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In-orbit timing calibration of the Resolve microcalorimeter spectrometer on the XRISM

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and XRISM SOT/CalIP team

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Introduction1. XRISM/Resolve

XRISM	
Launch Date	September 7, 2023 (JST)
Lead Agency	JAXA, NASA
Instruments	Resolve (Micro-calorimeter), Xtend (CCD)
Energy band	$0.3(1.7) - 12$ keV (Resolve) $0.4 - 13$ keV (Xtend)
Timing Accuracy Requirement (Resolve)	≤ 1.0 ms (1σ) To meet the requirements of millisecond-scale physics

Table.1:XRISM status
Terada et al., 2025, Tashiro et al., 2025

Fig.1:XRISM Overview Diagram
Credit: JAXA/XRISM Project (https://xrism.isas.jaxa.jp/)

Main topic: the in-orbit timing accuracy verification and calibration of Resolve

Introduction2. Grade and Pixel of Resolve

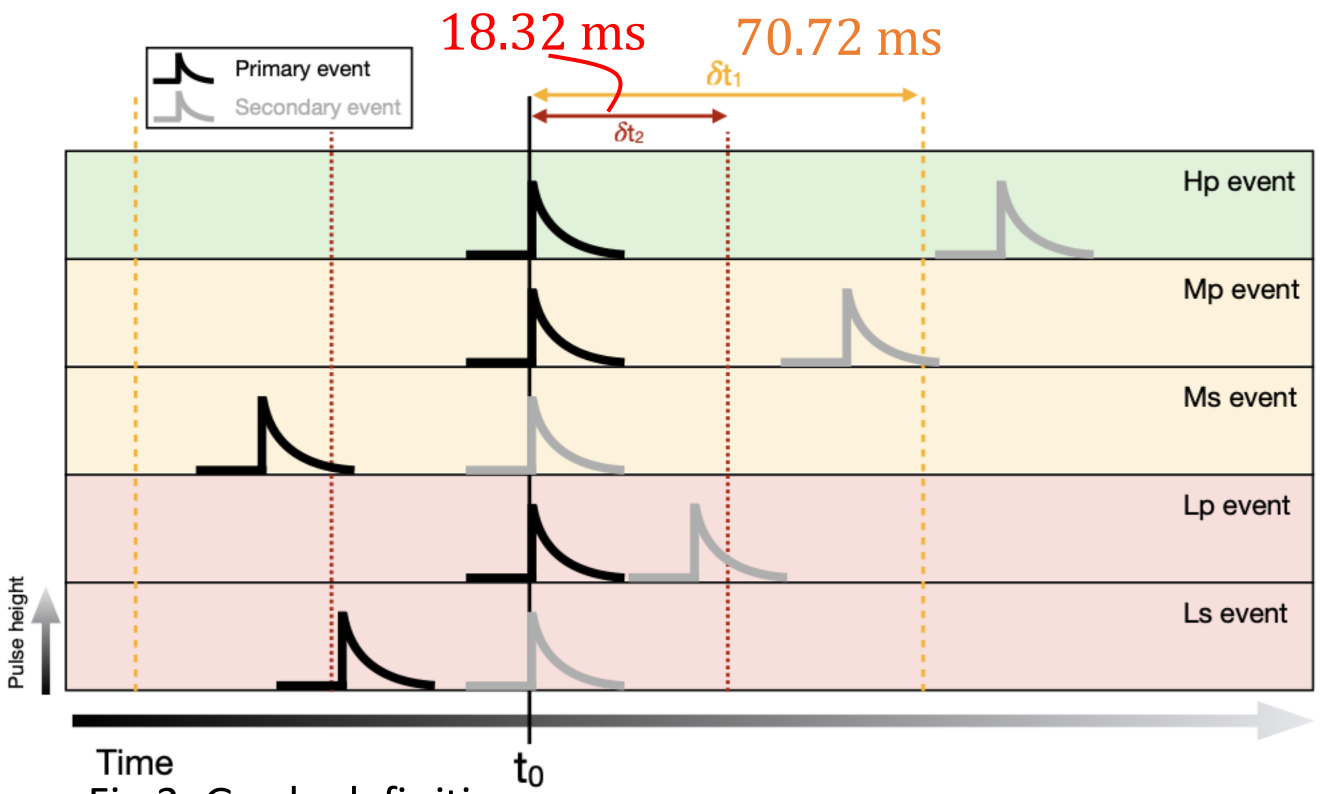


Fig.3: Grade definition
The XRISM Proposers' Observatory Guide

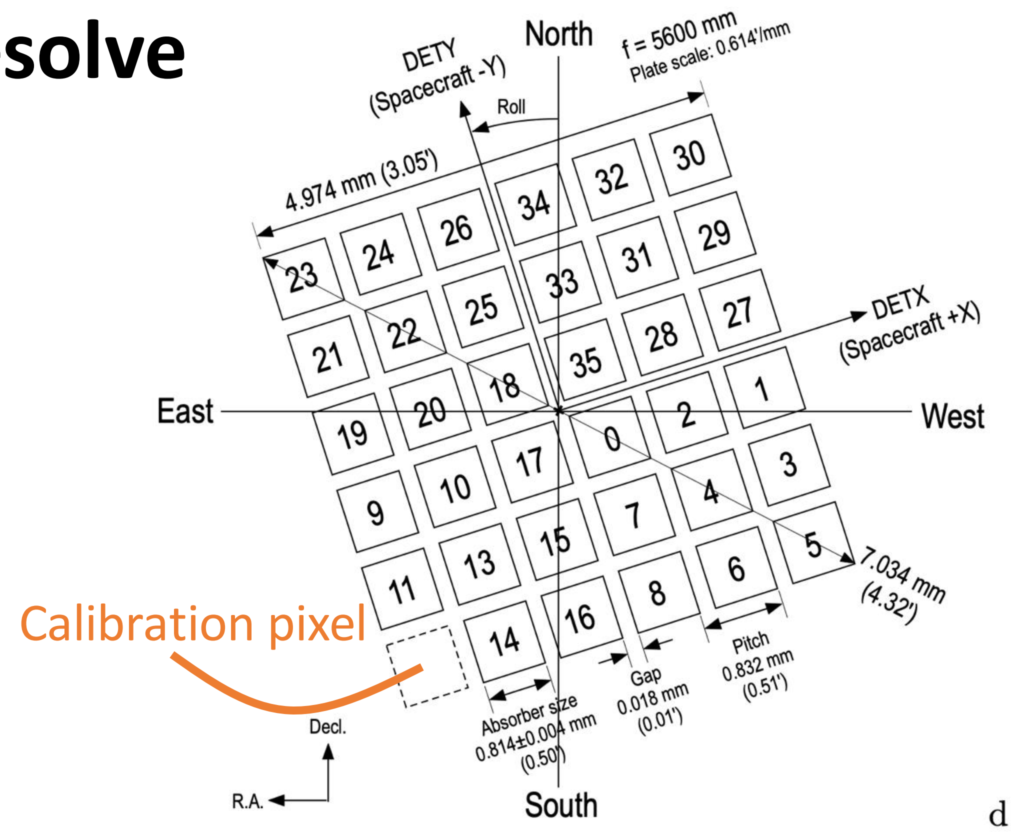


Fig.4: A schematic of the Resolve
The XRISM Proposers' Observatory Guide

Pixel: 35

Grade: H, M, L

Trigger time assignment onboard Resolve

1. All grade events: Calculated by the time of maximum pulse derivative
2. H, M grade events: Additional timing correction using cross-correlation with the ground-calibrated template

→H, M grades achieve significantly better timing accuracy than L grade

Introduction3. XRISM/Resolve timing system

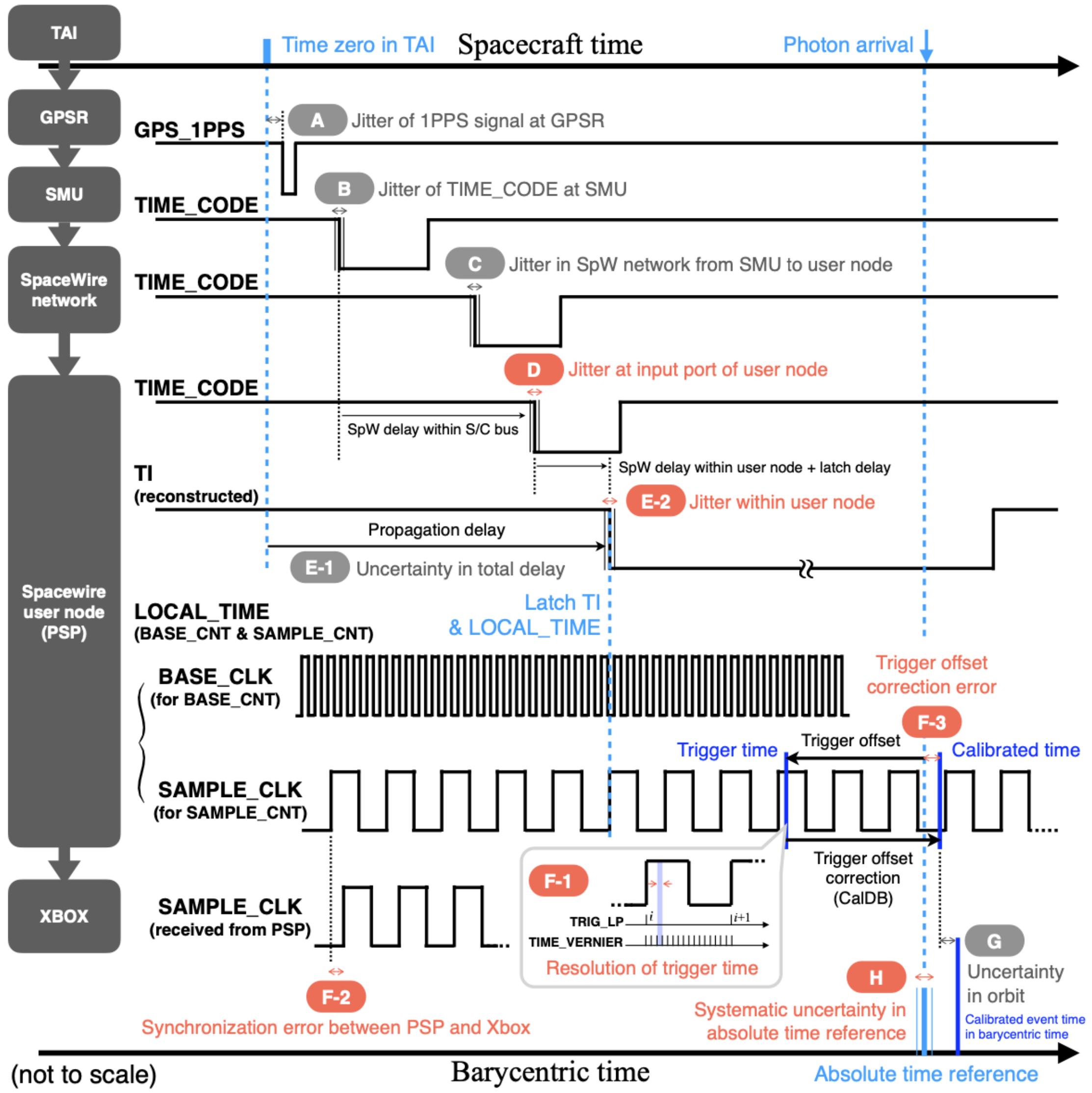


Fig.2:Timing diagram of XRISM/Resolve
Sawada et al., 2025

Orange: Resolve-related errors
Gray: other sources

In the left diagram, timing errors occur at each stage from GPSR to trigger time determination

- **JATIS Paper**
  1. Terada et al., 2025: A → E-1, G
  2. Shidatsu et al., 2025: B
     (GPS Unsynchronized Mode)
  3. Sawada et al., 2025: E-2 → F-3, H

This presentation focuses on the in-orbit verification and calibration

Summary of Observations for In-flight Timing Calibrations

Group	Observatory	Obs. ID	R.A. (°)	Dec. (°)	Start time	Exposure (ks)
1 2024/3	XRSIM	100006020	83.647901	22.027340	2024/03/19 04:18:52	17.89
		100006030	83.620658	22.028023	12:18:29	13.53
		100006040	83.648191	22.001824	18:42:12	15.33
		100006050	83.620297	22.002507	2024/03/20 04:38:33	13.10
	NICER	7013010101	83.632640	22.015160	2024/03/19 03:41:09	1.23
2 2024/10	XRSIM	101000010	83.647508	22.027158	2024/10/06 00:01:59	8.63
		101001010	83.617721	22.027249	04:42:40	9.80
		101002010	83.645212	22.001834	09:29:49	10.34
		101003010	83.617980	22.002103	14:16:58	16.39
	NICER	7013010106	83.633420	22.014160	00:41:39	5.77

Table 2:Observation log of the Crab pulsar

Simultaneous observations with NICER twice:
during the Performance Verification phase and the Guest Observation phase.

Data analyses1. Calculation Pulse Profiles

Phase definition: $$\phi = \left(\nu(t - t_0) + \frac{1}{2}\dot{\nu}(t - t_0)^2\right)$$

t: the calibrated barycenter time of an X-ray event

t_0: the radio phase origin

ν: frequency of the radio pulse

$\dot{\nu}$: Time derivative of ν

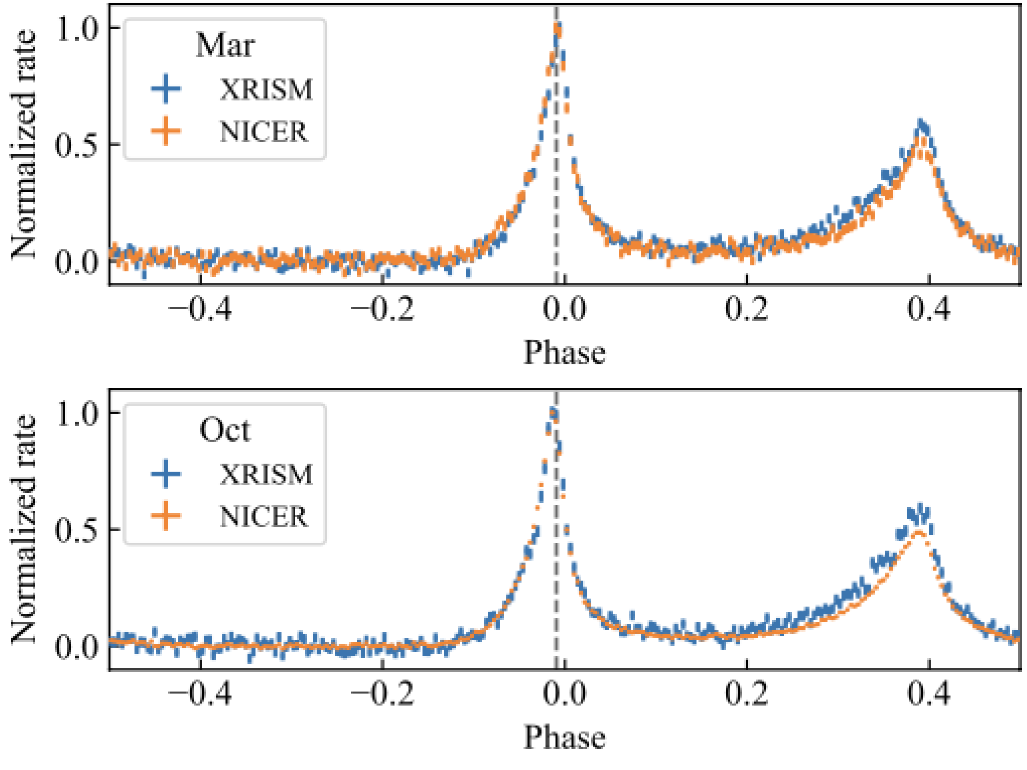


Fig.5: Crab pulse profiles
(XRSIM using H and Mp events)
Sawada et al., 2025

Observatory	MJD	ν	$\dot{\nu}$
Jodrell Bank Telescope	60384	29.56300275	−3.66709
XRISM & NICER	60388 - 60389	—	—
JBT	60415	29.56202062	−3.66668
JBT	60568	29.55717451	−3.66530
XRISM & NICER	60589	—	—
JBT	60598	29.55622451	−3.66489

XRISM/NICER ephemeris were determined by the interpolation between two near measurements by Jodrell Bank ephemeris

Data analyses2. Determination of X-ray Peak Phase

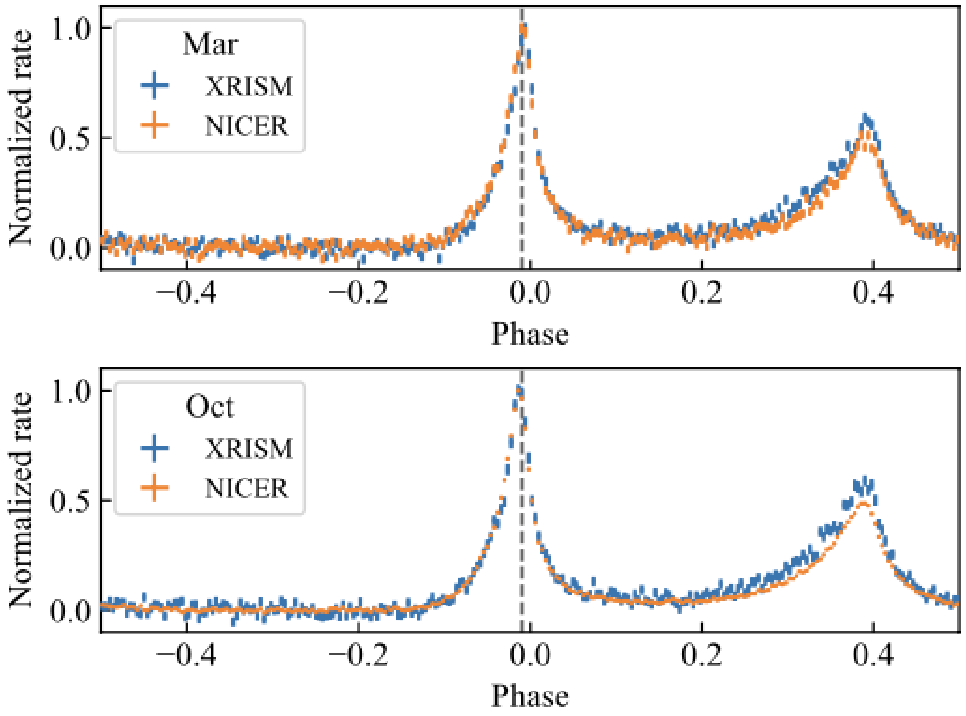


Fig.5: Crab pulse profiles
(XRSIM using H and Mp events)
Sawada et al., 2025

Derive pulse peak via fitting with **Nelson's formula**

$$L(\phi) = N \frac{1 + a(\phi - \phi_0) + b(\phi - \phi_0)^2}{1 + c(\phi - \phi_0) + d(\phi - \phi_0)^2} \exp\left(-f(\phi - \phi_0)^2\right) + l,$$

$L(\phi)$: the X-ray counts at phase ϕ
ϕ_0 : the peak phase
N : the peak height
l : the off-pulse intensity level
a, b, c, d, f : the shape coefficients (Fixed to Ge+16 value)

fitting range : $\phi = -0.075\ to + 0.0355$
Statistics: C-statistics

Numerical comparison of ϕ_0 values between NICER and XRISM
→ In-orbit verification and calibration of timing parameters measured on the ground

Result1. Timing Offset Relative to NICER for H+Mp

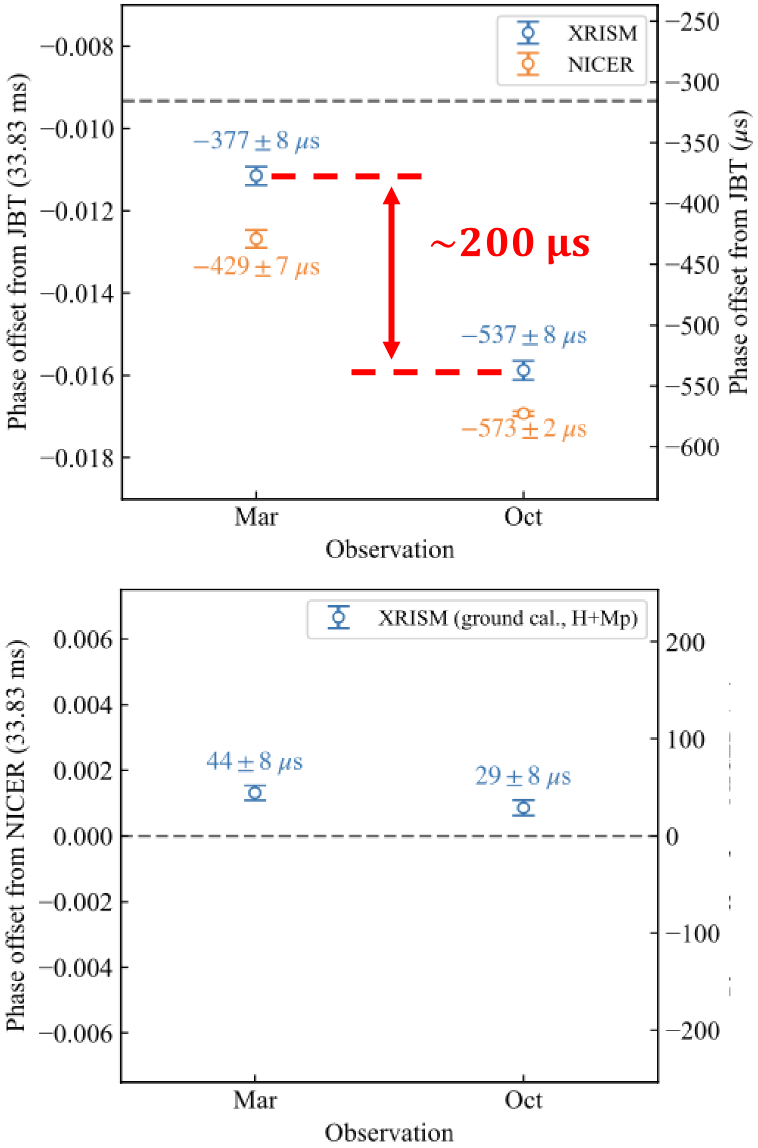


Fig.6: Phase offset using ground calibration
Sawada et al., 2025

① The offset from the radio pulse peak

The offset from the radio pulse peak changes by **~200 μs** between the two observations.

- The uncertainty on the radio ephemeris is **~100 μs**
- The remaining difference may be due to fitting method dependence, but the exact cause is still unclear.

② Offset relative to NICER (comparison in the X-ray band)

Consistent offset across observation epochs
→ **Successful timing parameters determined by ground calibration**

Result2. Grade Dependence on timing offset

Result after applying ground calibration

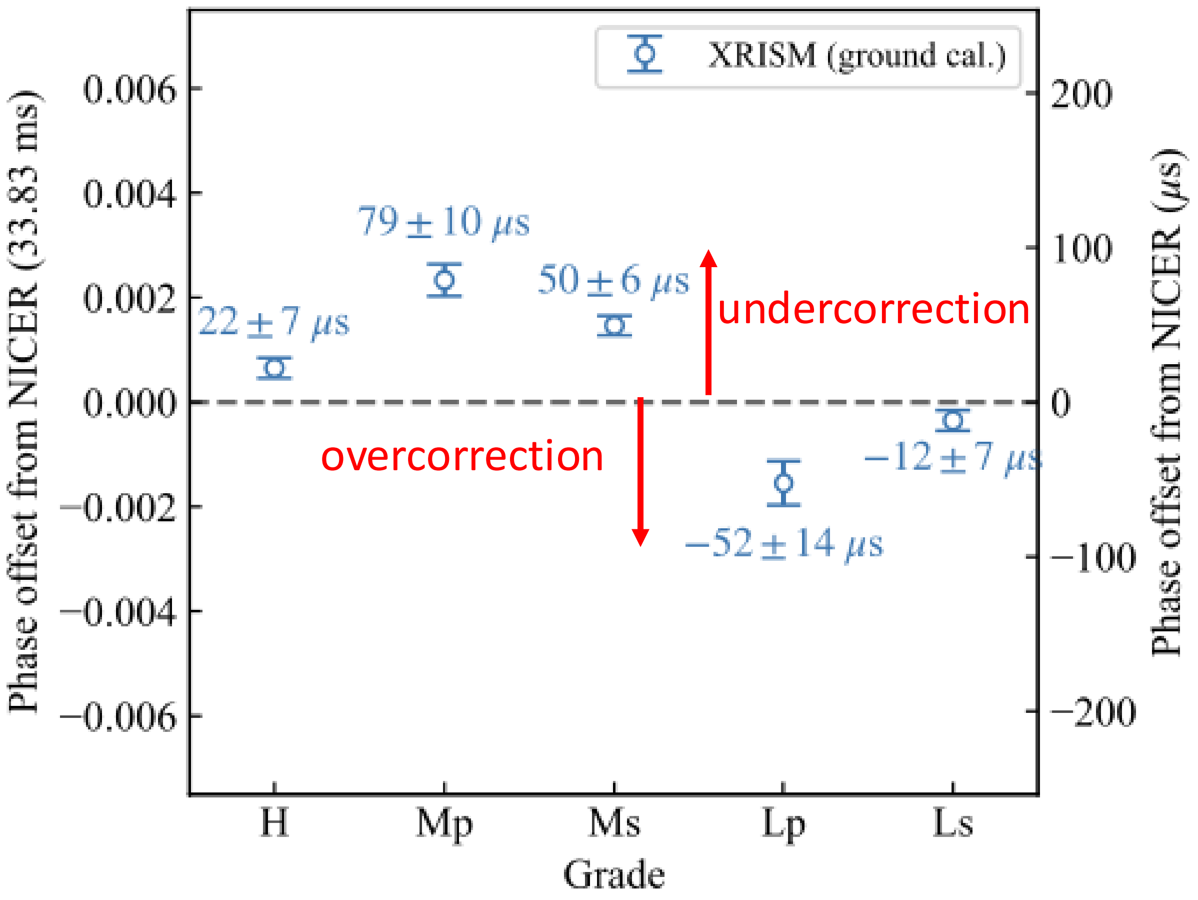


Fig.7: Phase offset using ground calibration(grade differences)
Sawada et al., 2025

We combined data from two calibration epochs to reduce statistical error

◆ **Summary of result**

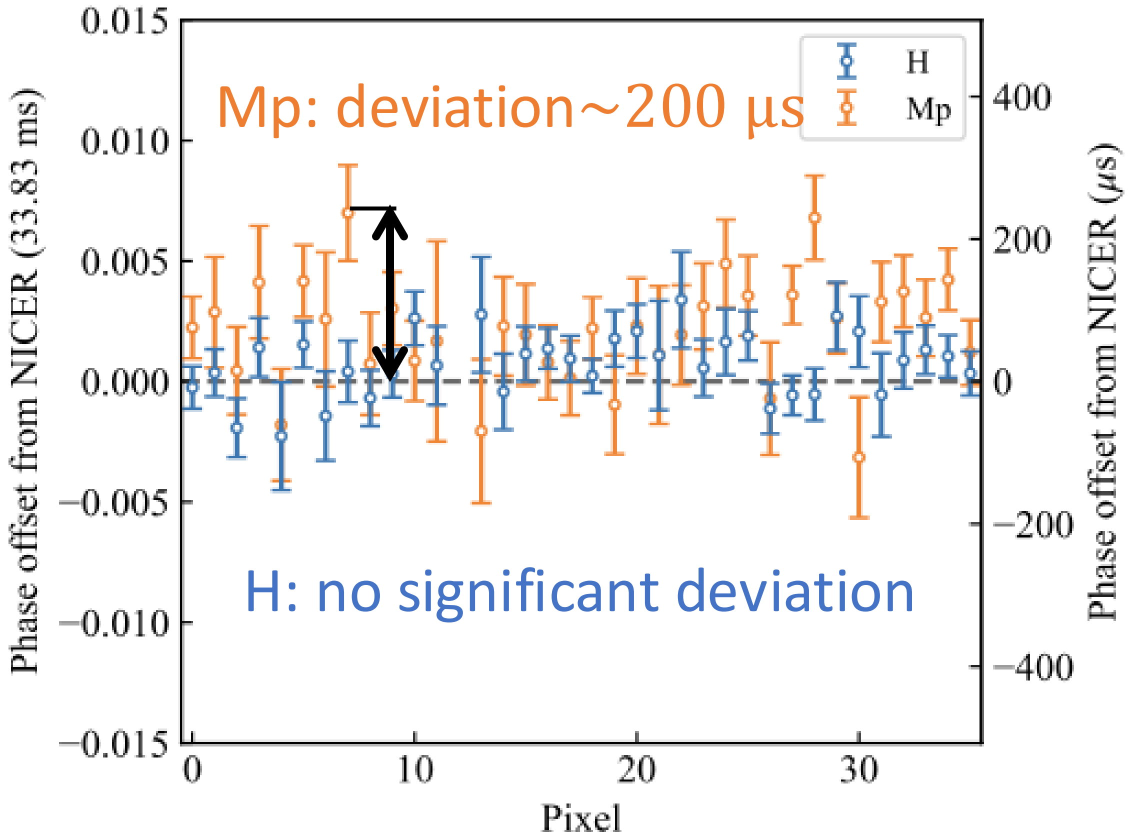
✓ H: $\sim 20\ \mu s$
(comparable to the statistical error in the absolute timing calibration on the ground)

✓ The other grades: $-50\ to + 80\ \mu s$

This grade variance can be recalibrated in the CALDB

Result3. Pixel Dependence on timing offset

Further classification by pixel



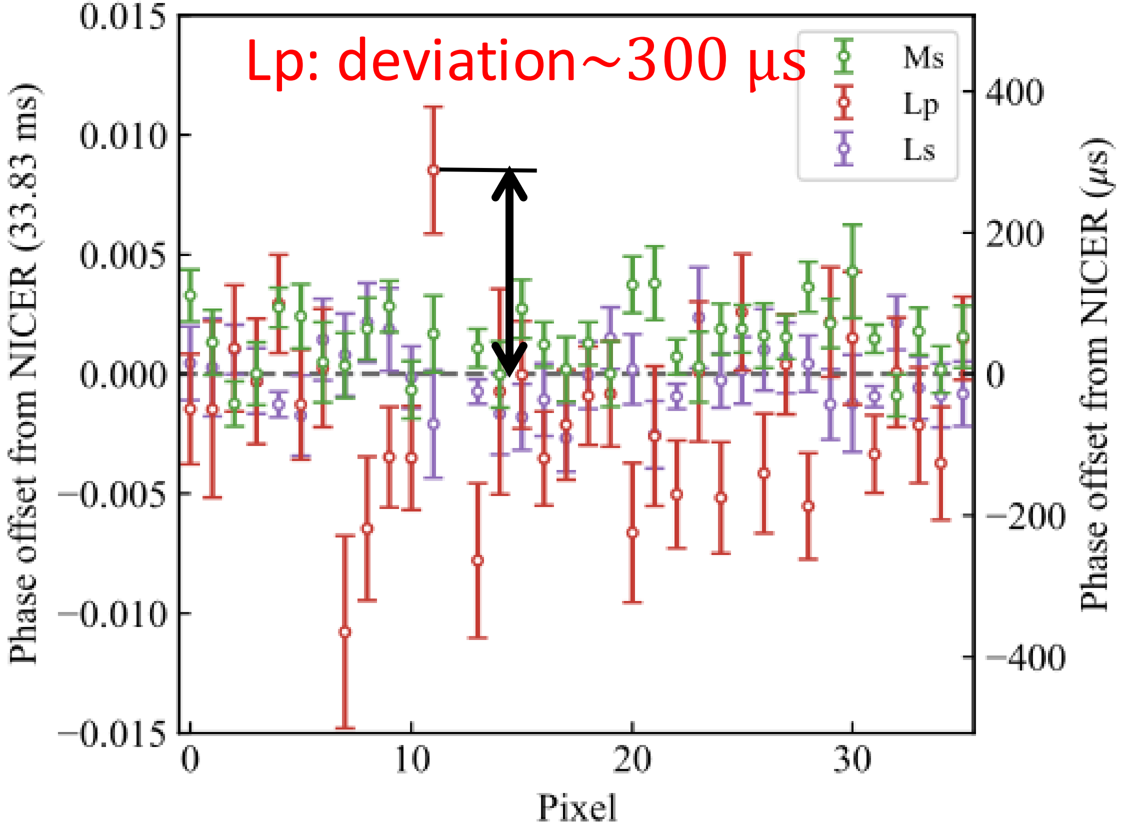


Fig.8: Phase offset using ground calibration(grade differences)
Sawada et al., 2025

Result4. After Applying In-orbit Parameters

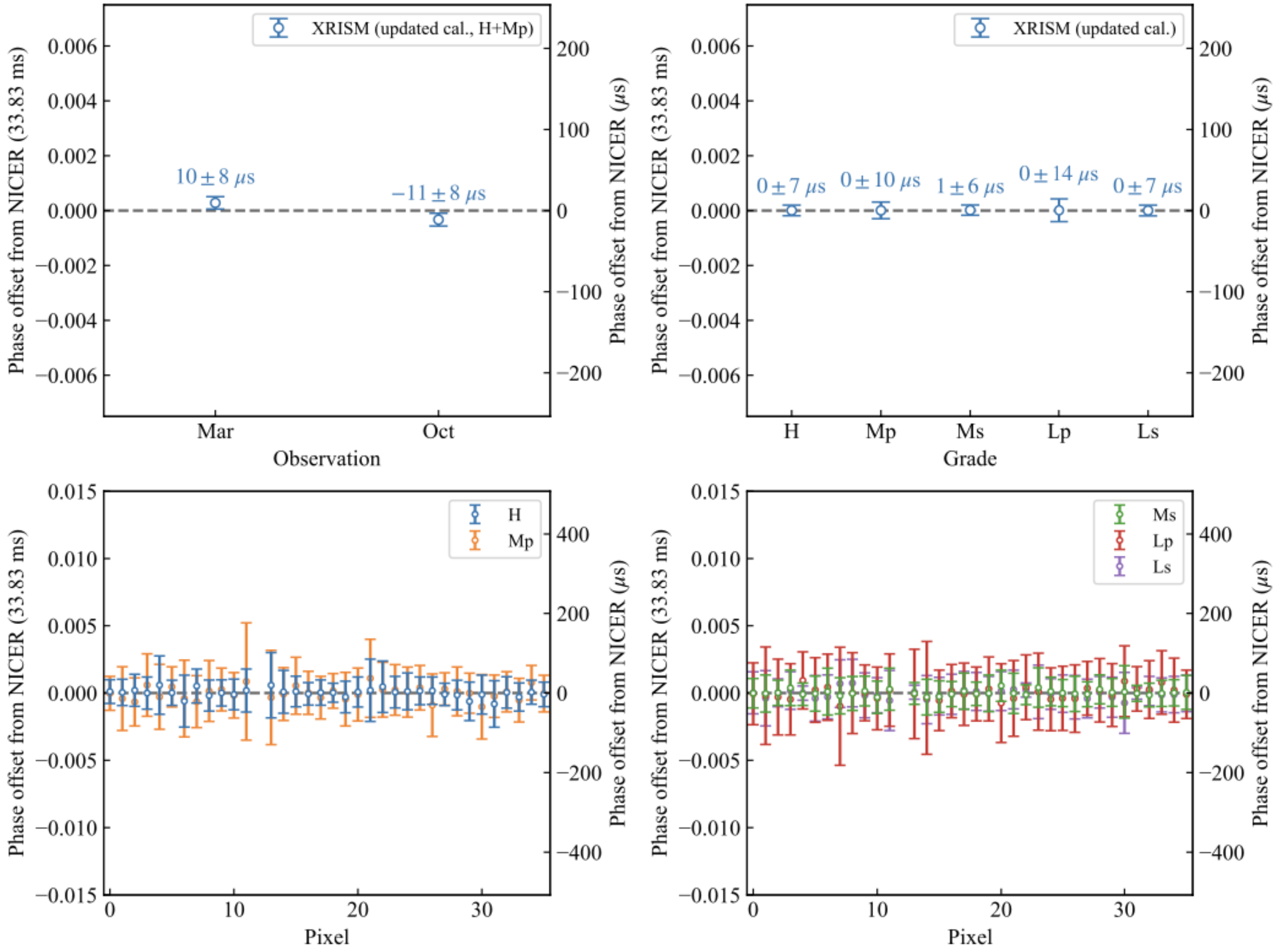


Fig.9: After in-orbit calibration
Sawada et al., 2025

Error item	ID	XRISM H	XRISM Mp	XRISM Lp
Cat. I	A through F-2[1]	15	15	38
Cat. II	F-3 (relative, grade)	—	7	8
	F-3 (relative, pixel)[2]	46	71	89
	F-3 (relative, DERIV_MAX)[3]	39	69	77
	F-3 (absolute)[4]		7	
	G′[5]	15	16	21
Cat. III	H[6]		7	
Total[7]		130	200	250

Table 3:Summary of errors
Sawada et al., 2025
Cat. Ⅰ errors: Terada et al. 2025

Reduced grade/pixel variations

Total timing error ≪ 1 ms requirement

Based on new parameters above,
new CALDB in preparation.

summary

- ◆ We investigated the timing offset relative to NICER, using the timing parameters that were determined through ground calibration.

- ◆ We investigated the timing offset dependence on event grade and pixel.

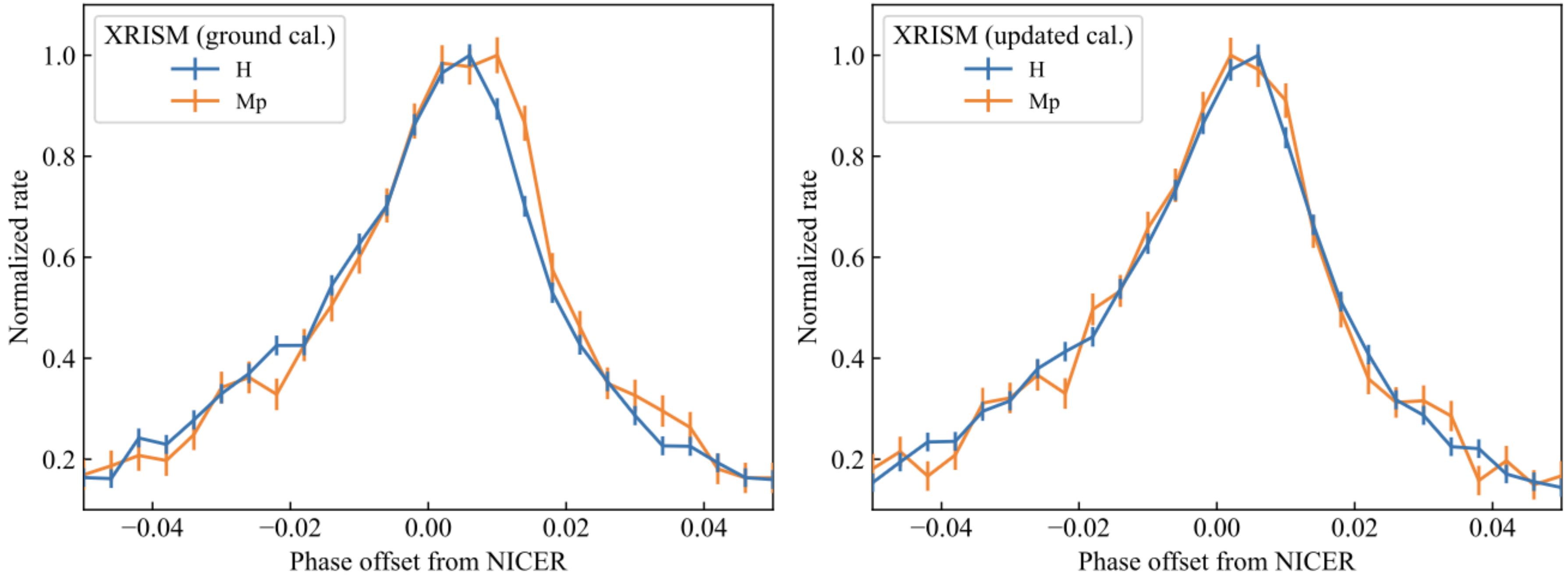
  →In M and L grade events, we observed slight pixel-dependent variance in the timing offset.

- ◆ Based on the measured offsets, we determined the in-orbit timing correction parameters.

  As a result of the calibration

  →The timing error was reduced to ~ 200 μs, comfortably meeting the 1 ms requirement.

backup


XRISM (ground cal.)
H
Mp
Normalized rate
Phase offset from NICER
1.0
0.8
0.6
0.4
0.2
−0.04
−0.02
0.00
0.02
0.04
XRISM (updated cal.)
H
Mp
Normalized rate
Phase offset from NICER