Calibration of Alignments of the MAXI/GSC

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Abstract

One of the important goals of MAXI is to discover X-ray transient objects and inform the world of their positions. For follow-up observations with other satellites and telescopes, we must reduce the position uncertainties as small as possible. We therefore performed calibration of alignments of the MAXI/GSC. As a result, we reduced the systematic error in position determination from the initial uncalibrated value of 1.0 degree to 0.2 degree.

Key words: MAXI: GSC

1. Introduction

MAXI(Monitor of All-sky X-ray Image) is an X-ray monitor on the ISS(International Space Station) and its operation started on August 2009. One of the important goals of MAXI is to discover X-ray transient objects and inform the world of their positions. For follow-up observations with other satellites and telescopes, we must reduce the position uncertainties as small as possible. We therefore performed calibration of alignments of the MAXI/GSC.

In this paper, we describe how the GSC alignment calibration was implemented, and show the resultant improvement of the position accuracy for X-ray point sources.

2. Gas Slit Camera(GSC)

The overview of MAXI and GSC are summarized well in (Matsuoka et al. 2009). Here, we describe the necessary explanation on the alignment calibration of GSC. GSC consists of six GSC units and each GSC unit is composed of two GSC half-units combined axisymmetrically. Each GSC half-unit is comprised of a GSC counter with one-dimensional position sensitivity and a collimator assembly. The collimator assembly is composed of a slit and orthogonally arranged slats, making fan-like long-narrow field of view (FoV) of 1.5 deg (FWHM) × 80 deg (Full-FoV). The angle along with the longer direction (ϕ) of the FoV is measured by the one-dimensional position sensitivity of GSC counters. Here, the one-dimensional position is reconstructed by the charge division method, in which the ratio of readout charges from the both ends of an anode wire is used as the position indicator. A GSC counter has six anode wires.

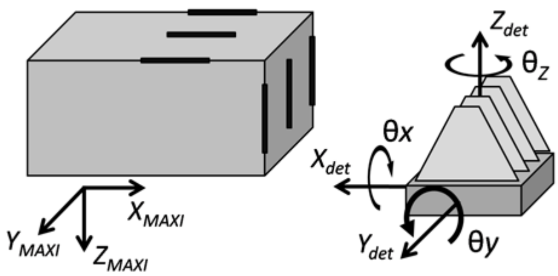

Fig. 1. The coordinates of MAXI ($X_{\rm MAXI}$, $Y_{\rm MAXI}$, $Z_{\rm MAXI}$) and a GSC half-unit ($X_{\rm det}$, $Y_{\rm det}$, $Z_{\rm det}$) is shown. In the left hand, the slits of six GSCs are depicted in thick lines on the cuboid (MAXI). In the right hand, a GSC half-unit is sketched in a combination of trapezoids (slats) aligned parallel on a cuboid (a GSC counter). The rotations around axes of the GSC half-unit coordinate are also shown ($\theta_{\rm X}$, $\theta_{\rm Y}$, $\theta_{\rm Z}$).

A group of three GSC units is arranged so that their FoVs orient to the horizontal(forward) or zenith direction with respect to the ISS orbital motion, which is called GSC-H or GSC-Z, respectively. The light curve of an X-ray source with a constant flux becomes a triangular shape during a scan transit of the FoV. These FoVs of GSC-H and GSC-Z scan the all-sky during an ISS orbit ($\simeq$ 92 min.), mutually complementing the unseeable area of the celestial sphere caused by an ISS passage of high-rate particle background regions. Here, each GSC unit of GSC-H(Z) covers the angle direction (β) of $-80°$–$0°$, $-40°$–$+40°$ and $0°$–$+80°$ with respect to the scanning great circle, when the attitude of the ISS is nominal.

The coordinates of MAXI and a GSC half-unit are defined as shown in figure 1.

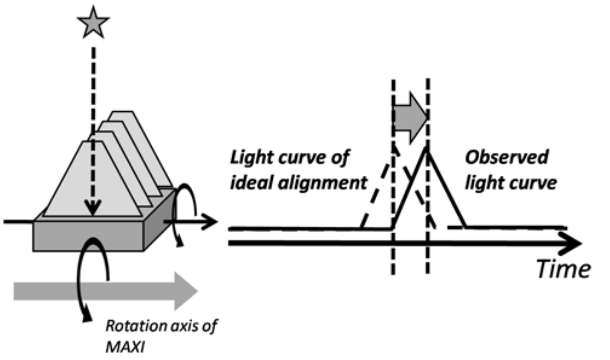

Fig. 2. The effect of $\Delta\theta_X$ in the observed light curve is presented. A schematic drawing of a GSC half-unit is shown in the left hand. In this example, a camera arranged at the center of MAXI covering a FoV of $\beta = -40°$–$+40°$ is shown. In this case the rotation axis of MAXI and the axis $X_{\rm det}$ is parallel. The observed light curve shifts in time with respect to the light curve expected in the ideal alignment as shown in the right hand. In the case of cameras arranged at the left and right hand sides of MAXI, the similar effect in the light curve is also expected.

3. Method of the GSC alignment calibration

The implementation of the GSC alignment calibration is to determine the actual conversion matrix (M) from the MAXI coordinate to the every camera coordinate (figure 1) by referencing the actual data of bright known X-ray point sources. The attitude of the MAXI coordinate itself is determined by the Attitude Determination System (ADS) in every 1 s using the Visual Star Camera (VSC) and the Ring Laser Gyroscope (RLG). The precision of the attitude determination is 0.1 arcmin when the VSC observe three or more stars. Even in the worst case, the ADS can determine the MAXI attitude in an accuracy of 0.1 degree.

The actual alignment matrix (M') is expressed by the products of three infinitesimal rotation matrices around the axes of $X_{\rm det}$, $Y_{\rm det}$ and $Z_{\rm det}$ ($R(\Delta\theta_X)$, $R(\Delta\theta_Y)$ and $R(\Delta\theta_Z)$) and the original alignment matrix (M) as $M' = R(\Delta\theta_Z)R(\Delta\theta_Y)R(\Delta\theta_X)M$.

The effects of these infinitesimal rotations are considered as follows. If only the $\Delta\theta_X$ is non-zero, the observed light curve of a known X-ray source shifts in time as shown in figure 2. If only the $\Delta\theta_Z$ is non-zero, the time shifts of the observed light curves of known X-ray sources are dependent on the position of the long direction of the FoV (ϕ) as shown in figure 3. If only the $\Delta\theta_Y$ is non-zero, the positions of the X-ray sources along the long direction of the FoV shift in an anode wire direction of a GSC counter as shown in figure 4 in the relation of $L_{\rm f}\tan(\phi + \Delta\theta_Y) = X_{\rm det}$, where $L_{\rm f} = 160$mm is the distance between the slit and the GSC counter.

A more detailed description is in (Morii et al. 2010).

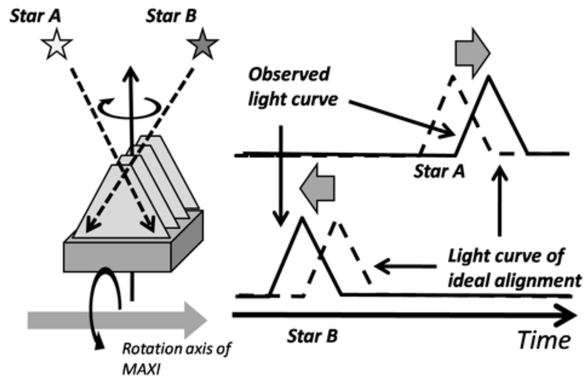

Fig. 3. The effect of $\Delta\theta_Z$ in the observed light curves is presented. Here, the center camera is shown like figure 2. The amount and direction of time shifts of observed light curves depend on the angle ϕ in the long direction of the FoV as shown in the right hand.

4. Results

Before the calibration (Fig. 6), the image of Sco X-1 is somewhat spreading and its position shifts greatly (actual position is the center of the image.). In September 2009, the attitude of ISS changed greatly because of docking of Space Shuttle. Therefore the shape of X-ray object is very distorted. But after the calibration (Fig. 7), it is improved.

Figure 5 demonstrates the improvement of the position accuracy for an X-ray point source. The systematic deviation of the X-ray position before the alignment calibration was 0.90 degree (90% containment radius), while that after the calibration was 0.12 degree (90% containment radius) for Sco X-1 in 5−10 keV band. The accuracy for other bright X-ray point sources were 0.16, 0.17, 0.18 and 0.19 degrees for Crab nebula, GRS 1915+105, Cyg X-1 and Cyg X-2, respectively. Since the Sco X-1 is much brighter than the other X-ray sources among those used in the calibration, the best position accuracy was achieved for Sco X-1. Even in the worst case, the position accuracy was within 0.2 degree (90% containment radius).

References

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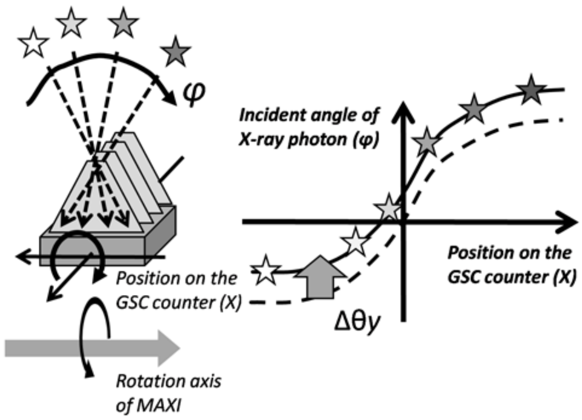

Fig. 4. The effect of $\Delta\theta_Y$ is presented. As an example the center camera is shown like figures 2 and 3. The effect of $\Delta\theta_Y$ appears in the relation between the incident angles (ϕ) of X-ray photons from known X-ray point sources and the detecting position on the GSC anode wire ($X_{\rm det}$) as the parallel shift as shown in the right hand.

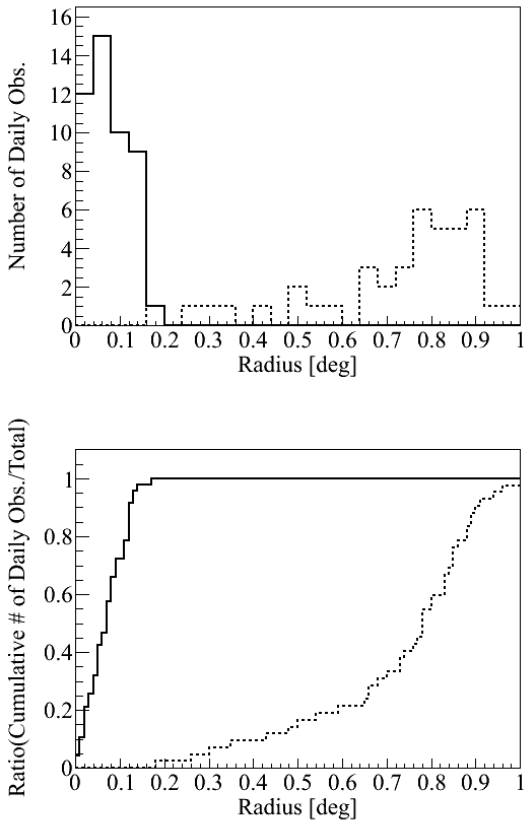

Fig. 5. The demonstration of the improvement of the position accuracy for an X-ray point source by the GSC alignment calibration. The upper panel shows the histogram for the radial distance of the observed position of Sco X-1 from the actual position. The each position is reconstructed by an one-day observation using all GSC counters. The dashed and solid histograms correspond to that before and after the calibration, respectively. The data used are those obtained from 2009 September 7 to 2009 October 30 in the 5$-$10 keV band. The lower panel shows the cumulative representation of the upper panel. Here, the vertical axis is the ratio of the cumulative numbers of daily observations to the total number of the observations. The dashed and solid histograms correspond to that before and after the calibration, respectively.

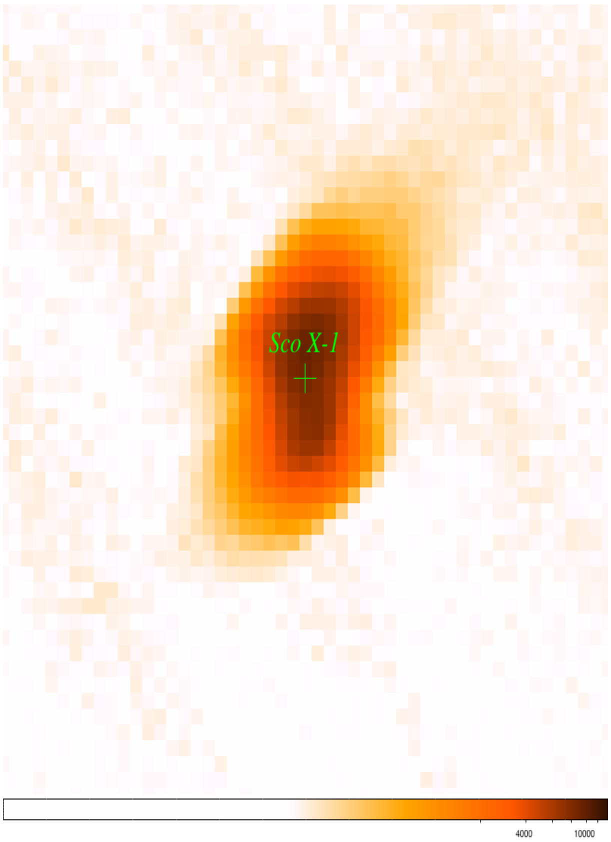

Fig. 6. X-ray image of Sco X-1 observed by MAXI (before the calibration). This image is made by using data from September 1, 2009 to September 30, 2009.

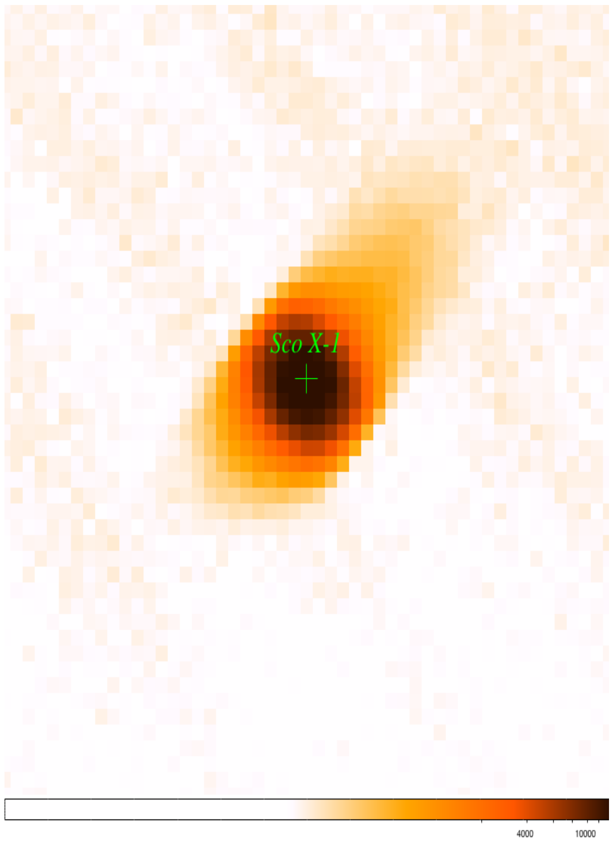

Fig. 7. X-ray image of Sco X-1 observed by MAXI (after the calibration). The data are the same as for Fig. 6.