Timing calibration of the X-ray Imaging Spectrometer on board Suzaku

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Abstract

We report current status of the timing calibration of the X-ray Imaging Spectrometer (XIS) on board Suzaku. The XIS is designed to be flexible enough and can be operated in various clocking modes. Since the absolute timing accuracy of the Hard X-ray Detector (HXD) was calibrated to be better than 360 μs, we calibrated the XIS timing accuracy referring to the HXD data. We employed Hercules X-1 and Cygnus X-1 for the calibration taking into account of the energy dependence of their time variations. We found no significant offset in the XIS time assignment in the normal mode (with burst/window options), whereas a marginal offset of 30 $\pm$ 16 ms was found in the Parallel-Sum mode.

Key words: instrumentation: detectors — techniques: cross correlation — X-ray: general

1. Introduction

The X-ray Imaging Spectrometer (XIS) on board Suzaku is designed to be flexible enough and can be operated in various clocking modes. As a result, the XIS can obtain useful data for time-series analysis. However, time assignment of the XIS was calibrated only for some of the clocking modes within the accuracy of the time resolution. Since the absolute timing accuracy of the Hard X-ray Detector (HXD) was calibrated to be better than 360 μs (Terada et al. 2008), we calibrated the XIS timing accuracy referring to the HXD data.

2. Details of CCD clocking

There are two kinds of clocking modes in the XIS, Normal and Parallel-sum modes. Furthermore, two options (window and burst options) may be used in combination with the Normal mode. We present below details of the CCD clocking for 3 sets of modes/options, which were calibrated in this paper. Because the time assignment tools of XIS did not fully support the modes/options, we manually corrected the event time if necessary. Note that the XIS functions in unit of 8 seconds, whose timing is synchronous to the satellite master clock.

2.1. Normal mode with a 0.1s Burst option

All the pixels are read out every 8 seconds. The effective exposure of 0.1 sec starts 7.844 sec after the 8 sec boundary.

2.2. Normal mode with a 1/8 window option

Eight sets of short exposure are obtained in 8 sec when 1/8 window option is employed. The exposure is 1.002 sec for the first one and 0.971 sec for the rest. These exposures are separated by 25 ms of the dead time required for the charge transfer.

2.3. Parallel-sum mode

The pixel data of 128-rows are summed in the Y-direction on the CCD, and the sum is treated as a single row in the subsequent process. No spatial information is available in the Y-direction. The time resolution is 8 sec/1024 $\sim$ 7.8 ms.

3. The calibration targets

We selected two targets, Hercules X-1 and Cygnus X-1, for the present calibration. Her X-1 is a low mass X-ray binary with a spin period of 1.24 s, an orbital period of 1.7 day, and the disk precession period of $\sim$ 35 days. The energy dependence of the pulse profile is small (Soong et al. 1990). Cyg X-1 is one of the most famous black hole candidates (Remillard & McClintock 2006), and shows random time variations called shot noise (Ibragimov et al. 2005). The energy dependence of the time variations is also small (Negoro et al. 1994).

4. Timing calibration of the XIS

4.1. Normal mode with a 0.1s burst option

We used the Her X-1 data obtained in the high state (2008 Feb 21, 39 ksec, SCI-on). Folded pulse profiles (1.237749 s) were created for the XIS and the HXD/PIN using the data in a common energy band (10-12 keV) taking into account of the large dead time in the XIS. We calculated the cross-correlation between the pulse profiles, and determined their relative shift (Fig. 1). The relative shift, which corresponds to the time assignment error of the XIS, was found to be < 24 ms.

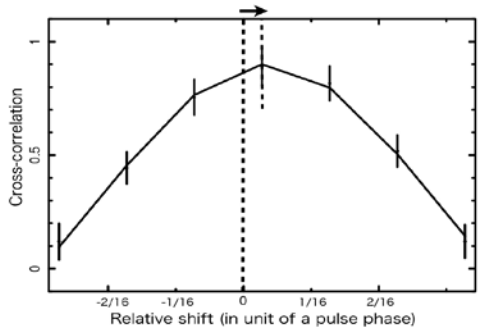

Fig. 1. The cross-correlation function between the XIS and the HXD/PIN pulse profiles (10-12 keV). The unit of abscissa is a pulse phase, and 1/16 phase corresponds to ∼77 msec.

4.2. Normal mode with a 1/8 window option

We used the Cyg X-1 data in the low state (2005 Oct 5, 17 ksec, SCI-off). Because the time variations in Cyg X-1 might have intrinsic energy dependence, we calculated the cross-correlation of the light curve in various energy bands taking 2-3 keV band as a reference. The relative shifts thus obtained are plotted as a function of energy in Fig. 2. Possible jump of the shifts between the XIS and the HXD/PIN data represents the XIS time assignment error, which was constrained to be < 59 ms, assuming a linear energy dependence.

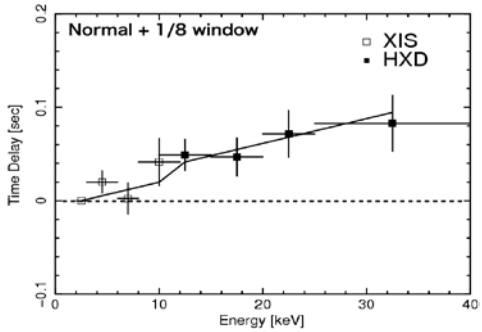

Fig. 2. Relative shift of the time variations between different energy bands of Cyg X-1 data taking 2-3 keV as a reference. Possible jump at $\sim$ 11 keV represents the time assignment error of the XIS.

4.3. Parallel-sum mode

We used the Cyg X-1 data in the low state (2008 Apr 18, 33.9 ksec, SCI-on). Same analysis as §4.2. was applied. The relative shifts thus obtained are plotted as a function of energy in Fig. 3. Possible jump of the shifts between the XIS and the HXD/PIN data represents the XIS time assignment error, which was constrained to be 30 ± 16 ms, assuming a linear energy dependence.

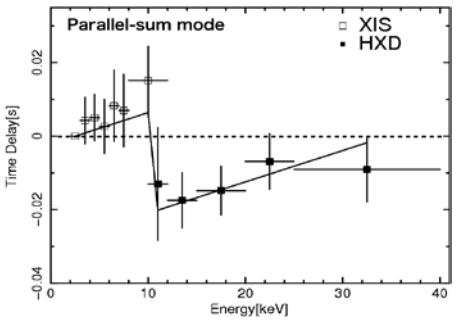

Fig. 3. Relative shift of the time variations between different energy bands taking 2-3 keV as a reference. Possible jump at $\sim$ 10 keV represents the time assignment error of the XIS.

5. Discussion & Summary

We summarize in table 1 the time assignment error of the XIS obtained in the current analysis. We could constrain the accuracy of the XIS time assignment in the Normal mode with a burst/window option much better than the time resolution. However, a marginal offset was found in the XIS time assignment in the Parallel-sum mode. Origin of this marginal offset is under investigation.

Table 1. Summary of the XIS time assignment error

Mode Option	Normal 0.1s burst	Normal 1/8 window	Parallel-Sum
Time resolution	0.1 s	1 s	7.8 ms
Relative shift	< 24 ms	< 59ms	30 ± 16 ms†

† Positive shift means XIS time is delayed behind HXD.

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