Timing calibration of *Resolve* microcalorimeter spectrometer on XRISM

**Makoto Sawada** (UMBC, NASA/GSFC), S. Koyama, C. Kilbourne, M. Tsujimoto, M. Eckart, M. Leutenegger, R. Cumbee, C. de Vries, Y. Terada, Y. Ishisaki, and many other members in the Resolve team

*At the 14th IACHEC meeting*
1. Introduction
   • Time assignment in SXS and Resolve
   • Time correction in SXS and Resolve

2. Results from SXS

3. Plan for Resolve
Resolve microcalorimeter

= Non-dispersive high-resolution spectrometer with nearly identical design/performance to Hitomi/SXS

- 6x6 pixels for 3’x3’ FoV
- \( \Delta E = 5-7 \text{ eV (FWHM)} \)
- 0.3-12 keV band pass

SXS spare array (≠ Resolve FM array)

Nearly identical detector & pulse processor
→ timing capability will also be identical to SXS
1. Relative timing:

Optimize coincidence screening of non x-ray backgrounds

- Kilbourne, Sawada, et al. PASJ, 2018

antico: \(~0.5\) cps \(\rightarrow\) time window \(<2\) ms for \(<0.1\)% false coincidence

2. Absolute timing:

Scientific requirements (LMXBs, pulsars, \(\ldots\)) \(\sim1\) ms
At the 14th IACHEC meeting

Time assignment of Resolve

1. Assign trigger time
2. Apply calibration coefficients to trigger time
3. Convert instrument time to satellite time

The same system as used in Hitomi/SXS

On-board process

On-ground pipeline process

Pulse shape processor (PSP)

Design of timing cal. (2.) depends on how PSP assigns trigger times (1.)
Pulse of a microcalorimeter event

~1 ms

~5 ms

Time samples (80 µs)
Trigger time by PSP

- Apply a threshold to derivative

- Energy dependent offset $\rightarrow$ corrected by “optimal filtering”
Time assignment by PSP

1. Get trigger time. (80 µs resolution)

2. Calculate PHA w/template. Repeat for various offsets.

3. Find optimal offset. (5 µs resolution)

4. Record trigger time shifted by optimal offset.

PSP assigns (almost) E-independent trigger times at 5 µs resolution
At the 14th IACHEC meeting

Trigger time for “Low-res” events

- If two pulses are too close, PSP cannot use opt. filtering (Low-res)
- For L-res, use time when derivative hits the maximum

Less energy dependent than the original trigger

![Graph showing the derivative over time samples (80 μs) with peaks at 5.9 keV and 3.1 keV.](image)
Anticipated calibration terms

- **Grade dependence**
  → trigger point definition

- **Pixel dependence**
  → threshold update after template generation

- **Energy dependence**
  → non-linearity of detector pulses

All these dependences are caused by imperfectness of optimal filtering.
Time correction in pipeline

Calibration formula

\[ \text{Calibrated time} = \text{Trigger time} - (a \times \text{RISE\_TIME} + b \times \text{DERIV\_MAX} + c) \]

- \(a\) and \(b\) for \(E\)-dependence (we didn’t use \(a\) in SXS)
- \(c\) for absolute timing

CALDB format

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 AH</td>
<td>36D</td>
</tr>
<tr>
<td>3 BH</td>
<td>36D</td>
</tr>
<tr>
<td>4 CH</td>
<td>36D</td>
</tr>
<tr>
<td>5 AM</td>
<td>36D</td>
</tr>
<tr>
<td>6 BM</td>
<td>36D</td>
</tr>
</tbody>
</table>

This formalization worked well for SXS, and will be used for Resolve.
## Summary of timing calibration

<table>
<thead>
<tr>
<th>Relative</th>
<th>Major mechanism</th>
<th>In SXS, calibrated by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixels</td>
<td>trigger threshold inconsistency</td>
<td>pulse records of cosmic-ray events</td>
</tr>
<tr>
<td></td>
<td></td>
<td>← Ground cal. confirmed w/cosmic ray</td>
</tr>
<tr>
<td></td>
<td></td>
<td>events in orbit</td>
</tr>
<tr>
<td>Grades</td>
<td>trigger point definition</td>
<td>pulse records of cosmic-ray events</td>
</tr>
<tr>
<td></td>
<td></td>
<td>← Ground cal. confirmed w/ Crab pulsar</td>
</tr>
<tr>
<td>Energies</td>
<td>non-linearity of pulse shape</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>folded light curve of Crab pulsar</td>
</tr>
<tr>
<td>Absolute</td>
<td>offset from real photon arrival time</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>folded light curve of Crab pulsar</td>
</tr>
</tbody>
</table>
- **Pulse records of cosmic ray events in the ground tests**
  - Calculate L-res times for H-res events and compare these
    - → grade-to-grade (L to H/M) offset
  - L-res times are insensitive to trigger thresholds
    - → pixel-to-pixel offsets

![Graph showing pulse records and time differences between ground and in-orbit tests](image)
SXS results - Energy dependence

- **In-orbit Crab pulsar data** (3/25, 9.7 ks after screening)
  1. Divide events for grades and three ranges of DERIV_MAX (~E)
  2. Make folded light curve for each and get peak phases
  3. Derive slope of peak phases as a function of DERIV_MAX

An example from H-res case

- 1. $E > 4$ keV
- 2. $4 < E$ (keV) $< 8$
- 3. $E$ (keV) $< 12$

~$-90$ µs
At the 14th IACHEC meeting

SXS results - Absolute timing

- Calibrated by Crab pulsar coordinated radio observations

1. Origin of absolute timing was determined by simultaneous radio observations (Terasawa et al.)

2. The known x-ray-to-radio offset was added –315 µs (Molkov et al. 2010)

3. SXS pixel times were aligned to the reference.

Calibrated to the level of ±30 µs (<< 1 ms)
After all the corrections were applied, pixel event times were compared to associated antico event times. Coincidence window size was set to 500 µs. 0.5 cps (ave.) * 500 µs ~ 0.03% false coincidence … small enough.
• We need to

1. Evaluate uncertainties in SXS timing cal.
2. Set *Resolve* timing cal. requirement
3. Make plan for *Resolve* timing cal.
Uncertainty in SXS timing calibration.

- **Source of uncertainty** - sampling, statistical, and **systematic**
- Any rel. timing can also be calibrated using detector pulse records

Example: energy dependence for H-res

- Energy dependence by direct measurement of detector pulse-shape non-linearity
  - $50 \, \mu s/12 \, keV$
- Energy dependence by Crab
  - $90 \, \mu s/12 \, keV$

- Although marginal, there is some discrepancy … need to watch in Resolve
(Tentative) timing cal. requirement is set based on SXS results

<table>
<thead>
<tr>
<th>Uncertainty (SXS)</th>
<th>H &amp; M-res</th>
<th>L-res</th>
<th>antico</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time assignment Resolution</td>
<td>5 µs</td>
<td>80 µs</td>
<td>80 µs</td>
</tr>
<tr>
<td>Statistical (Crab, $1\sigma$)</td>
<td>20 µs</td>
<td>30 µs</td>
<td>40 µs</td>
</tr>
<tr>
<td>Systematic</td>
<td>40 µs</td>
<td>120 µs</td>
<td>N/A</td>
</tr>
<tr>
<td>Relative timing requirement ($1\sigma$)</td>
<td>80 µs</td>
<td>160 µs</td>
<td>160 µs (~1 ms window)</td>
</tr>
<tr>
<td>Absolute timing requirement ($1\sigma$)</td>
<td></td>
<td>1 ms</td>
<td></td>
</tr>
</tbody>
</table>
Resolve timing cal. plan (tentative)

✨ Guiding principle: do what we did (successfully) in SXS

- Ground calibration
  - ✓ Pixel-to-pixel & grade-to-grade
    - Detector pulse records of cosmic-ray events
    - Modulated X-ray Source (MXS) data
- In-orbit calibration
  - ✓ Energy dependence
    - Folding analysis of Crab pulsar (hopefully with longer exposure)
    - Detector pulse records in orbit
  - ✓ Absolute timing
    - Folding analysis of Crab pulsar
      - Coordinated radio observations are required, as done in SXS

Used in SXS CALDB
Newly added for cross-check
1. XRISM/Resolve will use the same time assignment and correction system as Hitomi/SXS.

2. Timing requirement for Resolve is (tentatively) set based on the SXS calibration results.

3. Started discussion on Resolve timing calibration plan. Lessons from SXS will be used to improve the plan.