Improvement of the *ASCA* Position Accuracy

Y. Ueda, H. Inoue, Y. Ogawara, R. Fujimoto, K. Yamaoka, T. Kii
Institute of Space and Astronautical Science, Yoshinodai 3-1-1, Sagamihara, Kanagawa 229-8510, Japan

and

E. V. Gotthelf[1]
NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA

ABSTRACT

We report the reason behind the absolute-position uncertainty of *ASCA* and introduce a method to improve the position accuracy to an error radius of 0.5 arcmin (90% confidence), a factor of two improvement compared to the previous value. We conclude that the nominal error of 1 arcmin in the absolute attitude is attributed to a change of the direction of the field of views of the star tracker (STT) with respect to the satellite, probably caused by a thermal expansion/contraction of the base plate, on which the STTs are mounted. The amount of the thermal expansion varies from observation to observation, according to the average base-plate temperature when data from the STTs are available. This leads to a scatter of the offset in the attitude solution in the y-axis direction of the detector coordinates (DET-Y). The amount of the DET-Y offset has a good correlation with the base-plate temperature. We demonstrate that we can reduce the position uncertainty significantly using this correlation.

1. Introduction

In the sky coordinate system, the position of each photon is converted from the detector coordinate to a celestial position, referring to the information of the satellite attitude at every moment through the alignment matrix (see e.g., Gotthelf 1996). Attitude solution is determined in off-line analysis based on gyros (IRU) and star tracker (STT) data. The history of the attitude solution is written in the so-called "attitude file" made for each observation. Attitude determination has two aspects: relative one and absolute one. The former is important to correct for blurring of image arising from the pointing instability of the spacecraft. On the other hand, the absolute position accuracy is vital for source identification. Fundamentally, the IRU data are used to trace the history of the relative change of the attitude, whereas the STT data, transmitted via a dumping filter, are utilized to determine the absolute attitude .

After the launch, it was found that the accuracy of absolute source position measures with *ASCA* is limited to ~ 1 arcmin. Gotthelf (1996) systematically investigated the *ASCA* position accuracy, using 48 sources whose positions were known better than a few arc second from measurements in other wavelengths. According to the study, the angle separation between the position determined by *ASCA* and the standard

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[1] current address: Columbia Astrophysics Laboratory, Columbia University, 550 West 120^{th} Street, New York, NY 10027, USA

one follows a Poisson distribution with a mean displacement of 0.4 arcmin (0.7 arcmin at the 90% confidence level). These displacements are distributed randomly in R.A. vs. Dec. space, centered at zero. On the other hand, the blurring of image is found to be well corrected in the sky coordinate with accuracy of $0'.2$.

In this report we present the results of our investigation into the underlying cause of the large absolute error in the ASCA position determination. We locate the error to a temperature dependent mis-alignment between the STT and the SIS, which varies from observation to observation. Based on this study, we developed a method to improve the position accuracy to an error radius of 0.5 arcmin (90% confidence), a factor of two improvement compared to the previous value. The principle of this correction method is described in the final section.

2. Analysis of *ASCA* on board Data

2.1. Summary of Location of the Attitude Sensors

We summarize in Figure 1 the locations of the SIS, the STT, and the IRU in the spacecraft, and the relation to the detector coordinates (DET-X/Y). The focal plane detector (SIS and GIS) and the STTs (STT-A and STT-B) are mounted on the base plate. The IRU is mounted on a side plate, attached perpendicular to the base plate. The field of views (FOV) of the two STTs are 45 degrees away from the X/Y axis of the detector coordinates.

2.2. Analysis Method

To investigate the direct cause producing the large position error, we made the following analysis using onboard data. Selecting observations of bright sources, we traced the history of its peak position in the SIS image, which was accumulated every 2 minutes. We define this position as $SISX/Y$ (measured in the detector coordinates). Next, we determined the satellite attitude (Euler angles) every moment in two ways: (1) based on the IRU data alone and (2) based on the STT data alone. Using these Euler angles, we calculated the history of the expected peak position in the detector coordinates, which are defined as (1) $IRUX/Y$ and (2) $STTX/Y$, respectively. Comparison between $SISX/Y$ and $IRUX/Y$ (or $STTX/Y$) thus gives information of the relative alignment between the X-ray telescope and the attitude sensors.

In deriving $IRUX/Y$, we performed special attitude determination by utilizing basically only IRU data, except for estimation of the initial attitude and the drift bias. This enables us to distinguish the signals between the IRU and the STT, which is essential to identify the cause of this problem. Note that $STTX/Y$ can be obtained only when useful data from both of the STT-A and STT-B are available, i.e., both FOVs are not blocked by Earth and in the satellite-night time.

Figure 2 shows examples of the history of $SISX/Y$, $IRUX/Y$, and $STTX/Y$ just after the maneuver to the targets (Ser X-1 and Cyg X-2). Since the satellite was operated in the normal pointing mode where the feedback of the STT is enabled, the onboard attitude control are made based on both the IRU and the STT data. Hence, it is not simple to discuss the history of the absolute source position. But, the history of the relative positions ($SISX/Y$–$IRUX/Y$, or $SISX/Y$–$STTX/Y$), plotted in the middle panels, gives useful information on the change of the alignments between them. In the lowest panel, we have shown the history of the temperature of the satellite base-plate (BP4).

2.3. Results

From Figure 2, we obtained the following results:

- The alignment between $SISX$ and $STTX$ shows little variability.
- The alignment between $SISY$ and $STTY$ is variable at ~ 0.5 arcmin level on a time scale of less than one to a few orbital periods of the satellite (as seen in the case of Ser X-1 and Cyg X-2, respectively). The amount of this mis-alignment (in the DET-Y direction) correlates well with the temperature of the base-plate.
- The alignment between $SISX/Y$ and $IRUX/Y$ is stable at ~ 0.2 arcmin level. In other words, the IRU follows the source position in the focal plane very well.

These results suggest that a major part of the inaccuracy in the absolute position arises from a mis-alignment between the STT and the SIS, rather than that between the IRU and the SIS, which can be caused by distortions of the spacecraft structure. This is consistent with the report by Gotthelf (1996) that blurring of image can be corrected well in the sky coordinates by the attitude file, which relies on the IRU data to trace the relative pointing of the boresight.

The good correlation between the mis-alignment of $STTY-SISY$ with the base-plate temperature indicates the following scenario: the time dependent mis-alignment between the STT and the SIS is caused by slight change of the directions of the STT FOVs with respect to the satellite, due to thermal expansion/contraction of the base plate, on which the STTs are mounted. The base-plate is made of aluminium, which has a large thermal-expansion coefficient, while the structure of STTs is made of Carbon Fiber-Reinforced Plastic (CFRP), whose thermal expansion is much smaller compared to aluminium. A simple calculation shows that the STT FOV could direct upward (downward) with respect to the base plate (+satellite-Z direction) by an order of 1 arcmin if the temperature of the base plate decreased (increased) by $\sim$5 degrees, due to asymmetric structure of the supports of the STTs. We confirmed this by an experiment employing a pre-flight model of the STT, attached on a aluminium plate which simulates the base plate. Since any synchronized motion of the two STTs produces a moment in the DET-Y direction in the attitude determination (cf. Figure 1), we should see the mis-alignment only in the DET-Y direction, not in the DET-X direction. To confirm the above interpretation, we also examined data when onboard attitude control was made by the IRU only (Kii 1993, internal report). We found that the addresses of tracking stars in the STT FOVs (which reflects the mis-alignment between the STT and the IRU) changed as a function of the orbital phase of the satellite with a good correlation to the base-plate temperature. This is fully consistent with our interpretation.

3. Attitude Correction

Using the above results, we can now explain the reason behind the position inaccuracy of *ASCA*. The amount of mis-alignment between the STT and SIS that affects the absolute attitude determination is different from observation to observation, according to the average base plate temperature when both the STTs are available (i.e., during the satellite night time). This leads to a random scatter of the offsets in the attitude solution, particularly in the DET-Y direction. Figure 3 (a) shows the offset of the *ASCA* positions from absolute positions, measured in the detector coordinates, for the sample used in Gotthelf

(1996). The histogram of angular separation is given in Figure 4 (a). As expected, it is indeed seen from Figure 3 (a) that the error region is elongated along the DET-Y direction, rather than in a circle. We also see a systematic offset of about 0.1 mm in the DET-X direction, which is probably attributable to the mis-calibration in the alignment matrix.

Figure 5 shows the correlation between the DET-Y offset and the base-plate temperature that is averaged for each observation using HK data (BP4) in satellite-night phase (20 minutes per orbit). A clear correlation between DET-Y offset and the base-plate temperature is noticed. Finally, we found that the offsets in the detector coordinates, $\delta X/Y$, can be well represented in the following form [2] :

$$\begin{aligned} \delta X &= 0.1 \quad (\mathrm{mm}) \\ \delta Y &= 0.149 \times T \; - \; 0.26 \quad (\mathrm{mm}), \end{aligned}$$

where T is the average base-plate temperature (BP4) in units of degree. Using this correlation, we can correct the position offsets in the detector coordinates observation by observation. Figure 3 (b) and Figure 4 (b) show the results after applying this correction. The position accuracy is thus greatly improved, to an error radius of 0.5 arcmin (90% confidence) [2] , which is a factor of two improvement compared to the previous value.

A table of the $\delta X/Y$ values for each *ASCA* observation is available at

http://heasarc.gsfc.nasa.gov/docs/asca/coord/updatecoord.html.

This table shall be updated based on the results of Gotthelf *et al.* (2000).

We acknowledge Tetsu Saitoh, Hoshiko Takayasu, and the ACS team members of the NEC for their help on the *ASCA* attitude files. We are also grateful to Biswajit Paul for his careful review of the manuscript.

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[2] The values of these coefficients are being updated by further calibration by Gotthelf *et al.* (2000). The final error radius achieved may be revised accordingly.

This preprint was prepared with the AAS LaTeX macros v4.0.

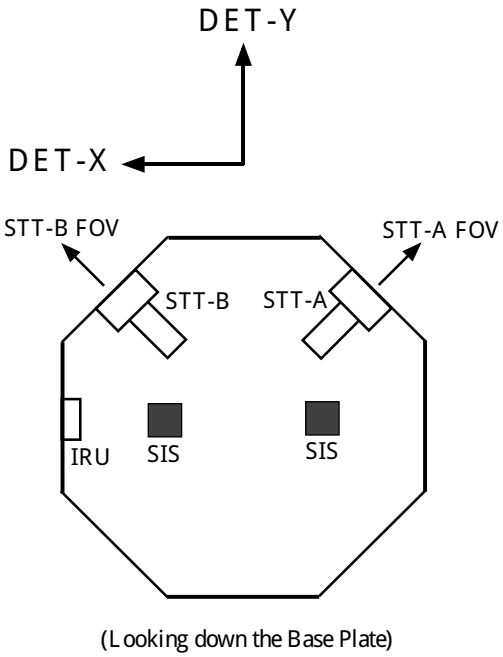

Fig. 1.— Location of the SIS and the attitude sensors (STT and IRU) when the base-plate is looked down. The relation to the detector coordinates (DET-X/Y) is also shown.

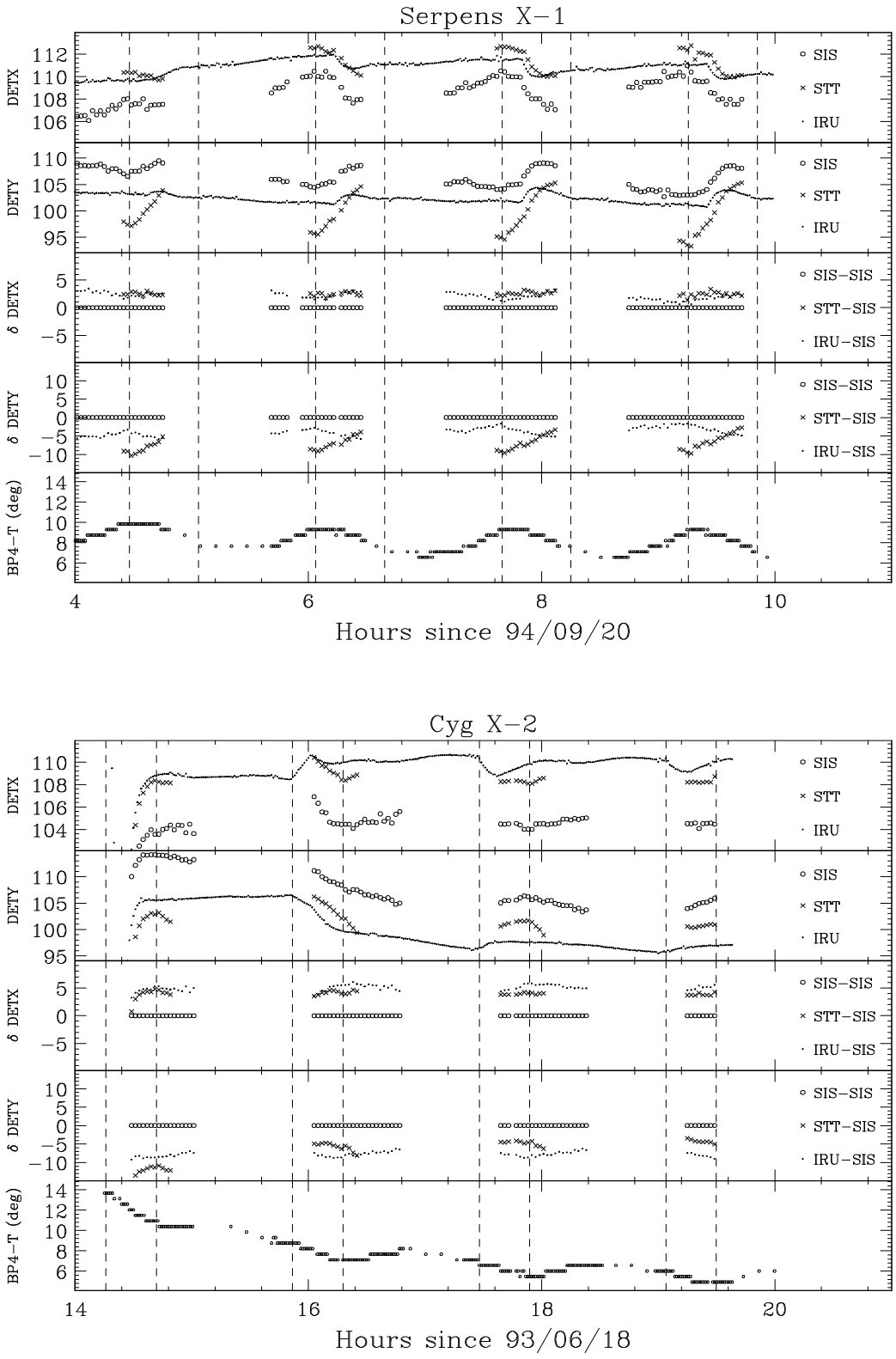

Fig. 2.— History of $SISX/Y$, $IRUX/Y$, and $STTX/Y$ (1st and 2nd panel), and the differences from $SISX/Y$ (3rd and 4th panel), traced for 4 satellite-orbits after the maneuver. Unit channel corresponds to 0.106 arcmin (4 SIS pixels). History of base-plate temperature is plotted in the bottom panel. (a) Upper: for Ser X-1. (b) Lower: for Cyg X-2.

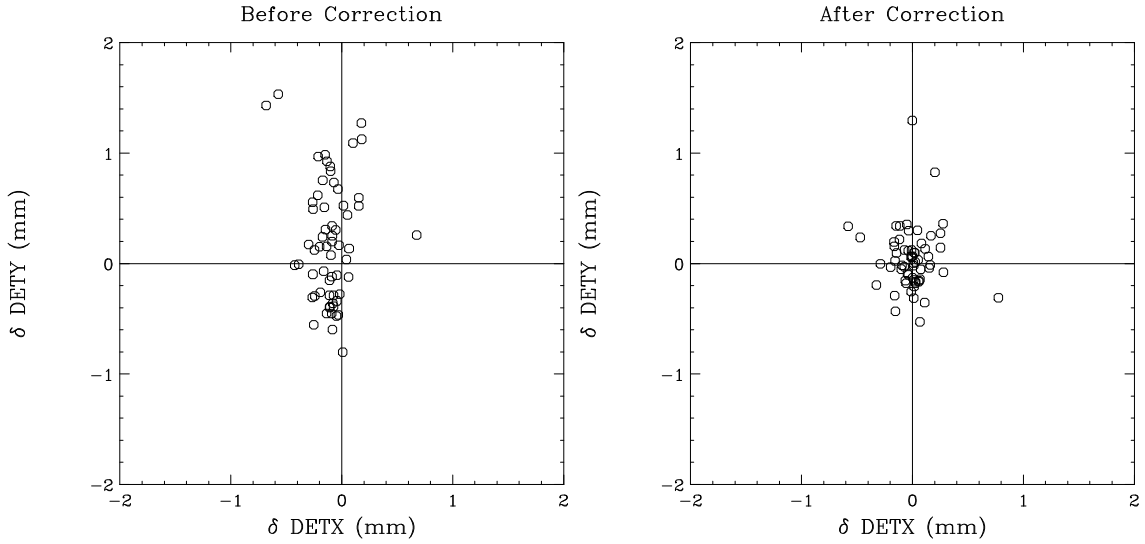

Fig. 3.— (a) Left: Scatter plot of offsets of *ASCA* position from the standard position, measured in the detector coordinates. (b) Right: The same plot obtained after the attitude correction is applied.

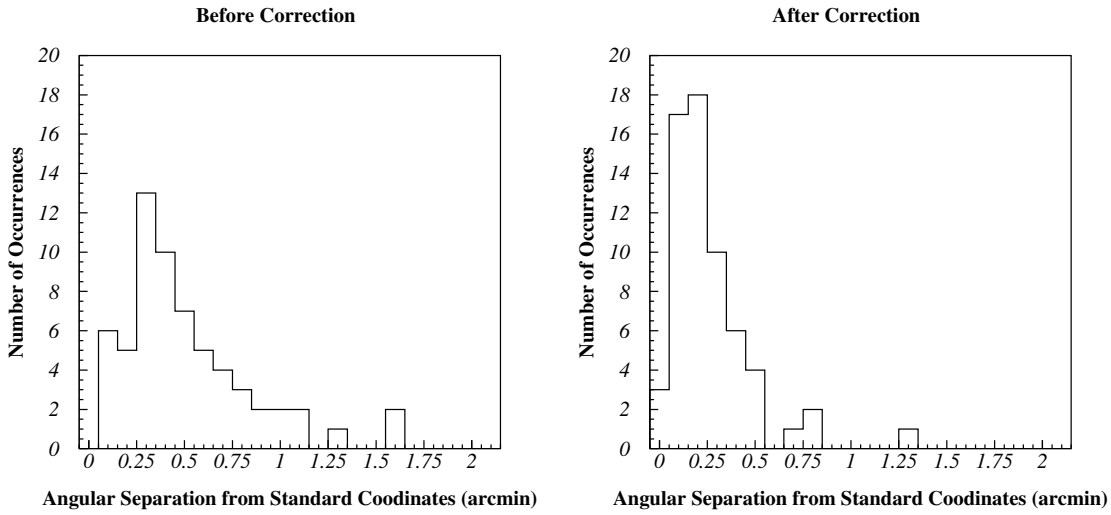

Fig. 4.— (a) Left: The histogram of angular separation between *ASCA* position and the standard position. (b) Right: The same histogram obtained after the attitude correction is applied.

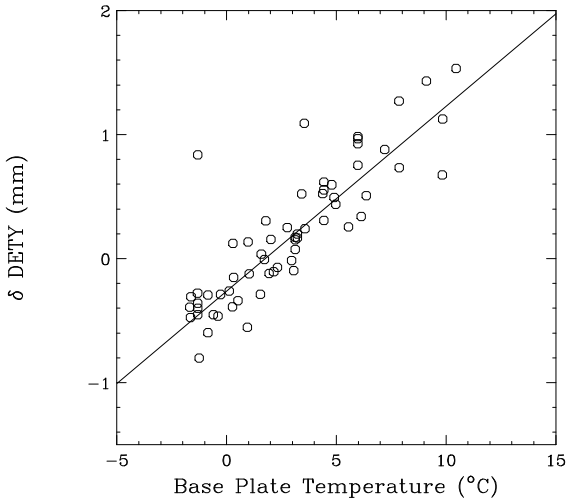

Fig. 5.— The correlation between the DET-Y offset and the base-plate temperature in satellite-night phase.