,
Y. Fukazawa, M. Kokubun, S. Watanabe and the HXD-team
e-mail: mizuno@hepl.hiroshima-u.ac.jp

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1 Introduction

The HXD (Hard X-ray Detector) is designed to have a very high signal-to-noise ratio by reducing an instrumental background as much as possible by adopting a novel concept of a well-type phoswich counter (Takahashi et al. 2006), and achieves an unprecedented low background in the energy ranges of 15–70 keV and 150-500 keV (Kokubun et al. 2006). Although the HXD has no capability of a rocking on-off observation like those of SAX-PDS and RXTE-HEXTE, a high sensitivity can be still obtained by modeling the residual non X-ray background (hereafter NXB) with a good accuracy, thanks to its lowness. Therefore a limiting factor for the sensitivity of the HXD is a reproducibility in the background estimation. Here we examine the background reproducibility of the HXD-PIN which covers the energy range below 70 keV, mainly by comparing the background model prediction and the data during the earth occultation of SWG observations, or of GO observations in a trend archive [1]). Since the earth is known to be dark in hard X-rays and soft gamma-rays, the earth occultation data can be regarded as the NXB for the HXD. For details of the background models, see Watanabe et al. (SUZAKU-MEMO, in preparation). The study on the HXD-GSO background model accuracy will be reported elsewhere (SUZAKU-MEMO-2006-43).

2 Spectrum and Light Curve of Typical Long Earth Observations

Figure 1 compares energy spectra between the real data and the model prediction during the earth occultation of one observation in SWG phase (MGC-6-30-15 observed from 2006 January 9 to 14). Events are selected by the following selection criteria: the cut-off-rigidity is greater than 8 GV, the elapsed time after the passage of SAA (South Atlantic Anomaly) is more than 500 s and the elevation angle from the earth rim is less than $-5°$. Data recorded in a bit-low mode or that with telemetry saturation are also discarded, and the net exposure for the earth

[1] ftp://ftp.darts.isas.jaxa.jp/pub/suzaku/rev1.2/trend

occultation is 85 ks. We see a good agreement of the model with the data in the full energy range of the HXD-PIN (12–70 keV). Figure 2 shows light curves of the same observation, individually for 15–40 keV and 40–70 keV energy band and in 1, 4, 16 ks and 1 day time scales. In the longer time scales the variance in residuals is determined by the reproducibility of the background by the model, whereas in the shorter time scales they become large not only statistically but also systematically because of the incompleteness of the modeling. The distribution of the residuals obtained from ten long earth observations are shown in Figure 3. The peak-to-peak of residuals in the 1 day time scale for these 10 observations is ~ 5 %. Please also see chapter 7 of the technical description for Suzaku AO-2 [2] for more detailed information.

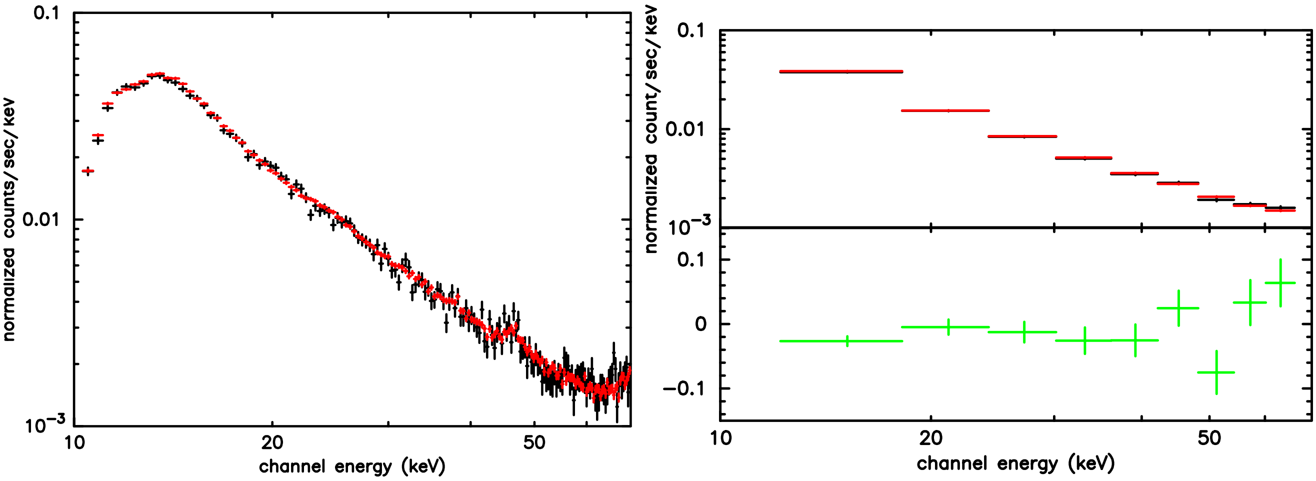


Figure 1: Comparisons of spectra between the data and the background model prediction of the HXD-PIN NXB for one observation taken in the SWG phase (MGC-6-30-15 observed from 2006 January 9 to January 14). Data during the earth occultation (elevation angle less than $-5°$) is used in the plot. (Left) Unbinned spectra of the data and the model shown by black and red histograms, respectively. (Upper right) Binned energy spectra. (Lower right) Residuals given as the ratio to the data.

3 Reproducibility in the HXD-PIN NXB

In this section, we examine the reproducibility of the HXD-PIN NXB by utilizing the available earth occultation data and the sky data with no known strong hard X-ray sources. Since parameters of the high voltage for the PIN diodes have been changed twice as of 2006 October, we define two time periods as below. a) From 2005 September 2 to 2006 May 24. All 64 PINs had been operated with a bias voltage of 500 V and the NXB model based on PIN-UD counts are released. b) From 2006 May 25 to October 3. One fourth of PINs (equipped to WPU 0) had been operated with 400 V [3] but the others (equipped to WPU 1, 2, 3; hereafter W123) had been applied the nominal bias voltage of 500 V. The same background models as before are applicable and are prepared for PINs on these electronics modules (W123 background model described in § 3.2). Since 2006 October 3, PINs on WPU 1 have also been operated with 400 V. Study on the accuracy of background models of this period is to be done in future.

[2] http://www.astro.isas.jaxa.jp/suzaku/doc/suzaku_td/node1.html

[3] Several settings of high voltage were tested for PINs on WPU 0 until May 29.

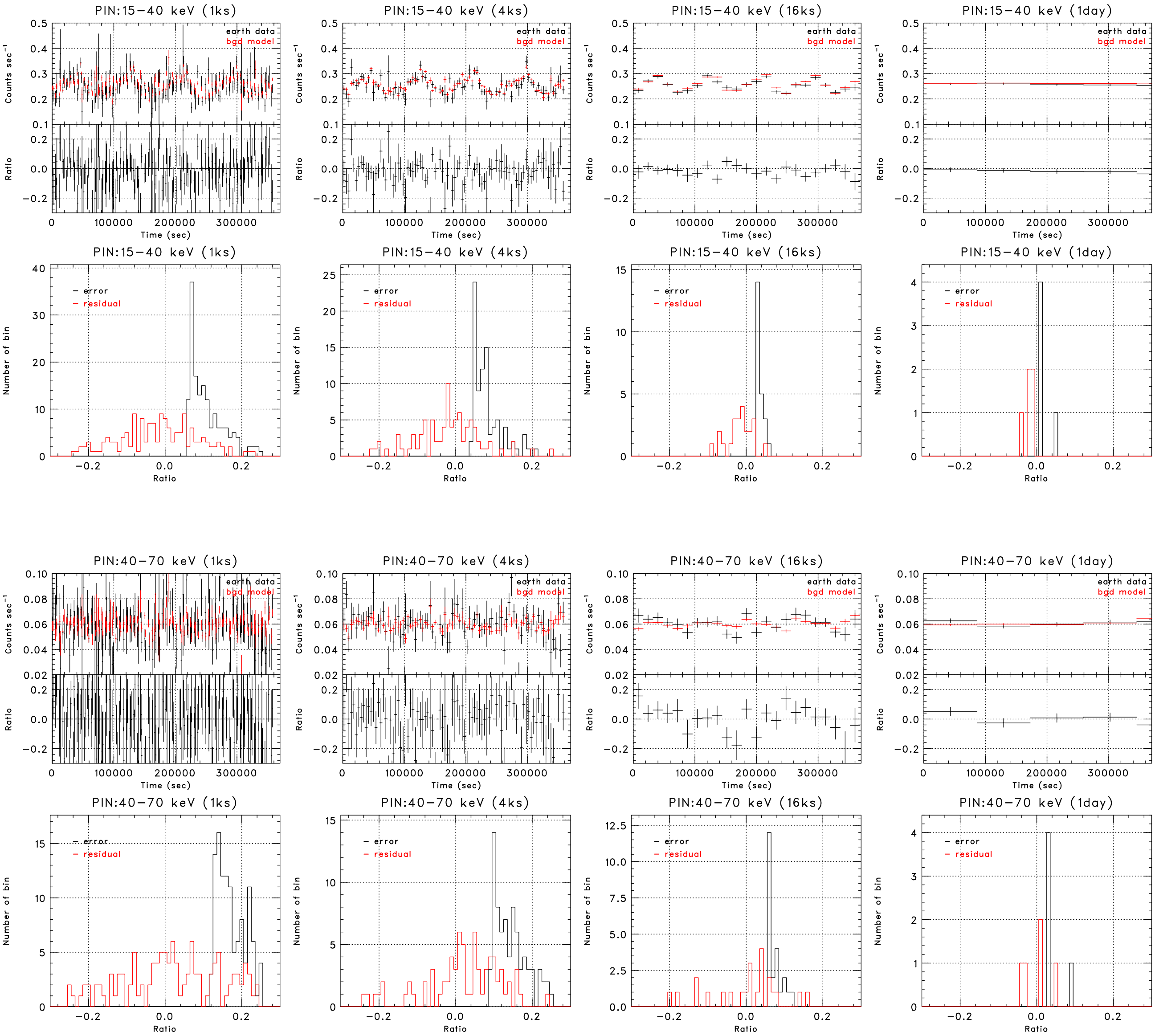


Figure 2: The same as Figure 1, but for comparisons of light curves for various time bins of 1, 4, 16 ks and 1 day. The first 4 panels show the case in 15–40 keV, while the last 4 panels do the case in 40–70 keV. In each panel, the upper figure shows the comparison of the light curves and residuals given as the ratio against the total background count rate, and the lower figure shows the distribution of the residuals (red) and the statistical errors (black), given as the ratio as the figure above.

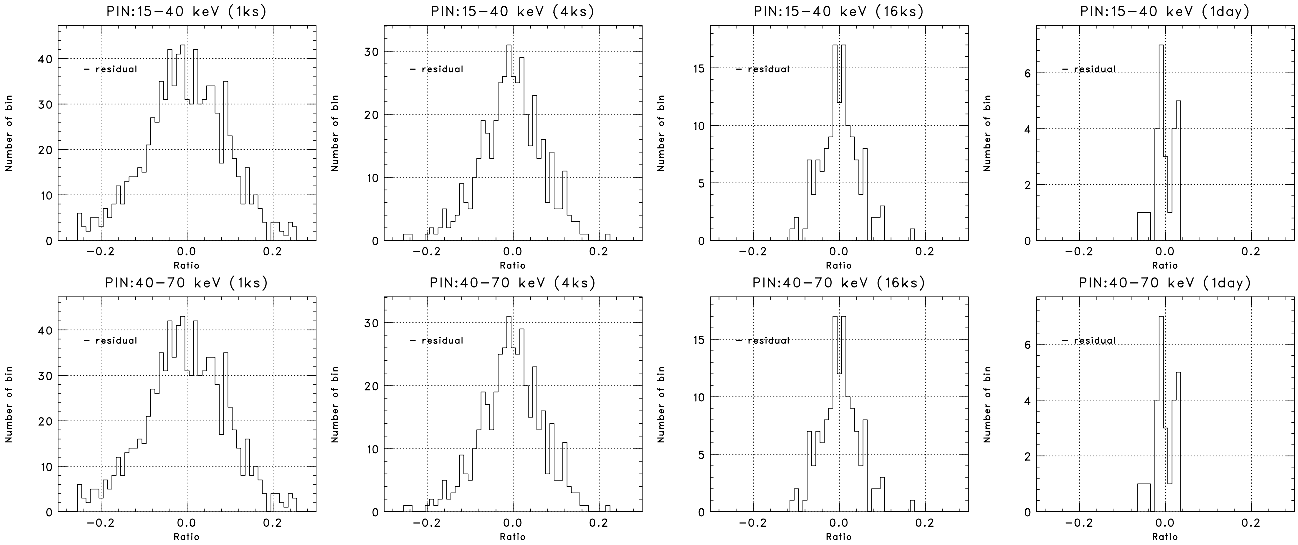


Figure 3: The same plots as the residual distributions shown in Figure 2, but extracted from ten long observations.

3.1 Background model for 64 PINs

In Figure 4, we compare the NXB count rates between the real data and the background model in 15–40 keV and 40–70 keV range in period (a). All the earth occultation data of SWG targets (with exposure to the earth more than 1 ks) are used in the plot. We also included the data before 2005 September 2, for which background models by a different method are released (Watanabe et al.). Lower discriminator (LD) level of the GSO had been changed from 2006 March 23 to May 13 and the PIN NXB might have been affected, therefore the data in this period are colored by green. Except during this period, the data and the model agree in $\sim$ 10 % (Note that the statistical error is large). No significant difference in reproducibility is seen between models before and after 2005 September 2.

As described in Kokubun et al. (2006), the NXB count rate of orbits with a passage of SAA (hereafter the SAA path) is relatively large due to radio isotopes of short half-lives and the reproducibility is expected to be worse. We thus divided the data into two, one in SAA paths (with elapsed time after the passage of SAA less than 6000 s) and the other in non-SAA paths, and compared the data and the background model. The results are summarized in Figure 5, in which data with exposure to earth more than 10 ks are selected. The data and the model agree with each other in 5 % for non-SAA paths. The background count rate is larger and the agreement with the model is worse in SAA paths; for some observations, the residuals are 5–10 % level.

3.2 W123 background models

To examine the reproducibility of W123 background models, we utilized all the available earth data and compared 15–40 keV count rates between the real data and the model prediction for period (a) and (b). We found that the data to model ratio is small by $\sim$ 10% from the end of March to the middle of May in 2006 as shown by Figure 6, probably due to the change of LD level of GSO [4]. Examples of the spectrum and the light curve of earth data in this period is shown

[4]The LD level of GSO was lowered on March 23 at 22:51 and was set back to the nominal level on May 13 at 16:33.

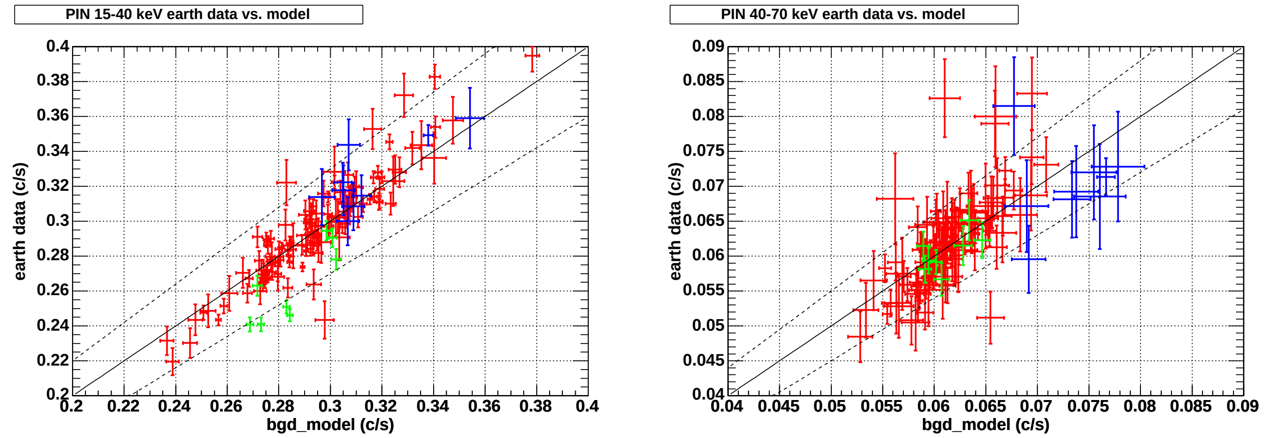


Figure 4: (left) A comparison of the NXB count rate in 15–40 keV between the data and the model prediction in period (a). A different method is used to model the background before 2005 September 2, and the data of this period (denoted by blue crosses) are also included. Data from 2006 March 23 to May 13 are shown by green crosses (see text). (right) The same plot but for 40–70 keV instead of 15–40 keV.

in Figure 7 and 8. No prominent feature is found in neither the spectrum nor the light curve. Summary plots of the NXB reproducibility for 15–40 keV and 40–70 keV are shown in Figure 9 and 10, respectively. Except during these two months, most of data agree with model by 5%. Although the statistical error is large, the background seems to be overestimated not by 10% but by $\sim 5\%$ in 40–70 keV when the GSO LD level were lowered. Study on the NXB of this period is in progress. For the moment, users are encouraged to take the apparent decrease of the NXB level into account in analysis.

3.3 Comparison with the blank sky data

As a final check of the background reproducibility, we compared the NXB model with the sky data which are expected to be a blank sky field for the HXD-PIN. We used so-called clean events which are already cleaned with the same selection criteria at those of § 3.1. Results by 8 SWG observations are summarized in Figure 11 where background subtracted spectra are compared with simulated CXB spectra based on the measurement by Boldt (1987). No systematic difference is seen between NXB-subtracted spectra and CXB spectra, indicating that the background model is applicable for sky observations. Note that this figure does not mean non-detection of excess hard X-ray emission above the CXB level in these observations below the current accuracy of the PIN NXB model ($\sim 5\%$)

We also compared the data and the NXB model light curves of the same objects as summarized in Figure 12. For some occasions, the background model underestimates the data in 15–40 keV in SAA paths where the background rate is high (see also Figure 5). As a result, residuals show modulations of a peak-to-peak amplitude up to ~ 0.05 c s^{-1} in a cycle of ~ 1 day. In 40–70 keV, light curves sometimes show similar modulations with a peak-to-peak amplitude up to ~ 0.02 c s^{-1} (Figure 13).

Reference

- Takahashi T. et al. 2006, accepted for publication in PASJ

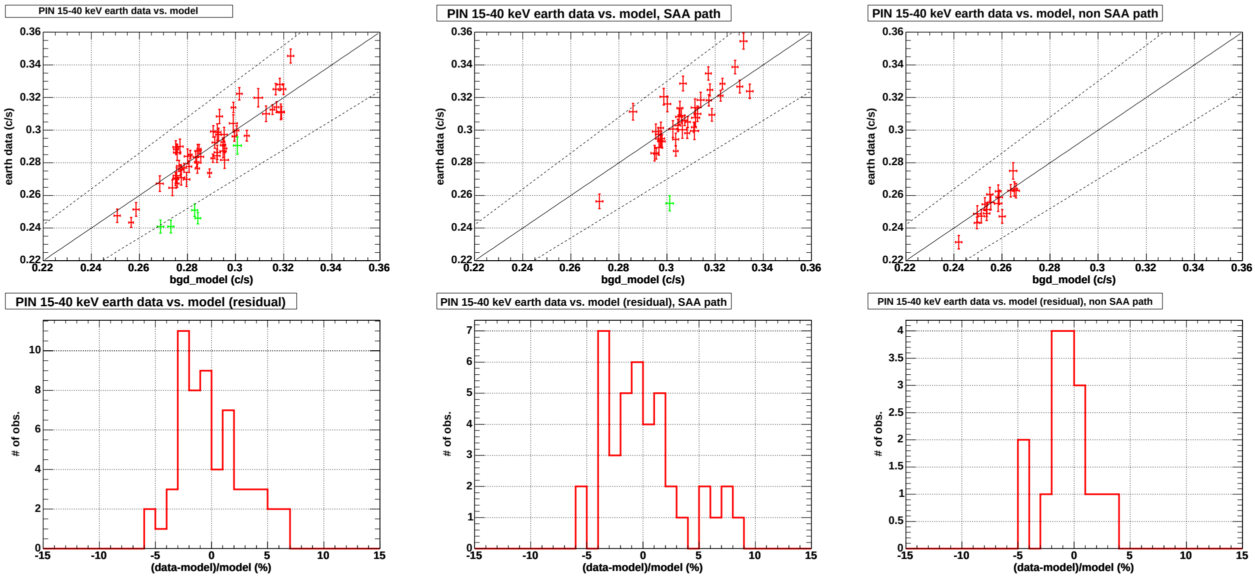


Figure 5: The same plots as that of left panel of Figure 4, but data with exposure more than 10 ks are selected. Data in SAA paths and non-SAA paths are summed together in the top-left panel, and data in SAA paths and non-SAA paths are individually shown in top-middle and top-right panels, respectively. The bottom figures show the residual distributions.

- Kokubun M. et al. 2006, accepted for publication in PASJ
- Watanabe S. et al., Suzaku Memo, in preparation
- Boldt E. 1987, IAU circ, 124, 611

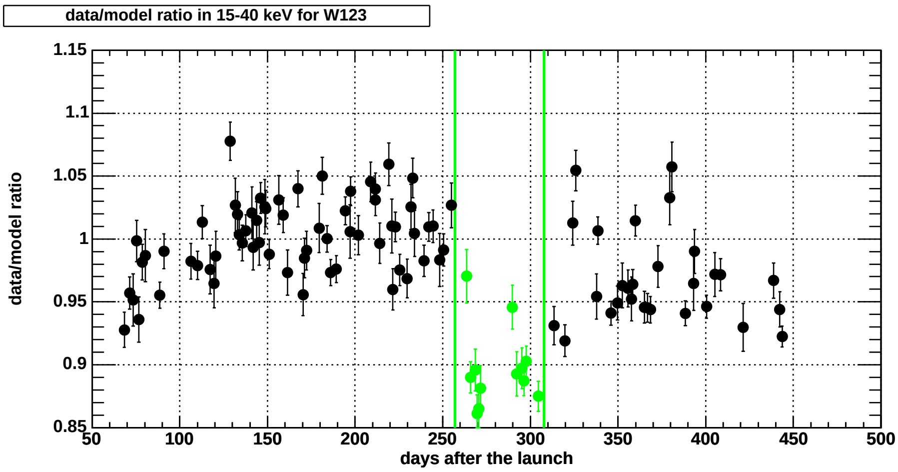


Figure 6: Data to model ratios of the NXB count rate in 15–40 keV for PINs equipped to W123, shown as a function of the elapsed day since 2005 July 10 (the day of the launch of Suzaku). Vertical green lines indicate the period when the GSO LD level was lowered from the nominal value.

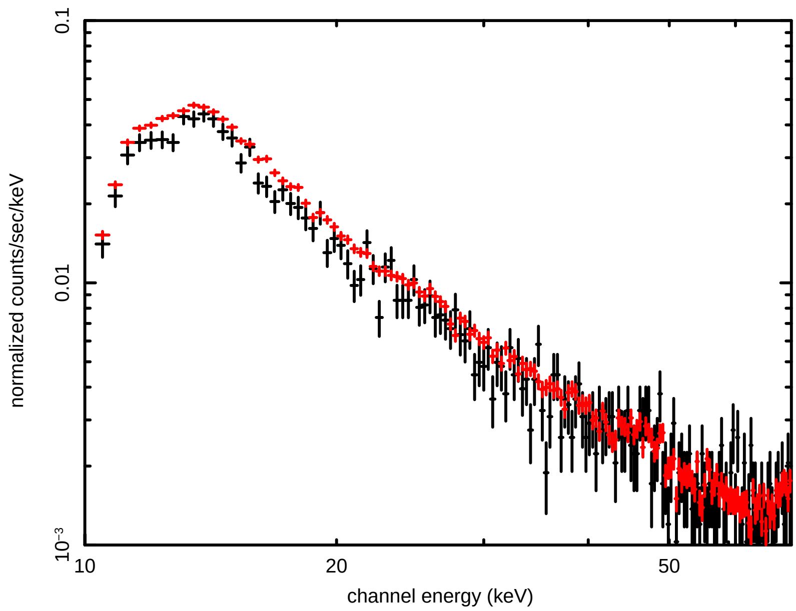


Figure 7: An example of the PIN NXB spectrum when the GSO LD level was lowered than the nominal value. Earth data of HESS 1804-216 (observed on 2006 April 6th) is plotted. Data and the model spectra are given by black and red histograms, respectively.

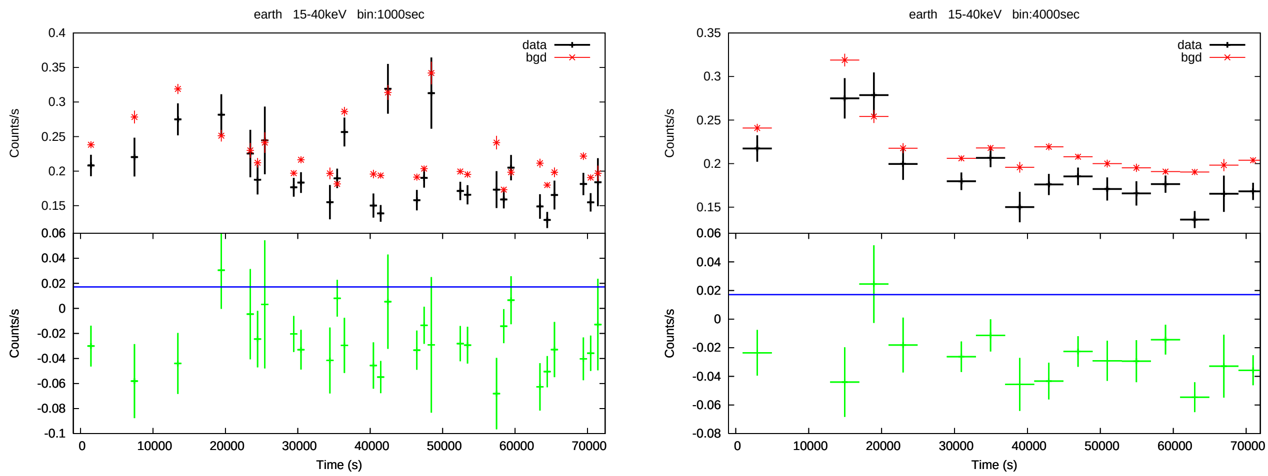


Figure 8: The same as Figure 7 but for light curves instead of the spectrum. Data and model light curves and residuals in time scale of 1 ks and 4 ks are given in the left and the right panel, respectively. The predicted CXB count rate is given by blue lines in the bottom figures.

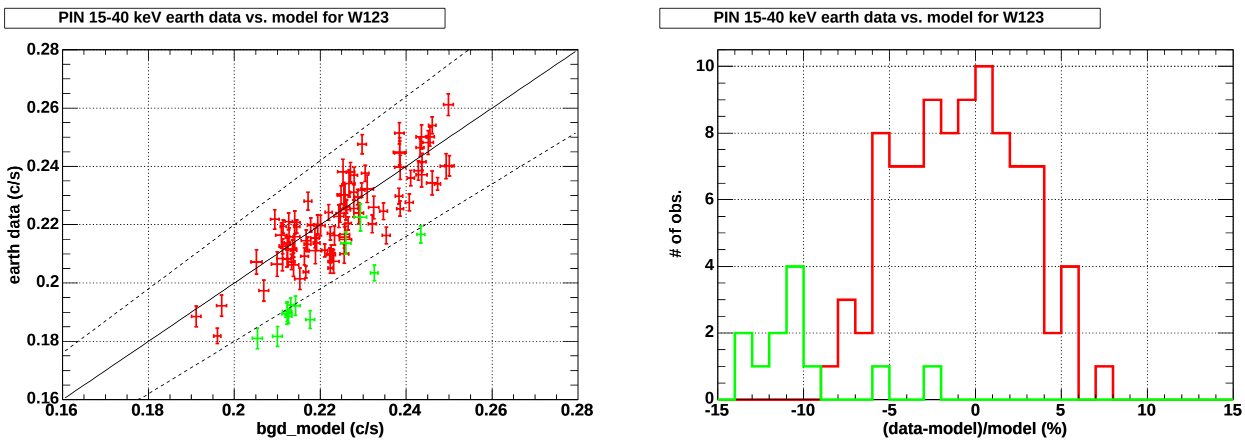


Figure 9: Comparison of the NXB count rate and the model prediction for PINs on W123 in 15–40 keV. Distributions of count rates and residuals are shown by the left panel and the right panel, respectively. Data when the GSO LD level was lowered are marked by green crosses and histograms.

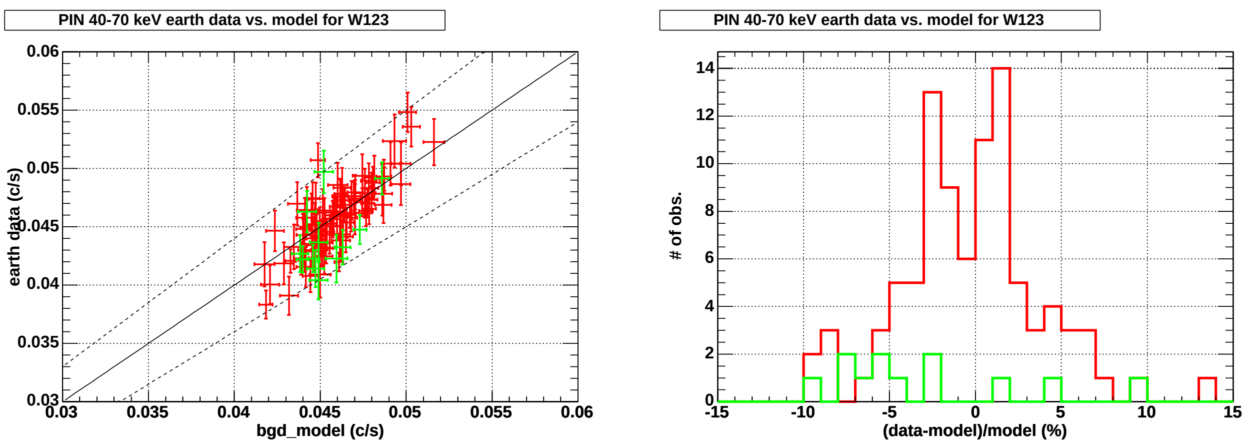


Figure 10: The same as Figure 9, but for 40–70 keV instead of 15–40 keV.

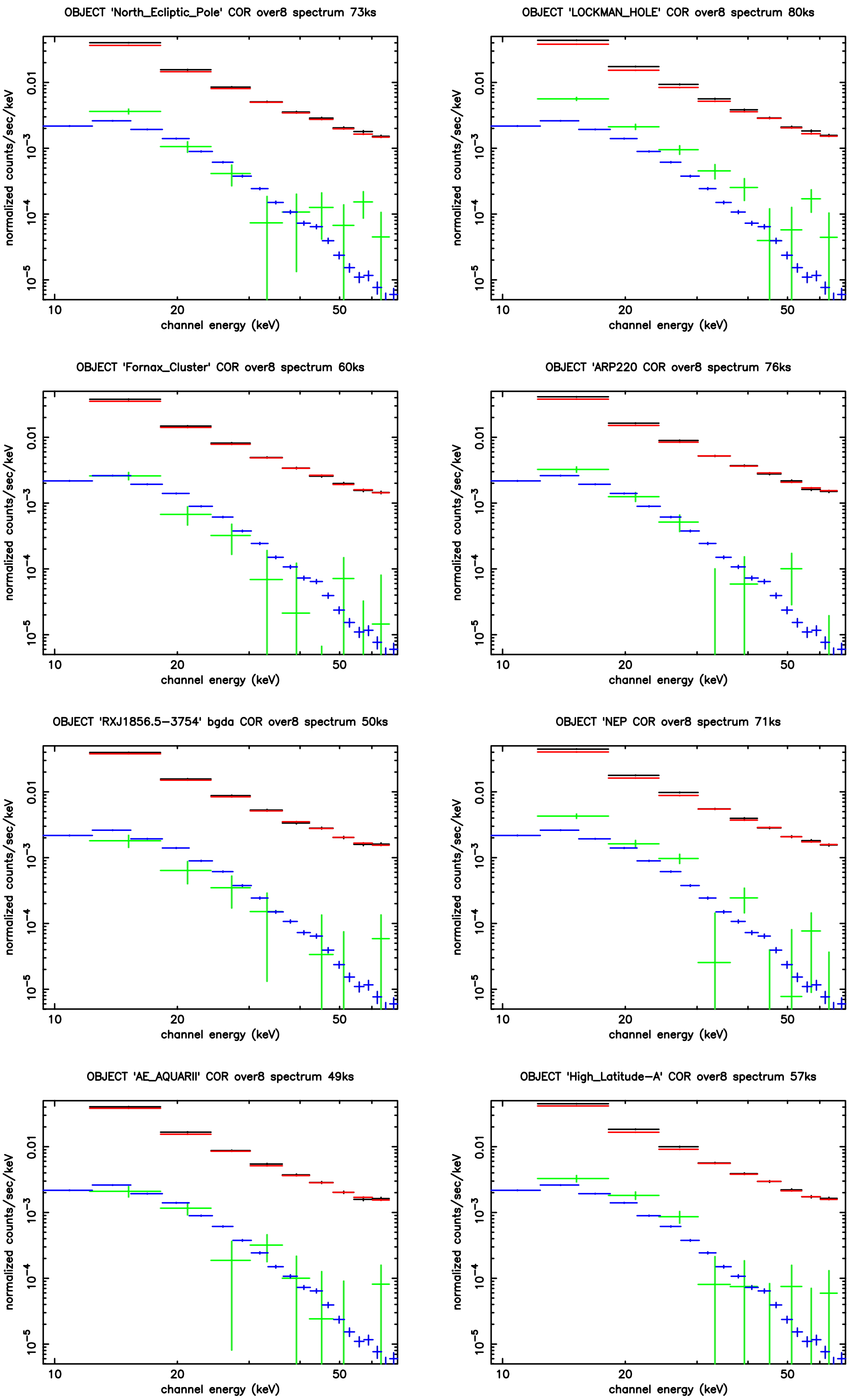


Figure 11: Examples of the background-subtracted spectra from observations of sources with no known strong hard X-rays. Data and background model spectra are given by black and red histograms, respectively, and the background-subtracted spectra (green histogram) are compared with the simulated CXB spectrum (blue histogram) based on Boldt (1987). (Left) Observation on 2005 September 2, 13, October 24 and 30 are shown from top to bottom. (Right) Observation on 2005 November 14, 2006 January 7, February 10 and 14 are shown from top to bottom.

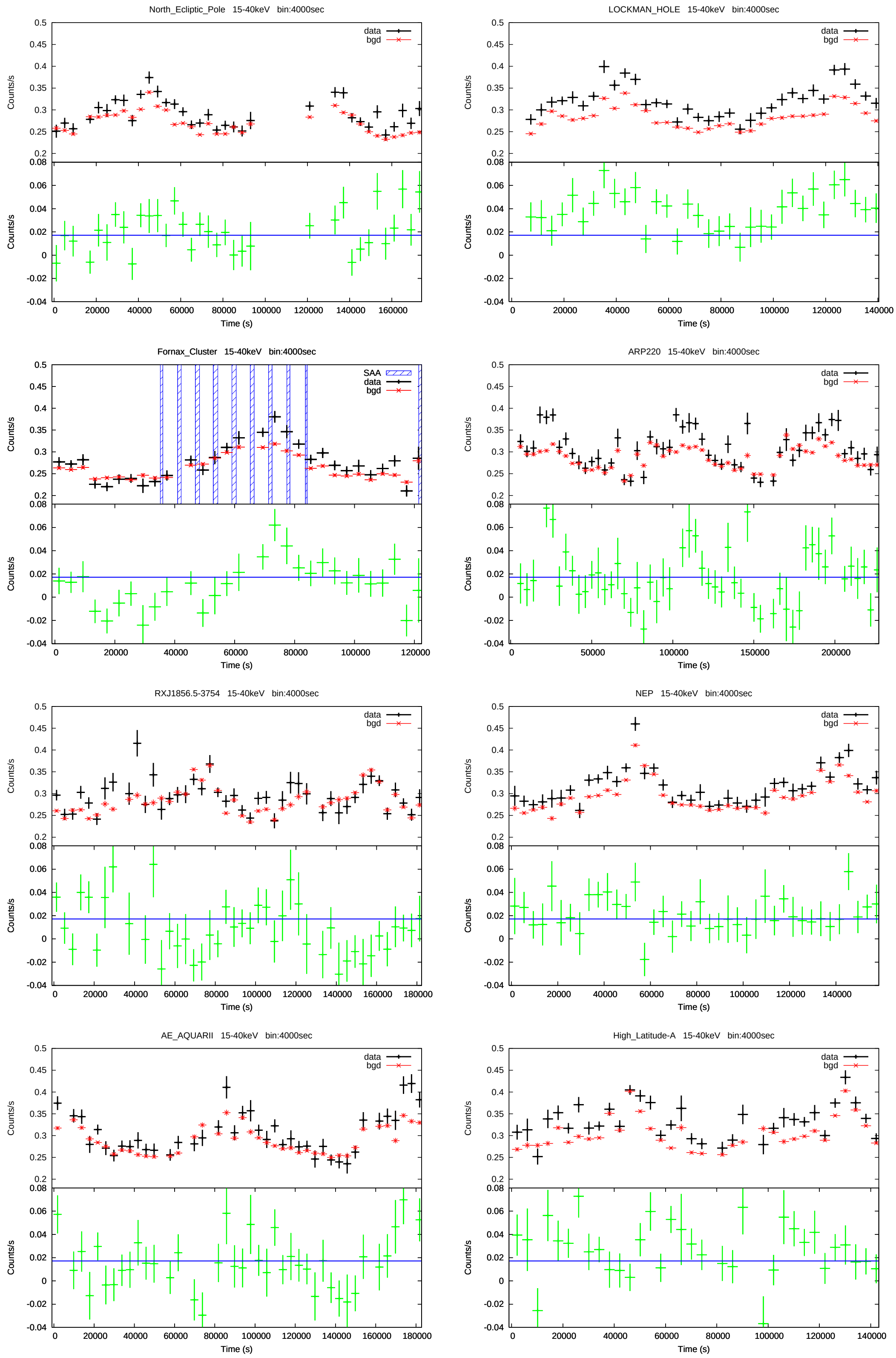


Figure 12: The same as Figure 11 but for 15–40 keV light curves instead of spectra. In each panel, the upper figure shows the light curve and the lower figure shows the residuals with the CXB level given by the blue line. For reference, passages of SAA are shown by shaded areas in the second uppermost left panel.

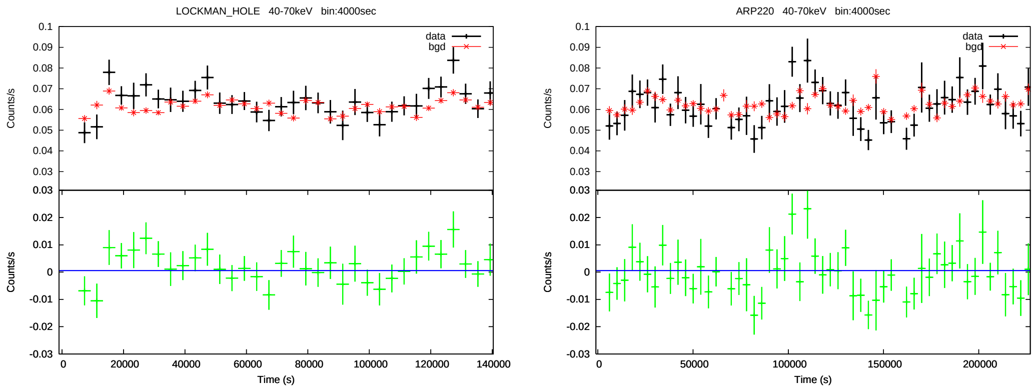


Figure 13: Examples of 40–70 keV light curves for sky data of 2005 November 14 (left panel) and 2006 January 7 (right panel).

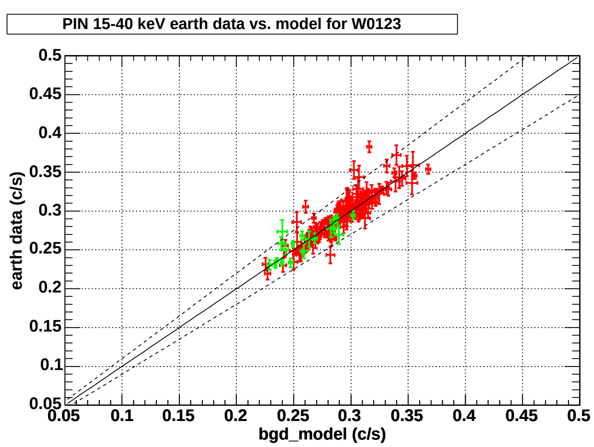
Appendix: Reproducibility of the HXD-PIN Non X-ray Background with the model bgd_d

February 23, 2007

1 Introduction

As described in the previous section, the current public PIN background model ("bgd_a") has been found to overestimate the PIN background in the period during 2006 Mar 27 to May 13. Therefore, the HXD team prepared the alternative background model for the data in this period. In addition, in the period before 2005 Sep 2 when the hit pattern mode was different, the public PIN background is based on the "bgd_d". The description of this modeling method is available as Y. Fukazawa et al. (Suzaku-Memo-2007-02). Here, we report the reproducibility of this model for the PIN background. The comparison is mostly the same as that described in the previous section, and thus only figures are briefly shown. For comparison, we used the data from 2005 Aug 17 to 2006 Nov 30. This model considers the change of the background rate due to the change of the operation model (high voltage, lower discrimination level, and so on), and the model can be applied to the case that PIN events of all the sensors are selected. Therefore, the comparison was performed for PIN events of all the sensors (i.e. W0123), and this is a different situation from that for the "bgd_a".

2 Comparison with the Earth Occultation Data



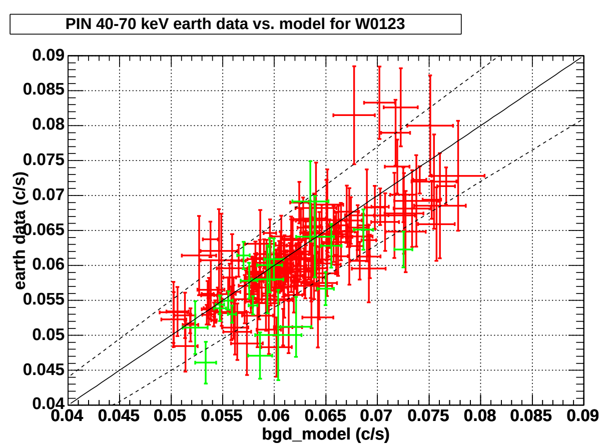


Figure 1: (left) A comparison of the NXB count rate in 15–40 keV between the data and the model prediction in period (a). Data from 2006 March 23 to May 13 are shown by green crosses (see text). (right) The same plot but for 40–70 keV instead of 15–40 keV.

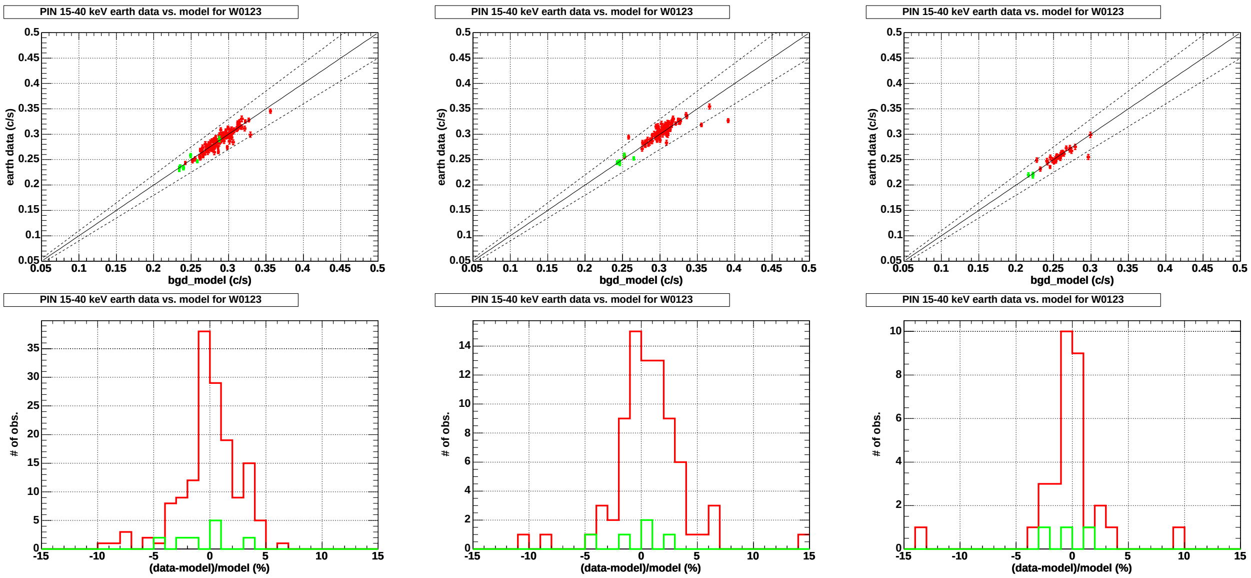


Figure 2: The same plots as that of left panel of Figure 1, but data with exposure more than 10 ks are selected. Data in SAA paths and non-SAA paths are summed together in the top-left panel, and data in SAA paths and non-SAA paths are individually shown in top-middle and top-right panels, respectively. The bottom figures show the residual distributions.

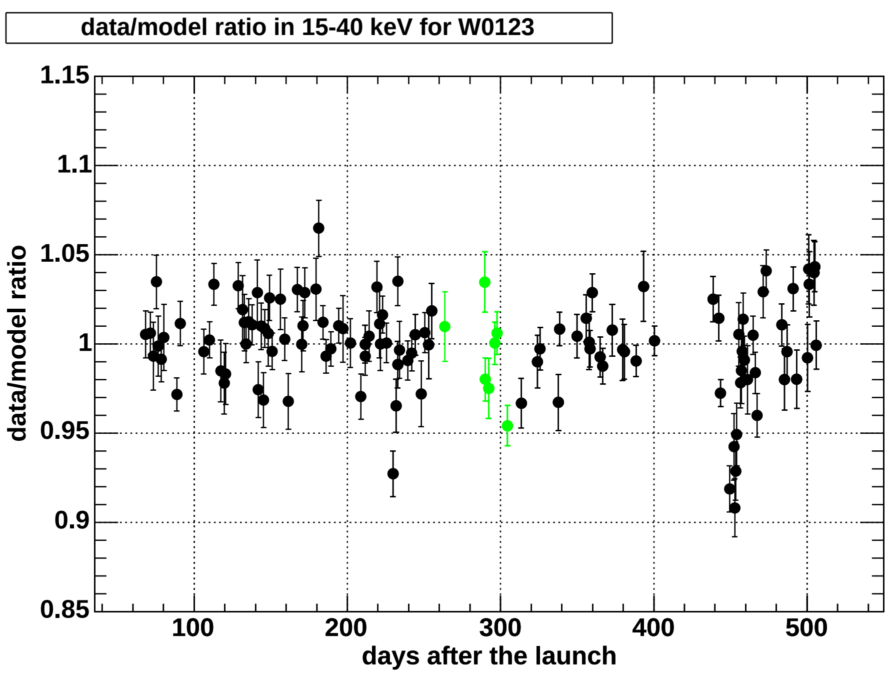


Figure 3: Data to model ratios of the NXB count rate in 15–40 keV, shown as a function of the elapsed day since 2005 July 10 (the day of the launch of Suzaku). Vertical green lines indicate the period when the GSO LD level was lowered from the nominal value. During the period of 2006 Sep 29 to Oct 7, the ratio is less than 0.95, possibly due to the PIN count rate troble and PIN-HV operation.

3 Comparison with the Blank Sky Data

Reference

- Fukazawa Y. et al., Suzaku Memo 2007-02

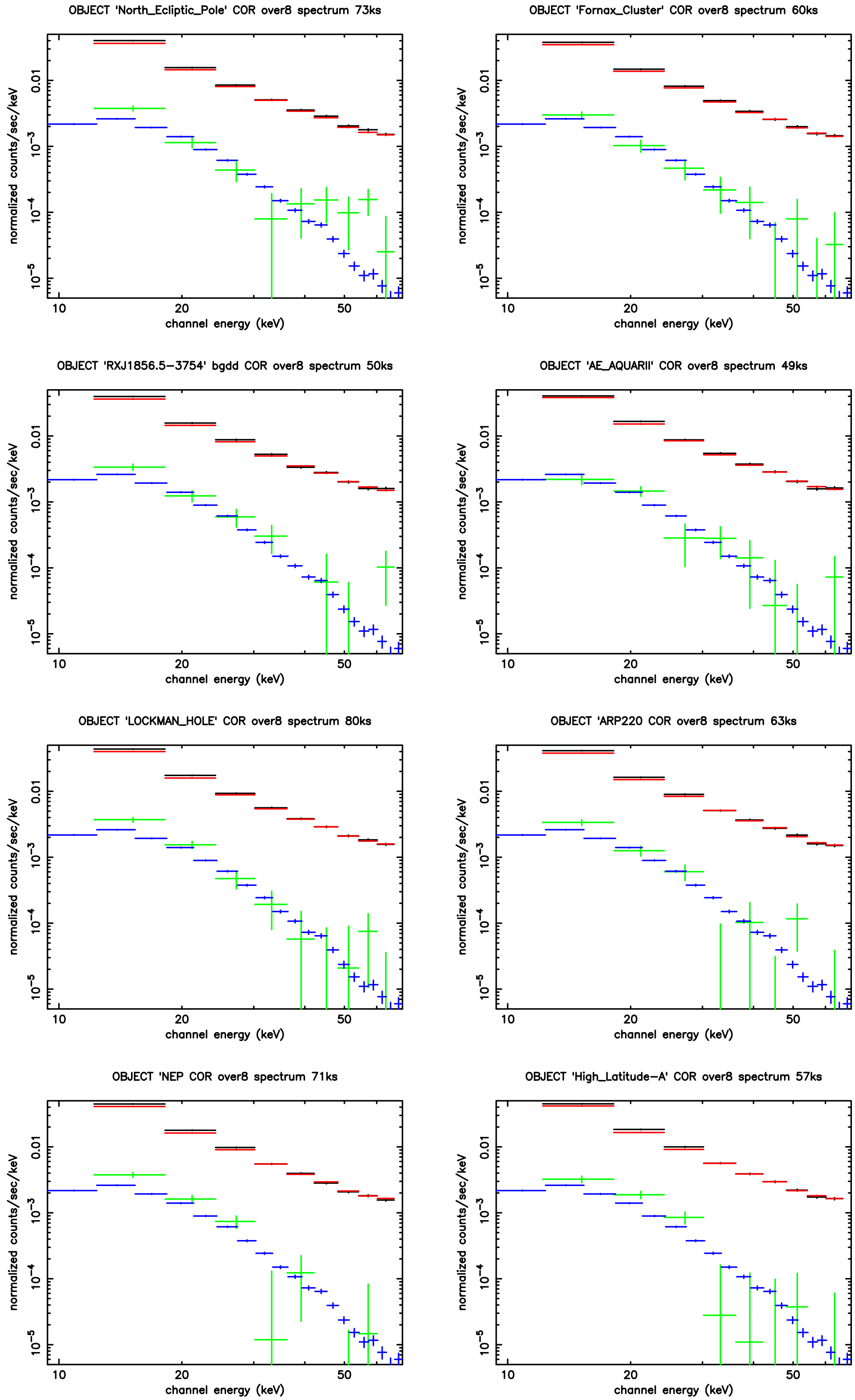


Figure 4: Comparison of spectra between the data (red) and BGD model (green) for observations of objects with no known strong hard X-rays. Data and background model spectra are given by red and green histograms, respectively, with fractional residuals (blue histogram). Observations on 2005 September 2, 13, October 24 and 30, November 14, 2006 January 7, February 10 and 14 are shown from top to bottom.

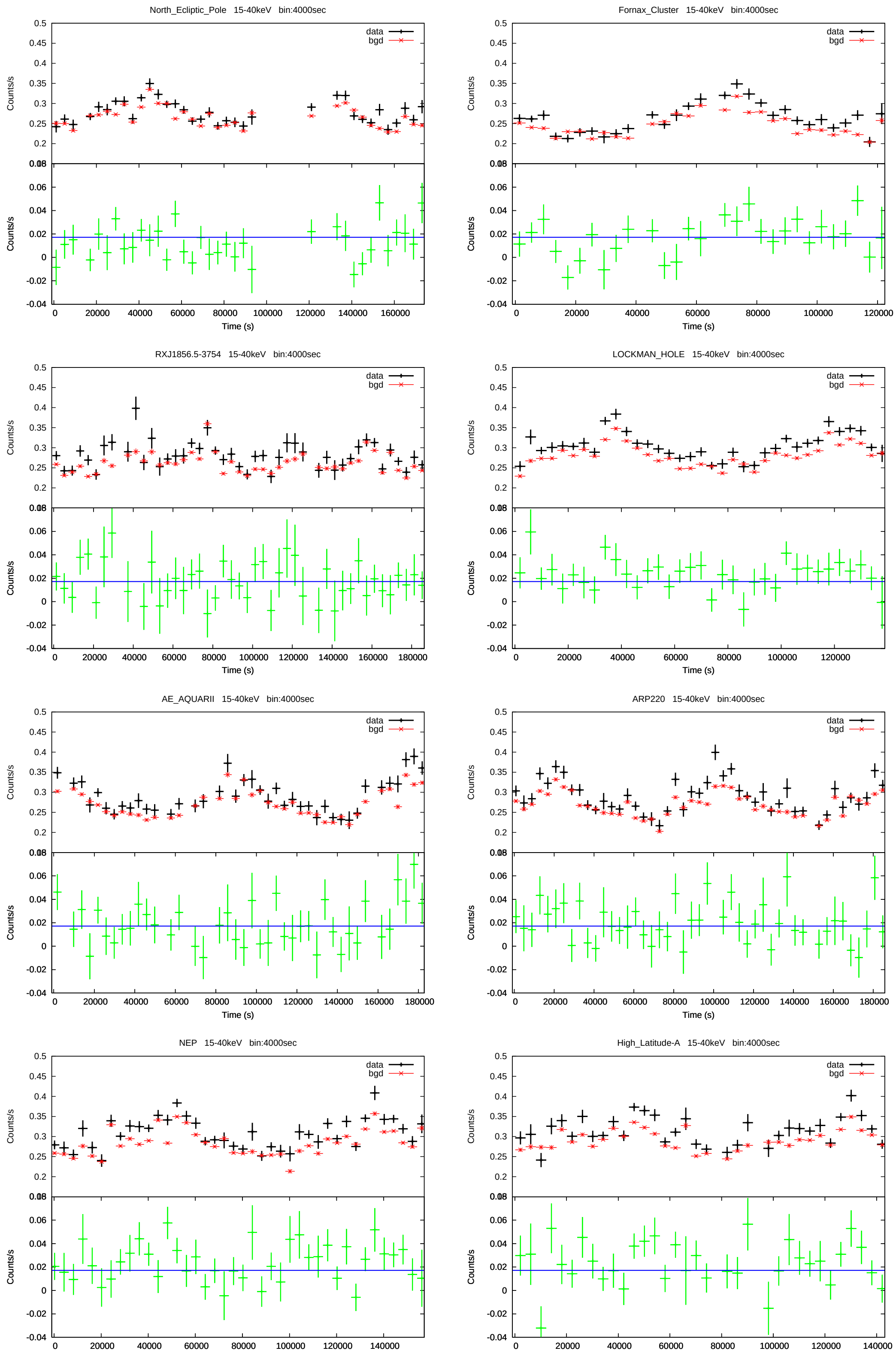


Figure 5: The same as Figure 4 but for 15–40 keV light curves instead of spectra. In each panel, the upper figure shows the light curve and the lower figure shows the residuals.

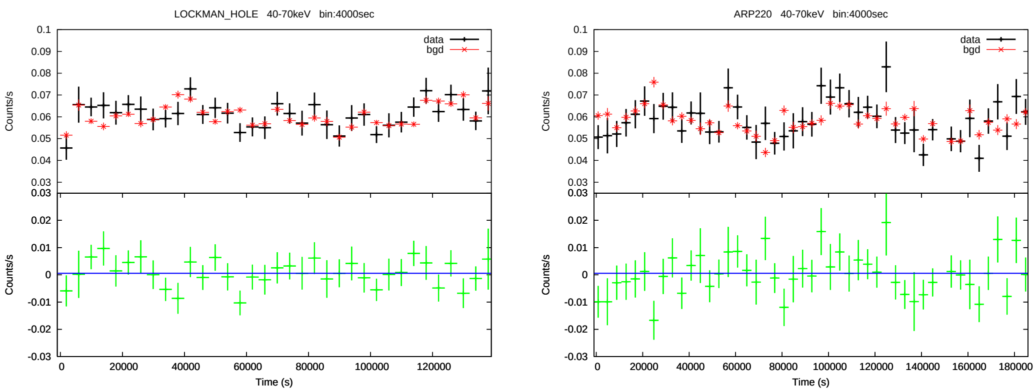


Figure 6: Examples of 40–70 keV light curves for sky data of 2005 November 14 (left panel) and 2006 January 7 (right panel).