# ASTRO-H

# INSTRUMENT CALIBRATION REPORT
# SXS TIMING COEFFICIENTS
# ASTH-SXS-CALDB-COEFTIME

Version 0.2

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**ISAS/ GSFC**

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# 1. Introduction

### 1.1 Purpose

The SXS events are classified in pixel event ITYPEs (0, 1, 2, 3, 4, 5, 6, 7) = TYPEs (Hp, Mp, Ms, Lp, Ls, BL, LO, Rj) and anti-co events (see SXS document). Among of them, the photon events are Hp through Ls and they are categorized in three "major" type of H (Hp), M (Mp and Ms), and L (Lp and Ls). The first two (H and M) of events are time assigned through the optimal filtering process implemented in the flight software onboard the PSP. Since the L (Lp and Ls) events and anti-co events skip the filtering process, they are tagged with a hardware-determined local time counter (at DERIV_MAX time for L and at the trigger threshold for anti-co). The TYPE = BL events are not photon events and need no time correction with this CALDB file. The TYPEs LO (= lost count event) and Rj (= reject) employ different format and need not to be time assigned in the process, either.

### 1.2 Scientific Impact

This file contains various time coefficients related to above pixel events of TYPEs, antico detector events and MXS events. Its structure is an empty primary header with 2 extensions. The first extension consists of 12 columns. The first one is TIME. The following 3 columns define time intervals for *sxssecid* task to determine pixel event TYPEs if the regrade option is set to yes, while the rest define parameters for *sxsflagpix* to flag events indicating coincidence among pixel, anti-co, or MXS events. The second extension describes parameters to re-calculate photon arrival time compensating TYPE, energy, and rise-time of event pulses. Details of these parameters are described in section 2.

# 2 Release CALDB 20160310

| Filename | Valid data | Release data | CALDB Vrs | Comments |
|---|---|---|---|---|
| ah_sxs_coeftime_20140101v001.fits | 2014-01-01 | 20160310 | 001 | |

### 2.1 Data Description of the first extension: DELTIMES

This extension consists of the following 12 columns, all with units of seconds. The TIME column defines the time when the coefficients in that row become applicable.

The 3 columns after TIME are used by the *sxssecid* task for identifying the primary event associated with a given secondary event, and in event re-grading. The values are defined by onboard software parameters. DTPRIMARY column stores the time interval that distinguishes primary from secondary events (based on the time from the preceding event). The DTLOWMID column stores the time interval that distinguishes low ("major" pixel event type L) from mid-resolution (M) events, and DTMIDHIGH column stores the time interval that distinguishes high

(H) from mid-resolution (M) events (both based on the time to the nearest event, whether preceding or following).

The following 8 columns are for defining the window used for antico flagging by the *sxsflagpix* task, which determines the time interval of pixel event discrimination with the anti-coincidence with the antico events, pixel cross-talk events or MXS photons.
The ANTSHIFT column stores the time offset between event time and central anti-co time, while the ANTDTPRE column stores the time interval preceding the time of an antico event (shifted by ANTSHIFT) used to define the lower limit of the window, and the ANTDTFOL column stores the time interval following the time of an antico event (shifted by ANTSHIFT) used to define the upper limit of the window. The ANTSHIFT column has two values for each row to accept different values for the two sides of the PSP.

The CTRECDT column stores the time interval that identifies background events originating from cal-pixel recoil electrons. Events occurring within CTRECDT of a cal-pixel event may be flagged by *sxsflagpix*. PROXDT is similar, but applies to any two pixels, in order to flag tightly correlated pairs of background events, such as from an electron lost from one pixel and absorbed by another. The reason to distinguish them is that pairs involving the cal pixel are primarily due to cal-source x-rays, thus the pulses are similar and the dispersion in event timing is small. Thus, if the acceptance window for other pairs needs to be expanded to include the full range of events, it could be restricted for cal-pixel pairs to control the number of false coincidences.

The CTELDT column stores the time interval between events required for electrical crosstalk to be flagged by *sxsflagpix*. This is for the purpose of identifying crosstalk events that have triggered. The CTEL2DT column stores the time interval between events that could be contaminated by untriggered electrical crosstalk. Both of these apply only to pairs of electrical nearest neighbors. Thus, if a small, fast event on pixel 2 occurs within CTELDT of a normal pulse on pixel 3, then pixel 2 would be provisionally flagged as electrical crosstalk. (In practice, the size and rise time should be sufficient to identify it as such.) If events on pixel 2 and pixel 3 occur within CTEL2DT of each other, both events will be flagged because the energy assignment of both events may be contaminated.

The MXSDT column stores the time interval by which the MXS pulse stop times given in the MXS GTI are extended to account for MXS afterglow in flagging events for coincidence with MXS operation in *sxsflagpix*.

### 2.2.1 evaluation of values: DELTIMES

The values for DTPRIMARY, DTLOWMID, and DTMIDHIGH are intended to match parameter used in the PSP. No study was required for their determination.

Cosmic ray events observed on May 18, June 21, and June 25, 2015 were used to characterize anti-co timing relative the calorimeter pixels.

Background data from June 21, 2015 were used to characterize the time intervals between correlated pairs of calorimeter events.

Low threshold data from May 19, 2015 were used to study the timing of electrical crosstalk. The dependence of pulse-height determination of a pulse contaminated by undetected electrical crosstalk on the separation in time of that crosstalk was determined by modeling and verified via analysis of MXS data (e.g. in the “Normal operations test” and FNC-D on November 10-11, 2015).

### 2.2.2 results: DELTIMES

The distribution of time intervals between the trigger times of array events and of their associated anti-co events peaks at $200 \pm 40$ micro-s, except pixel 26, which peaks 130 micro-s later. The difference for pixel 26 is eliminated with the conversion from SAMPLECNTTRIG to SAMPLECNT (see next section). The systematic difference between pixel and anti-co trigger times is due to the different triggering schemes; the assigned anti-co times are later. The distribution is slightly asymmetric towards longer delays. A range of 40 micros-s to 440 micro-s (relative to the pixel time) covered the distribution in the ground background data. Since there are three parameters available to specify these two numbers, we have made the arbitrary choice to make ANTDTPRE = ANTDTFOL = 200 micro-s and ANTSHIFT = – 240 micro-s (for the both sides of the PSP).

To study pixel-pixel correlations not involving electrical crosstalk, data taken with a high PSP threshold (120) was analyzed, and all events with E < 100 eV were ignored. The most probable time interval of correlated pairs (looking at all pairs closer than 1.5 ms) was 0, with an RMS of 38 micro-s. Given the limited statistics in ground background data, we did not separate pairs involving the cal-pixel from those that did not, and we have set CTRECDT = PROXDT = 240 micro-s to cover an integral number (3) of time samples. This choice allows flagging of in-band events paired with extraordinarily large events on other pixels, as occurs when a recoil electron is detected from a low-angle cosmic-ray event on another pixel.

To study timing offsets to electrical crosstalk, data taken with a low PSP threshold (~25) were analyzed, and correlated pairs involving electrical nearest-neighbor channels were studied. The source x-rays were predominantly $^{55}$Fe, with some channels also seeing Cu K x-rays from the MXS. Because the shape of crosstalk is very different from thermal pulses, the time assignment is not robust. Relative to the primary event, crosstalk would need to be flagged within the window of – 640 to +240 micro-s. (Crosstalk from the anti-co into channels 17 and 35 would need an exclusion window of – 1600 to +400 micro-s, relative to anti-co pulse times, which is very different from ordinary anti-co screening.) However, timing is not needed to identify electrical crosstalk. Crosstalk appears at shorter risetimes than normal pulses, and smaller PH values. The gain scales of all grades map electrical crosstalk pulses from x-ray events to energies below 100 eV. Thus energy discrimination easily removes most crosstalk, and risetime discrimination will remove rare crosstalk events from unusually large events. Thus the plan for early operation is not to attempt to identify individual crosstalk pulses, and CTELDT has been set to 1000 micro-s as a placeholder.

Undetected crosstalk needs additional consideration. The presence of a crosstalk pulse on an x-ray pulse will alter the energy that the PSP determines for that pulse. Computing the impact of the crosstalk from an 8 keV x-ray on a normal x-ray pulse as a function of displacement from the arrival time of the x-ray event, we determined that the error could be kept to < 0.5 eV if the coincidence window of ±25 ms for electrical nearest neighbors was excluded, with the exception of a very small window of enhancement if a crosstalk pulse arrives in the last 2 ms of a pulse record, due to non-zero power in the filter at the end of the template. The results of this modeling agree with MXS data, for which the pulsed output increases the probability of pulses occurring on adjacent pixels within the pulse time. Thus we set CTEL2DT = 25 ms.

The time scale of the MXS afterglow was measured in many data sets, most extensively in the "Normal operations test" and FNC-D on November 10-11, 2015. The decay time of the afterglow is characterized by two time constants: 0.6 ms and 4.5 ms. The required waiting time is set by the background requirement, but the relationship between that requirement and MXSDT depends on how the MXS will be used in orbit. We have set MXSDT at 21 ms based on a worst-case operation scenario.

### 2.2.3 summary of the first extension: DELTIMES

DTPRIMARY = DTMIDHIGH = 69.92 ms
DTLOWMID = 17.52 ms
ANTDTPRE = ANTDTFOL = 0.2 ms
ANTSHIFT = – 0.24 ms (common to PSP-A/B; anti-co time is LATER than calorimeter event)
CTRECDT = PROXDT = 0.24 ms
CTELDT = 1 ms (placeholder, not expected to be used)
CTEL2DT = 25 ms
MXSDT = 21 ms

### 2.2 Data Description of the second extension: ARRCOEFFS

As described in "ASTRO-H Time assignment system (ASTH-SCT-021)", photon arrival time of SXS is calculated from the trigger time or derivative maximum time tagged to each event data. However, methods of trigger time or derivative maximum time determination are different between event grades – "TYPEs", and hence there are to be systematic differences between "TYPEs". The second extension describes the parameters to compensate the discrepancy.

The photon arrival time (TIME) of the SXS instrument are determined by the *ahtime* task using the LOCAL_TIME counter "SAMPLECNT" which is determined by the *sxssamcnt* task as follows (subsection 6.2.4 in ASTH-SCT-021),

SAMPLECNT = SAMPLECNTTRIG - a * (0.25 * RISE_TIME) - b * DERIV_MAX – c.

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The parameter set (a, b, c) is defined for each major TYPE (H, M, L) as described above. The corresponding columns in CALDB are AH, AM, AL for the parameter a, BH, BM, BL for the parameter b, and CH, CM, CL for the parameter c. They are stored in units of SAMPLECNT (). In total, 10 columns are defined including the TIME column to specify an applicable time interval for each row. Each of the columns AH through CL stores 36 values for each row to accept pixel dependence of the time coefficients.

### 2.2.1 evaluation of parameters: ARRCOEFFS

**TYPE dependence**
ITYPE dependence defined in this CALDB file is determined by analysis of data obtained in Spacecraft integration test in 2015. The data where from observations taken on SXS-MXS irradiation test in the ASTRO-H integration tests: SXS comprehensive test on 19 May 2015, system function test (FNC-D) in 21 – 22 May 2015 and thermal vacuum test (TVT) in 26 – 27 June 2015. Since the gate valve (GV) was shut during the test 27 of 35 pixels are shaded by the structure of GV.

The data were analyzed with the FTOOLs xronos version 5.22. We extracted pixel event data observed during the MXS periodic pulse irradiation and carried out folding analysis of each pixel or each TYPE events using “efsearch” and “efold”. The start and end times of pulses are recorded in HK data of SXS-MXS (HK_SXS_FWE extension in SXS HK1) and the period and length were set (PLS_SPAC, PLS_LEN) = (78.125 ms, 15.875 ms) for SXS comprehensive & FNC-D or = (62. 500 ms, 5.000 ms) for TVT. We evaluate the time epoch and derived phase shift in folded light curve of each TYPE irradiated pixel and determine the rising phase to determine the time shift from the rise time of MXS pulse.
We analyzed data observed in the three occasions and obtained consistent results. The data obtained in TVT is the most statistically significant. We report the TVT result below.

**PIXEL, RISE_TIME, DERIV_MAX dependence**
Systematic time difference associated with pixel number, event pulse rise time and derivative peak defined in this CALDB file are determined by analysis of cosmic ray events observed on June 21 and 25, 2015 and FW $^{55}$Fe events observed on June 25, 2015. For the cosmic-ray data, pixel events associated with anti-co events (within a 1.5 ms time window) were identified, and the relative time differences from the anti-co event were evaluated. For the $^{55}$Fe data, ~ 100 pulse dumps were analyzed from each channel. The derivative of each pulse dump was calculated using the PSP algorithm and the time of derivmax was determined and compared with the time assigned to the associated H event. This method allows systematic comparison of H and L time assignments for the same pulse.

### 2.2.2 Results: ARRCOEFFS

**Difference in TYPEs**
In this evaluation we employed all irradiated pixels but compare the rising phase of folded light curves of TYPEs (Hp, Mp, Ms, Lp, Ls). Consequently there we see no difference in the observed time delay between “primary” and “secondary” events. We hereafter summarize the time offset

parameters for three “major” event types, H (Hp), M (Mp and Ms), and L (Lp and Ls) in this CALDB file. As results, we observed time delay from the expected MXS irradiation on time were, 450±30 micro-s and (1360±30) micro-s for TYPEs H & M and TYPE L, respectively.

The obtained absolute value of time difference are determined from the time of LED ON command, although there is a certain response time (~ 1 ms or less) for MXS to radiate X-rays. On the other hand, since the TYPE=H/M event time is determined at the event threshold crossing time of pulse derivative, it is ahead of raw pulse rise by about DERIV_HALF_LEN (half length of the BOXCAR filter = 640 micro-s). Therefore the time delay of ~450 micro-s is reasonable, but with this experiment only the relative time difference of TYPE=H/M and TYPE=L of (910± 30) micro-s is reliable to adopted in CALDB data. The time difference is reasonable since TYPEs L event time corresponds to DERIV_MAX time which is expected to delay by the full length of the BOXCAR filter = 1280 micro-s minus the time between onset and triggering). Simulations of calorimeter pulses filtered by the Xbox anti-aliasing filter, digitized to 80 micro-s samples, and differentiated by the PSP indicate that for the trigger levels used at the time the optimal filter was generated, the reported trigger time is within a sample of the true arrival time.

The TYPE to TYPE difference is also evaluated for all 36 pixels using H x-ray events with PSP-assigned times and comparing with L-type times computed from the derivatives of the associated pulse dumps . The obtained relative time difference between TYPE=H/M and TYPE=L is (930 ±25) micro-s, except for channel 26, as discussed in the next section. We adopt this value (930 micro-s) as the systematic time difference between TYPE=H/M and L for all pixels except channel 26.

**Difference in pixels**

In contrast with the other pixels, the computed difference between H/M and L timing for pixel 26 was 800 micro-s instead of 930 micro-s. Additionally, for every pixel except pixel 26, the distribution of trigger time offsets from each associated anti-co event time peaks at – (200±40) micro-s. However, the offset of pixel 26 is 130 micro-s later. The PSP uses tickshift to assign a trigger time that is independent of changes to the trigger threshold, but the time of that assignment relative to the true onset of the pulse remains dependent on the thresholds used at the time the optimal filter was computed. A higher threshold was used for pixel 26 due to its high-frequency ringing; thus the time reference for pixel 26 is later than for the other channels (and thus closer to the time determined at DERIV_MAX). This timing offset for pixel 26 is to be compensated by parameter ‘c’.

**Difference in RISE_TIME or DERIV_MAX**

In principle, it is expected that the time delay of the triggering time depends on the rise time (and pulse height) of each event pulse. However, the difference of raw pulse shape is convolved by the BOXCAR filter and is expected to be small. We saw cosmic-ray event time distribution in reference to event RISE_TIME or DERIV_MAX. Although we saw small dependence both on RISE_TIME and DERIV_MAX in the range up to 50 keV, it is not significant below 12 keV event. Therefore, in this version of CALDB, we ignore the RISE_TIME dependence (parameter a) and pulse-height (which is approximately in proportion to the DERIV_MAX) dependence (parameter b) (a = b = 0).

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### 2.2.3 Summary of the second extension: ARRCOEFFS

RISE_TIME and DERIV_MAX dependence is negligible.
$a = b = 0$,
for all pixels and all TYPEs. Thus, AH = AM = AL = 0 and BH = BM = BL = 0 for all pixels.

TYPE dependence c is determined as,
For pixel 26;
c = 130 micro-s = 1.625 SAMLEPCNT (for TYPEs H and M)
c = 930 micro-s = 11.625 SAMPLECNT (for TYPEs L).

For the other pixels;
c = 0 micro-s = 0 SAMLEPCNT (for TYPEs H and M)
c = 930 micro-s = 11.625 SAMPLECNT (for TYPEs L).
Thus, CH = CM = 1.625 for pixel 26 while CH = CM = 0 for the others, and CL = 11.625 for all pixels.

## 3 Comparison with previous releases

This is the first release.