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Title: Calibration above 10 keV
Category: XIS
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Summary

We report the calibration accuracy of the XIS above 10 keV band. We analyzed several bright and power-law sources and successfully fitted the spectrum up to 14 keV in a consistent manner with the spectrum below 10 keV. We also used some sources observed simultaneously with NuSTAR, and the $10 - 14$ keV band flux by XIS is in agreement with that by the NuSTAR within an accuracy of 10%. The accuracy is consistent with an independent study by the NuSTAR team. We thus conclude that the XIS data can be used for scientific purposes above 10 keV.

1 Background

It is officially claimed that the XIS energy bandpass is 0.2–12 keV (Koyama et al., 2007). Cross-calibration studies have been conducted below 10 keV between XIS and other instruments in the orbit (Chandra ACIS, XMM-Newton EPIC, Swift XRT, etc) by Ishida et al. (2011) and Tsujimoto et al. (2011). However, the calibration above 10 keV remained to be uncertain for the lack of good cross-calibration counterparts. Recently, NuSTAR was put into the operation and its calibration result was released (Madsen et al., 2015). This serves as a good reference for the XIS calibration above 10 keV.

2 Data & Results

Table 1: Datasets

Terget	PSR 1509–58	NGC 2110	RXJ 2056.6+4940	Mkn 421
data#	(1)	(2)	(3)	(4)
Telescope	Suzaku	Suzaku	Suzaku	Suzaku
Sequence ID	100009010	100024010	406014010	703043010
Obs. Date	2005-08-23	2005-09-16	2011-11-22	2008-05-05
Obs. Mode	normal	normal	normal	1/8 window
Exp. Time [ksec]	65.2	101.7	42.4	180.8
Sensor	XIS0,1,2,3	XIS0,1,2,3	XIS0,1,3	XIS0,1,3
Terget	PKS 2155–304		3C 273	
data#	(5)	(6)	(7)	(8)
Telescope	Suzaku	NuSTAR	Suzaku	NuSTAR
Sequence ID	108010010	60002022002	107013010	10002020001
Obs. Date	2013-04-23	2013-04-23	2012/07/16	2012/07/14
Obs. Mode	1/4 window	–	1/4 window	–
Exp. Time [ksec]	53.4	45.1	39.8	244.0
Sensor	XIS0,1,3	FPMA,B	XIS0,1,3	FPMA,B

2.1 Data

Table 1 shows the dataset used for the calibration study. We selected bright sources with the spectrum represented by a single power-law. Among them, PKS 2155–304 and 3C 273 were observed simultaneously among multiple X-ray observatories including Suzaku and NuSTAR. We used cleaned event file produced through the standard pipeline process both for the Suzaku and NuSTAR data.

2.2 Comparison between below and above 10 keV in the XIS

Using the datasets (1)–(4) in table 1, we evaluated the calibration consistency between below and above 10 keV in the XIS. We fitted the XIS spectra between 1.0–14 keV. The model and the best-fit parameters are shown in table 2, while the spectra and the best-fit models are shown in figures 1 and 2. The same model describes both below and above 10 keV spectra for all sources. Some sources have poor photon statistics above 12 keV, and their scatter in the residual is very large, Still, there is no apparent inconsistency between the models and the data.

2.3 Comparison between NuSTAR and XIS above 10 keV

Using the datasets (5)–(8) in table 1, we evaluated the consistency between the XIS and NuSTAR. We made time interval cuts to make exactly the same observation times. The XIS spectra in the 1.0–14.0 keV range and the NuSTAR spectra in 3.0–70.0 were fitted using the same model independently except for the tied amount of interstellar absorption. The best-fit parameters are shown in table 3, while the spectra and the best-fit models are shown in figure 3. We compared the flux in the 10–14 keV and derived the value relative to the XIS0. The three sensors of the XIS agree with each other at a 5% level, which is consistent with the proceeding studies at <10 keV (Ishida et al., 2011; Tsujimoto et al., 2011). The 10–14 keV flux is systematically larger in the NuSTAR than XIS by ∼10%, which is also consistent with the proceeding study at <10 keV (Madsen et al., 2015).

3 Conclusion

We used four observations to compare the XIS spectra between below and above 10 keV. We used two observations to compare the XIS and NuSTAR spectra in the 10–14 keV. All results are consistent with the result obtained below 10 keV. We conclude that the current XIS calibration is reliable above 10 keV at a similar level with below 10 keV, and the data above 10 keV can be used for scientific purposes.

References

Koyama, K., et al. 2007, PASJ, 59, 23

Ishida, M., et al. 2011, PASJ, 63, S657

Tsujimoto, M., et al. 2011, A&A, 525, 25

Madesen, K., et al. 2015, arXiv: 1504.01672v1

Table 2: Fitting parameters

(1)	PSR 1509–58	Fitting range: 1.0–14.0 keV	
	TBabs*pegpwrlw*const.		
	TBabs	$N_{\rm H}$ [a]	1.44 (fixed)
	pegpwrlw	Γ [b]	1.67±0.003
		Flux (10–14 keV) [c]	15.86±0.06
	const.	XIS0	1.000 (fixed)
		XIS1	1.065 (fixed)
		XIS2	1.035 (fixed)
		XIS3	1.067 (fixed)
(2)	NGC 2110	Fitting range: 3.0–14.0 keV	
	TBabs*(pegpwrlw+gaussian)*const.		
	TBabs	$N_{\rm H}$ [a]	5.44±0.10
	pegpwrlw	Γ [b]	1.59±0.01
		Flux (10–14 keV) [c]	49.2±0.2
	gaussian	Line E [keV]	6.357±0.003
		Sigma [keV]	0.044±0.007
		norm [d]	8.6±0.4
	const.	XIS0	1.000 (fixed)
		XIS1	1.026 (fixed)
		XIS2	0.999 (fixed)
		XIS3	0.984 (fixed)
(3)	RXJ 2056.6+4940	Fitting range: 1.0–14.0 keV	
	TBabs*pegpwrlw*const.		
	TBabs	$N_{\rm H}$ [a]	2.42±0.02
	pegpwrlw	Γ [b]	2.07±0.01
		Flux (10–14 keV) [c]	6.09±0.07
	const.	XIS0	1.000 (fixed)
		XIS1	1.038±0.007
		XIS3	1.017±0.007
(4)	Mkn 421	Fitting range: 1.0–14.0 keV	
	TBabs*pegpwrlw*const.		
	TBabs	$N_{\rm H}$ [a]	0.166±0.002
	pegpwrlw	Γ [b]	2.579±0.002
		Flux (10–14 keV) [c]	39.73±0.11
	const.	XIS0	1.000 (fixed)
		XIS1	0.773±0.001
		XIS3	0.950±0.001

Confidence range: 1 sigma.

[a] H-equivalent column density in 10^{22} cm^{-2}.

[b] Photon index.

[c] 10–14 keV band flux in 10^{-12} erg s^{-1} cm^{-2}.

[d] Normalization 10^{-5} photons s^{-1} cm^{-2}.

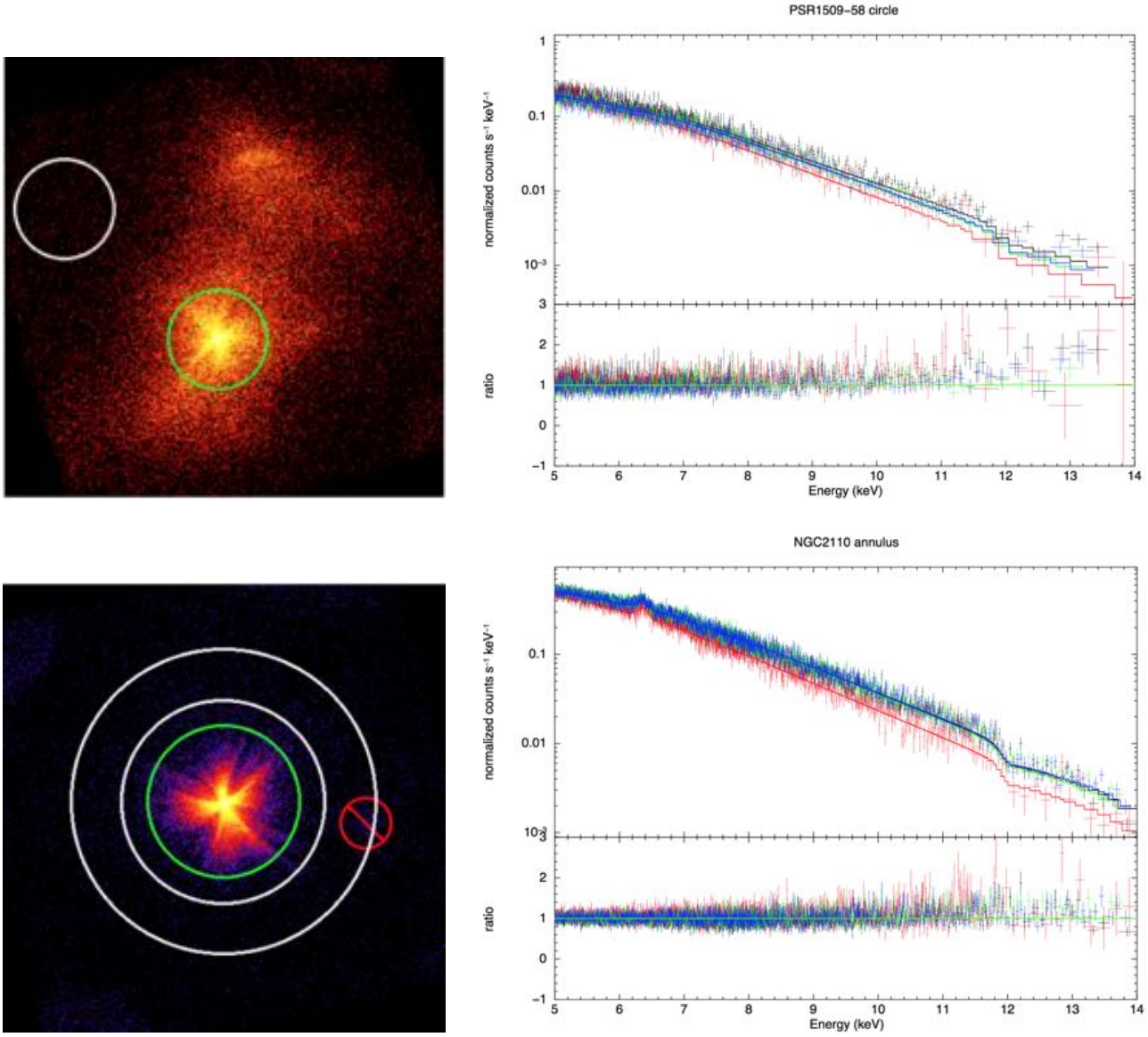

Figure 1: PSR1509–58 (top panels) and NGC 2110 (bottom panels). The left panels show the XIS0 image, in which source and background regions are shown with green and white circles or annulus. In NGC 2110, a near-by contaminating source region was masked. The right panels show the fitting result in the 5–14 keV with different colors for different XIS sensors (black: XIS0, red: XIS1, green: XIS2, and blue: XIS3).

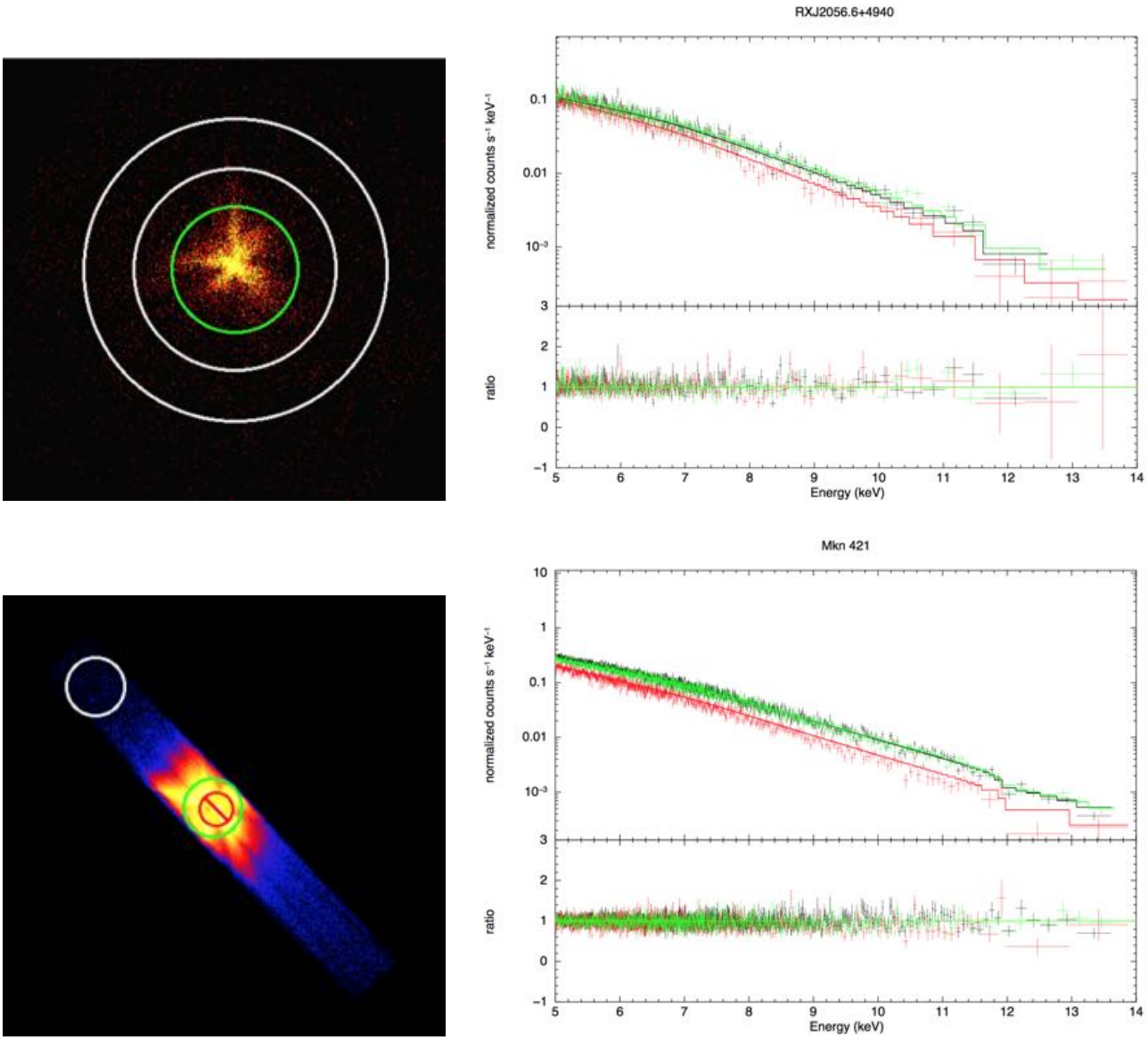

Figure 2: RXJ 2056.6+4940 (top panels) and Mkn 421 (bottom panels). The left panels show the XIS0 image, in which source and background regions are shown with green and white circles or annulus. In Mkn 421, the central region was removed from the source region to avoid the pile-up effect. The right panels show the fitting result in the 5–14 keV with different colors for different XIS sensors (black: XIS0, red: XIS1, and green: XIS3)

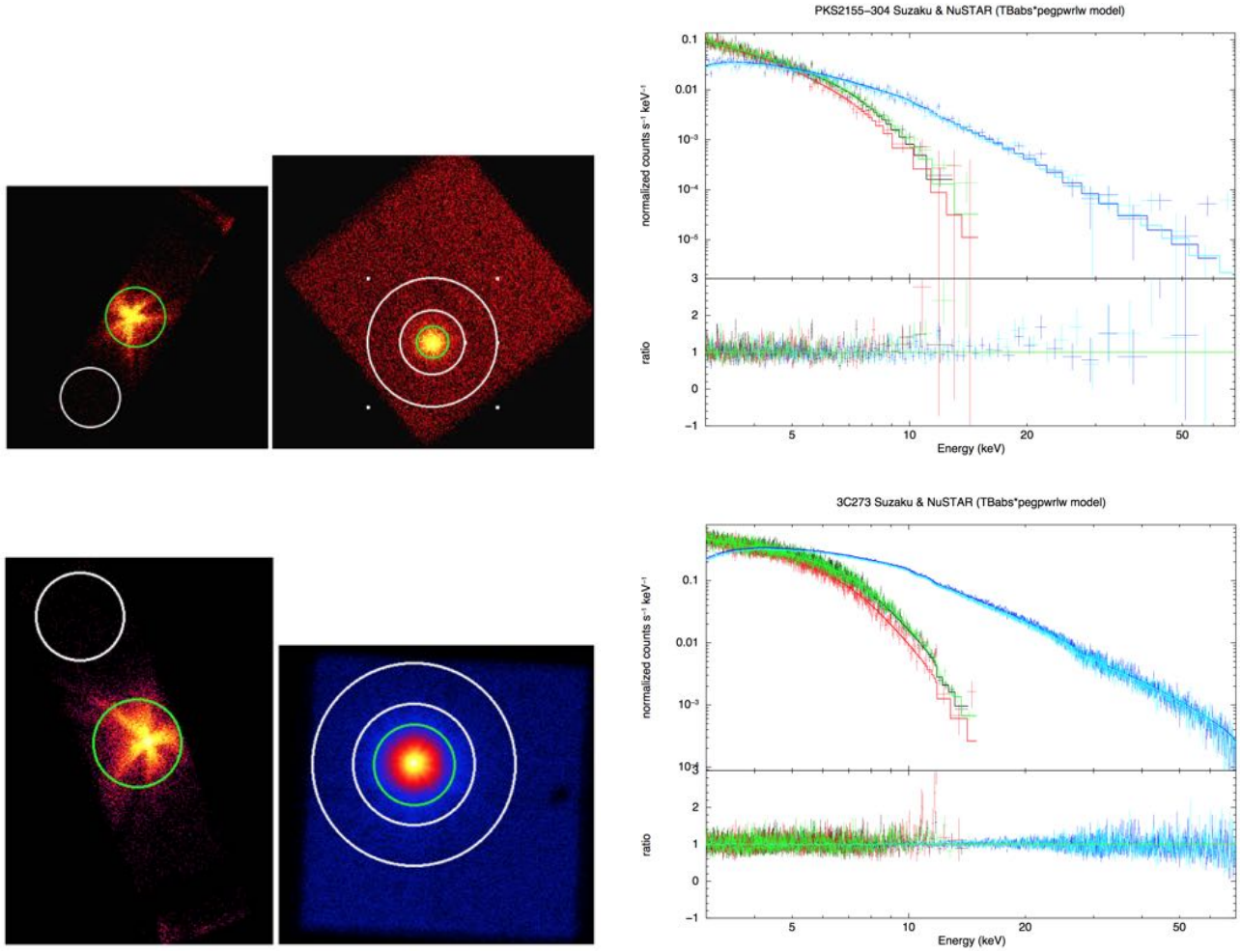

Figure 3: PKS 2155–304 (top panels) and 3C 273 (bottom panels). The left and middle panels show the XIS0 and FPMA images, in which source and background regions are shown with green and white circles or annulus. The right panels show the result of simultaneous fitting of the XIS and NuSTAR in the 3–70 keV with different colors for different sensors (black: XIS0, red: XIS1, green: XIS3, blue: FPMA, and cyan: FPMB.)

Table 3: Fitting parameters

	$N_{\rm H}$ [a]	Γ [b]	Flux [c]	Flux ratio
PKS 2155–304				
XIS0	0.015	2.77±0.04	0.91±0.04	1.00
XIS1	(tied)	2.84±0.05	0.89±0.05	0.98±0.07
XIS3	(tied)	2.77±0.04	0.94±0.04	1.03±0.06
FPMA	(tied)	2.73±0.03	1.02±0.02	1.12±0.05
FPMB	(tied)	2.70±0.03	1.07±0.03	1.17±0.06
3C 273				
XIS0	0.0179	1.624±0.015	21.89±0.30	1.00
XIS1	(tied)	1.673±0.017	20.76±0.35	0.95±0.02
XIS3	(tied)	1.648±0.015	21.93±0.30	1.00±0.02
FPMA	(tied)	1.678±0.002	23.26±0.04	1.06±0.01
FPMB	(tied)	1.674±0.002	24.25±0.04	1.11±0.02

Confidence range: 1 sigma.

[a] H-equivalent column density 10^{22} cm^{-2}.

[b] Photon index.

[c] 10–14 keV band flux in 10^{-12} erg s^{-1} cm^{-2}.