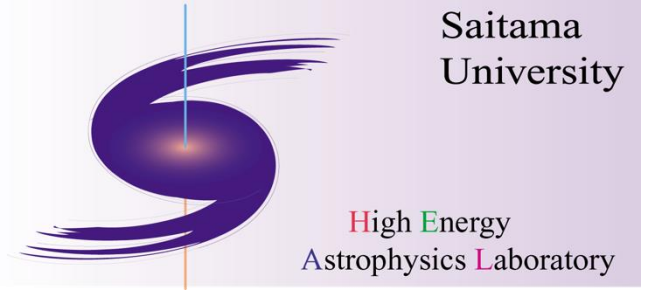

Verification of the Timing Accuracy of XRISM/Resolve with the Updated CALDB

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and XRISM SOT/CalIP team

a Saitama U., b Rikkyo U., c RIKEN, d ISAS / JAXA, e Ehime U., f Hiroshima U., g MIT

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)
Absolute 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/)

Introduction2. Grade and Pixel of Resolve

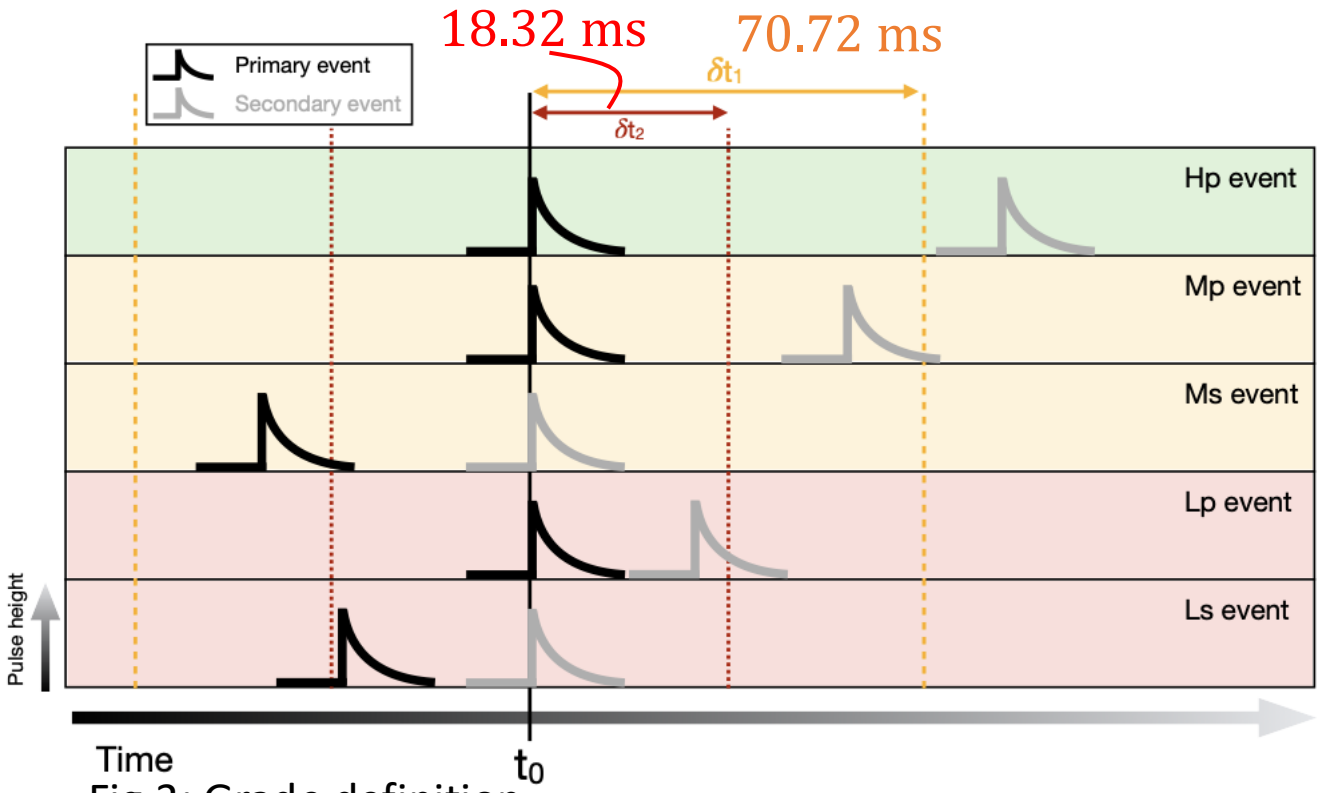


Fig.3: Grade definition
The XRISM Proposers' Observatory Guide

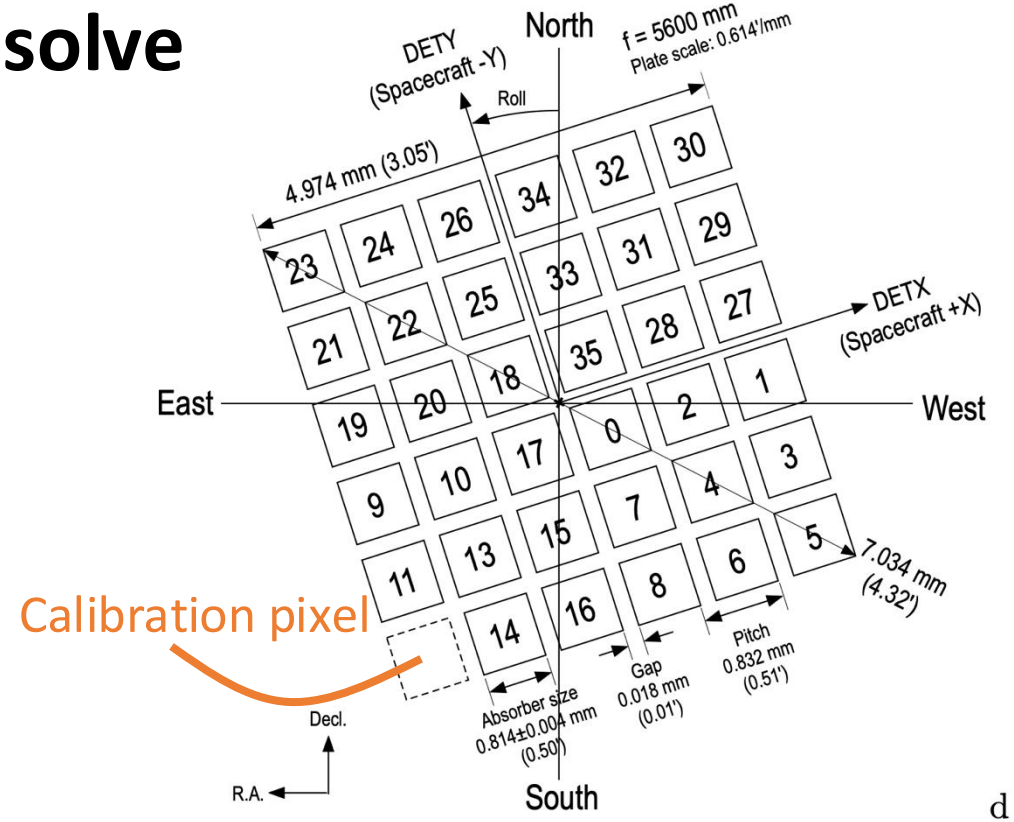


Fig.4: A schematic of the Resolve
The XRISM Proposers' Observatory Guide

Pixel: 35

Grade: Hp, Mp, Ms, Lp, Ls

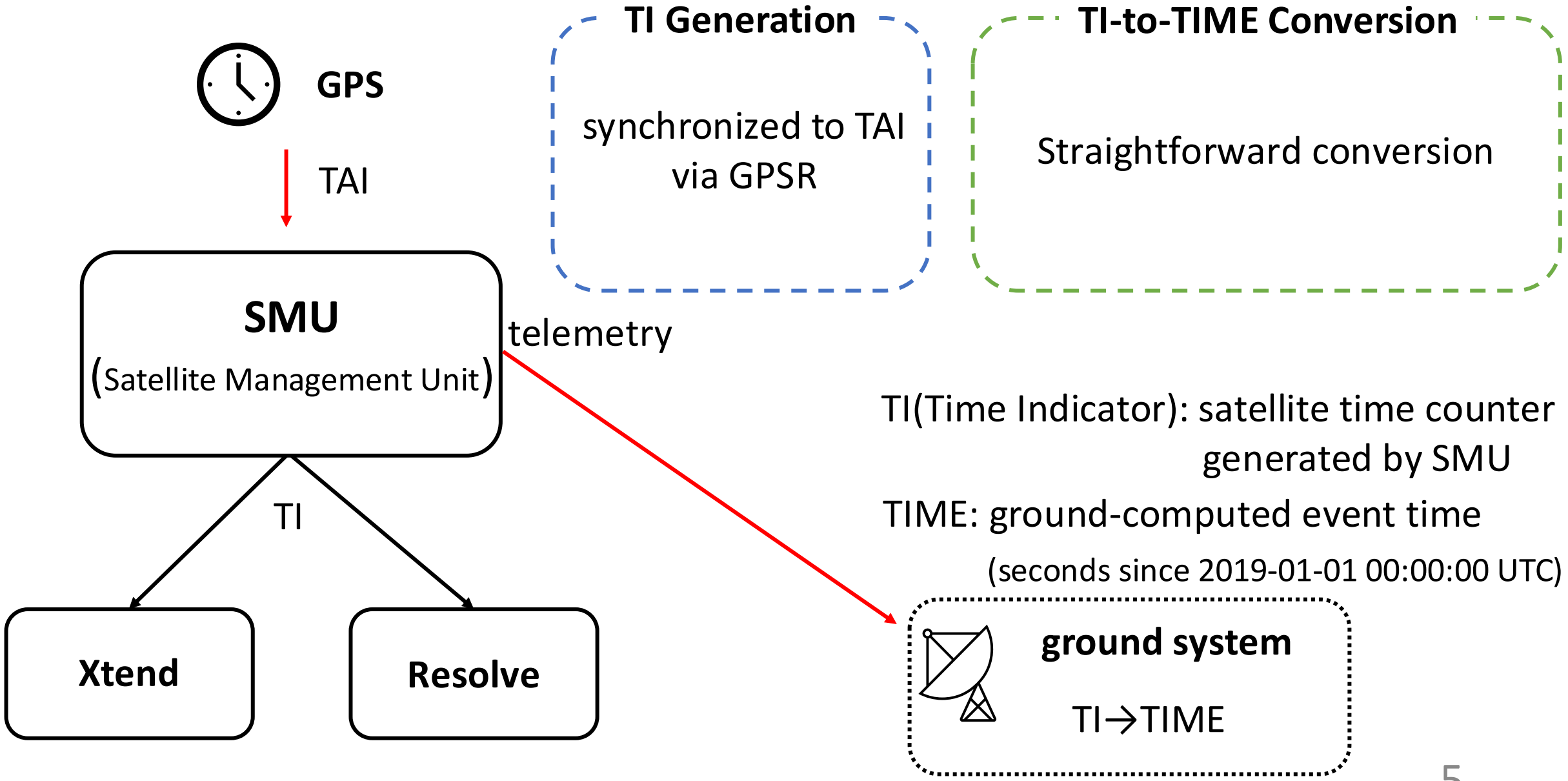
<u>Trigger time assignment onboard Resolve</u>

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

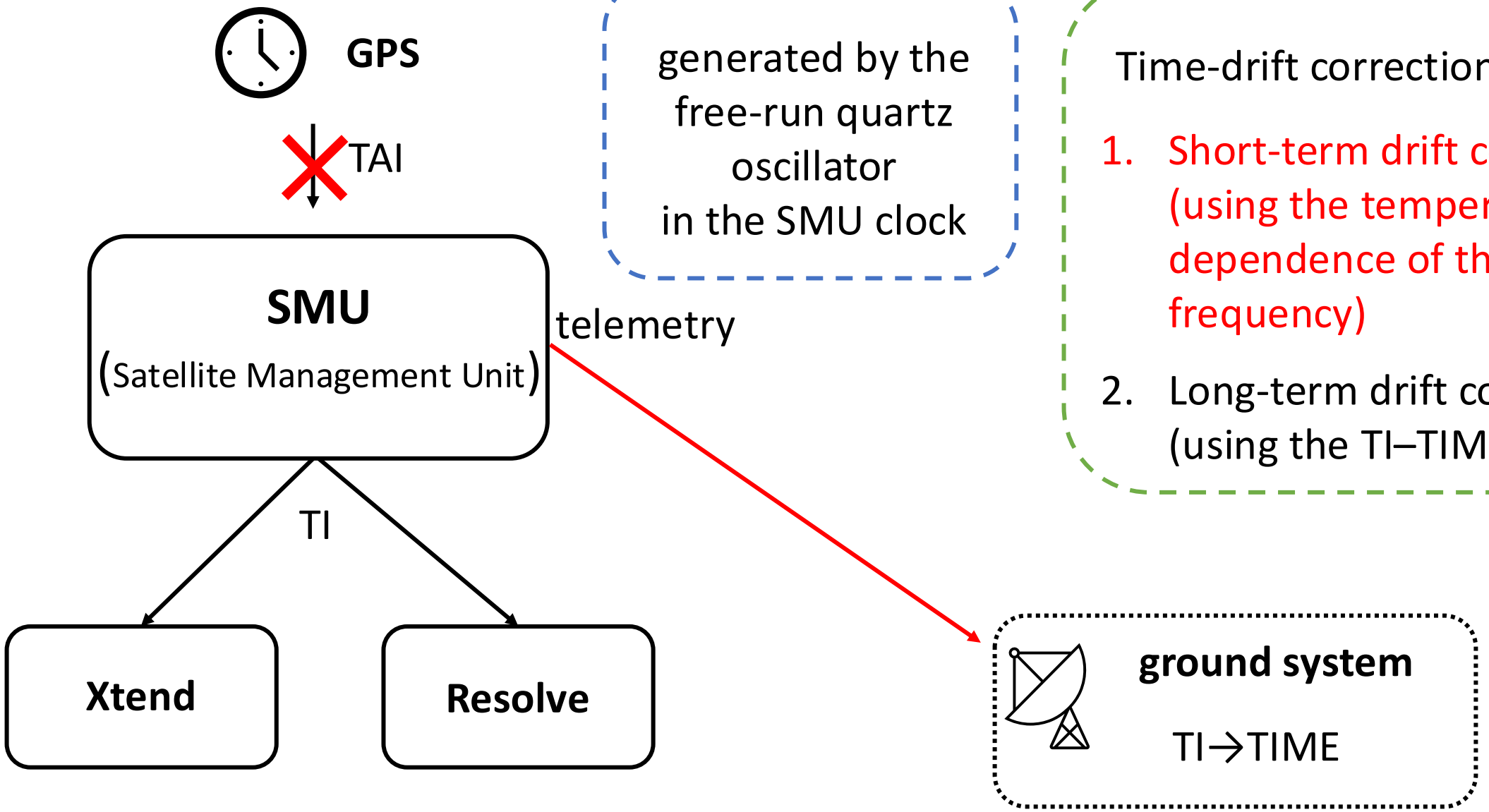
→H, M grades achieve significantly better timing accuracy than L grade

XRISM Timing System:
GPS-Synchronized
vs.
GPS-Unsynchronized Modes

GPS-Synchronized



GPS-unsynchronized



TI Generation

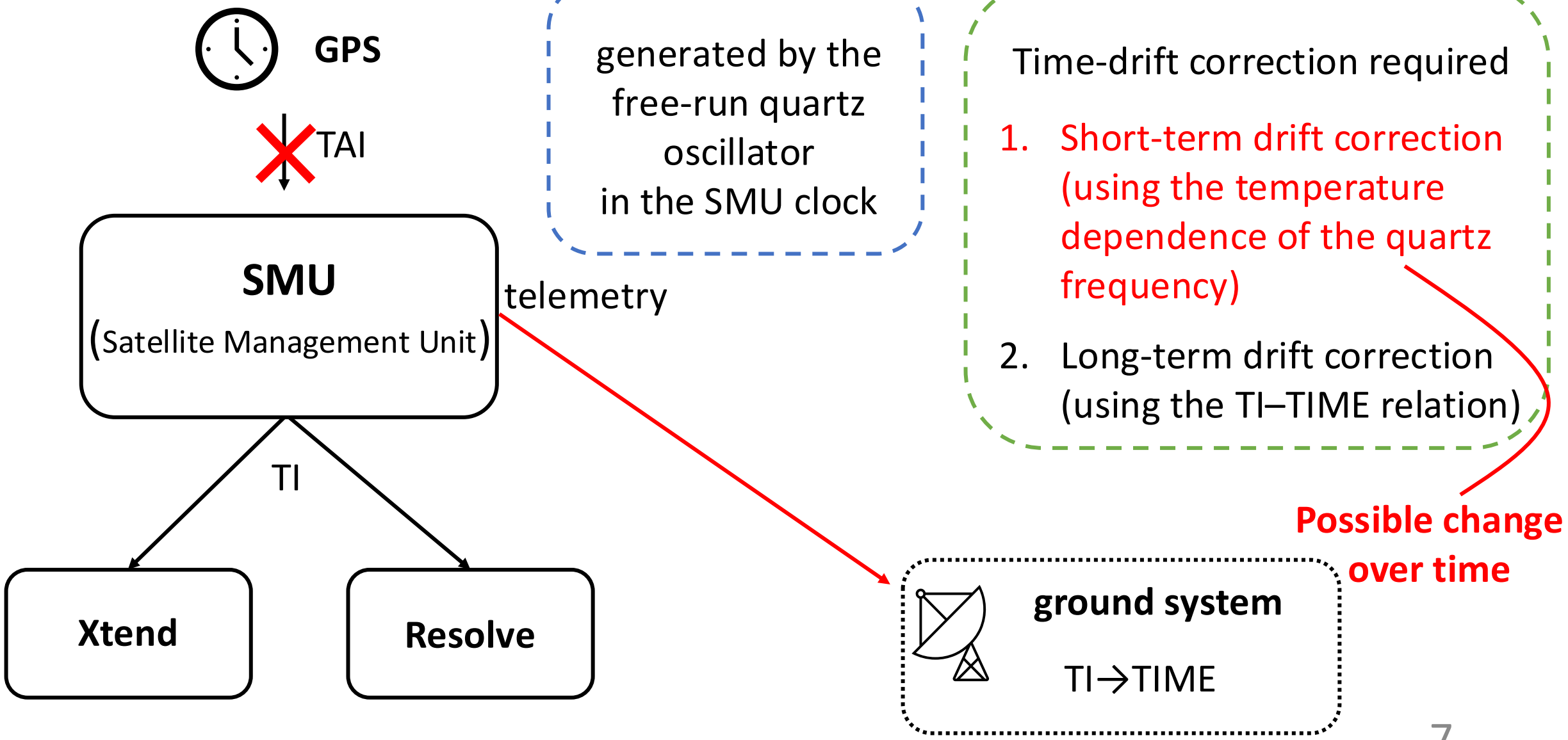
generated by the free-run quartz oscillator in the SMU clock

TI-to-TIME Conversion

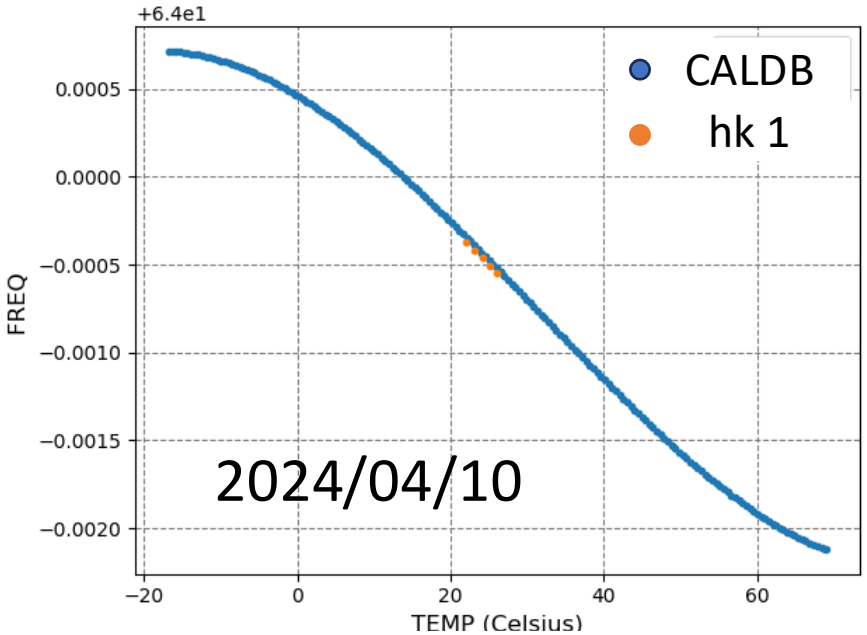
Time-drift correction required

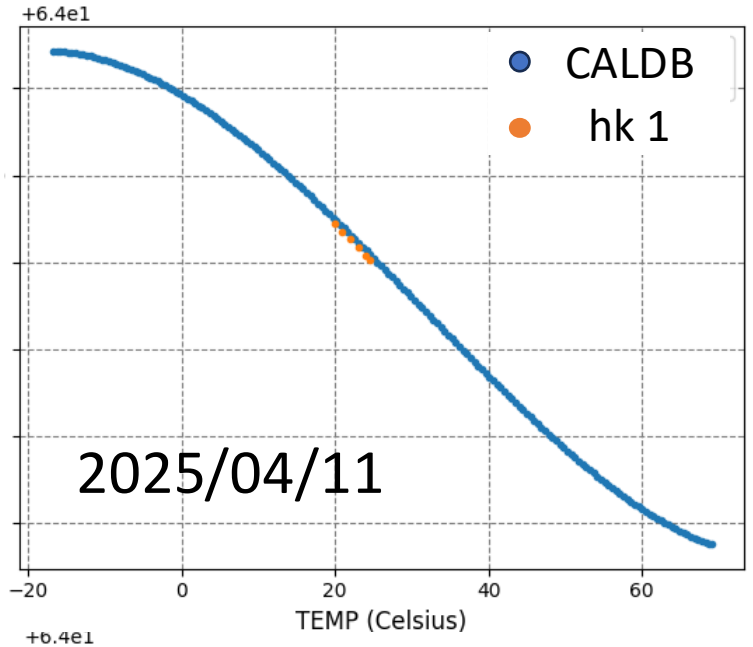
1. Short-term drift correction (using the temperature dependence of the quartz frequency)
2. Long-term drift correction (using the TI–TIME relation)

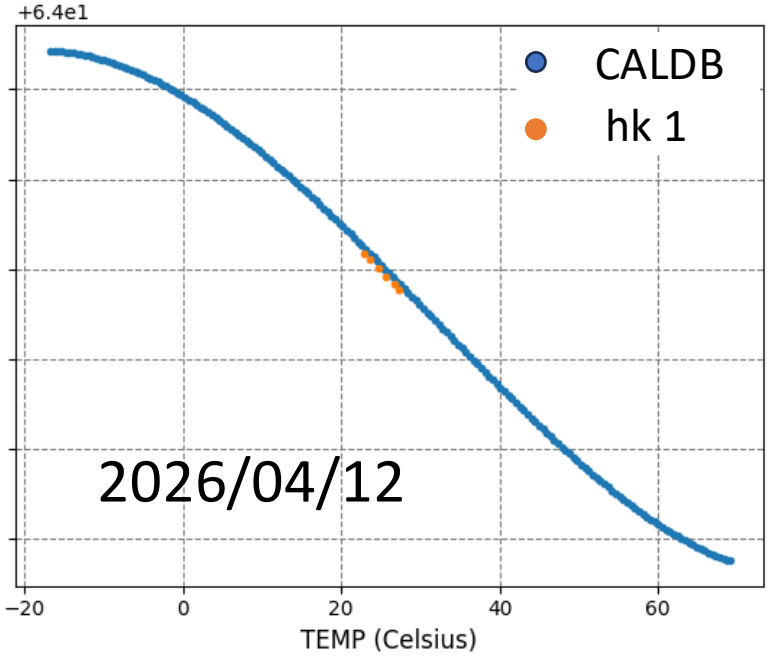
GPS-unsynchronized

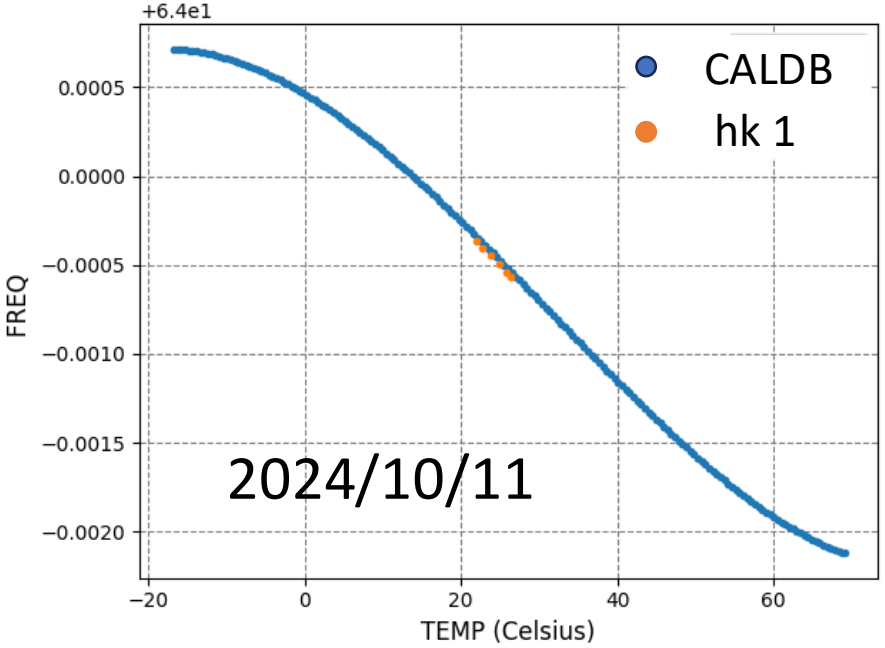


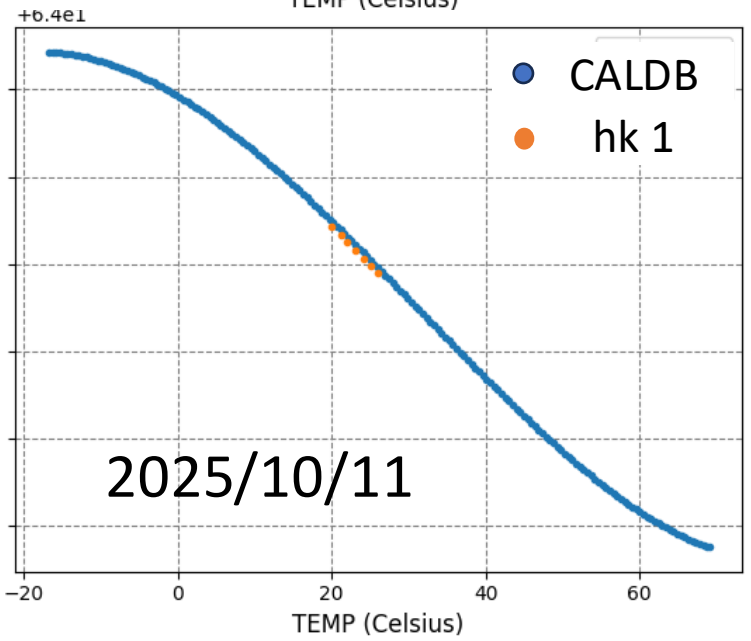
Verification of the Temperature–Frequency Trend







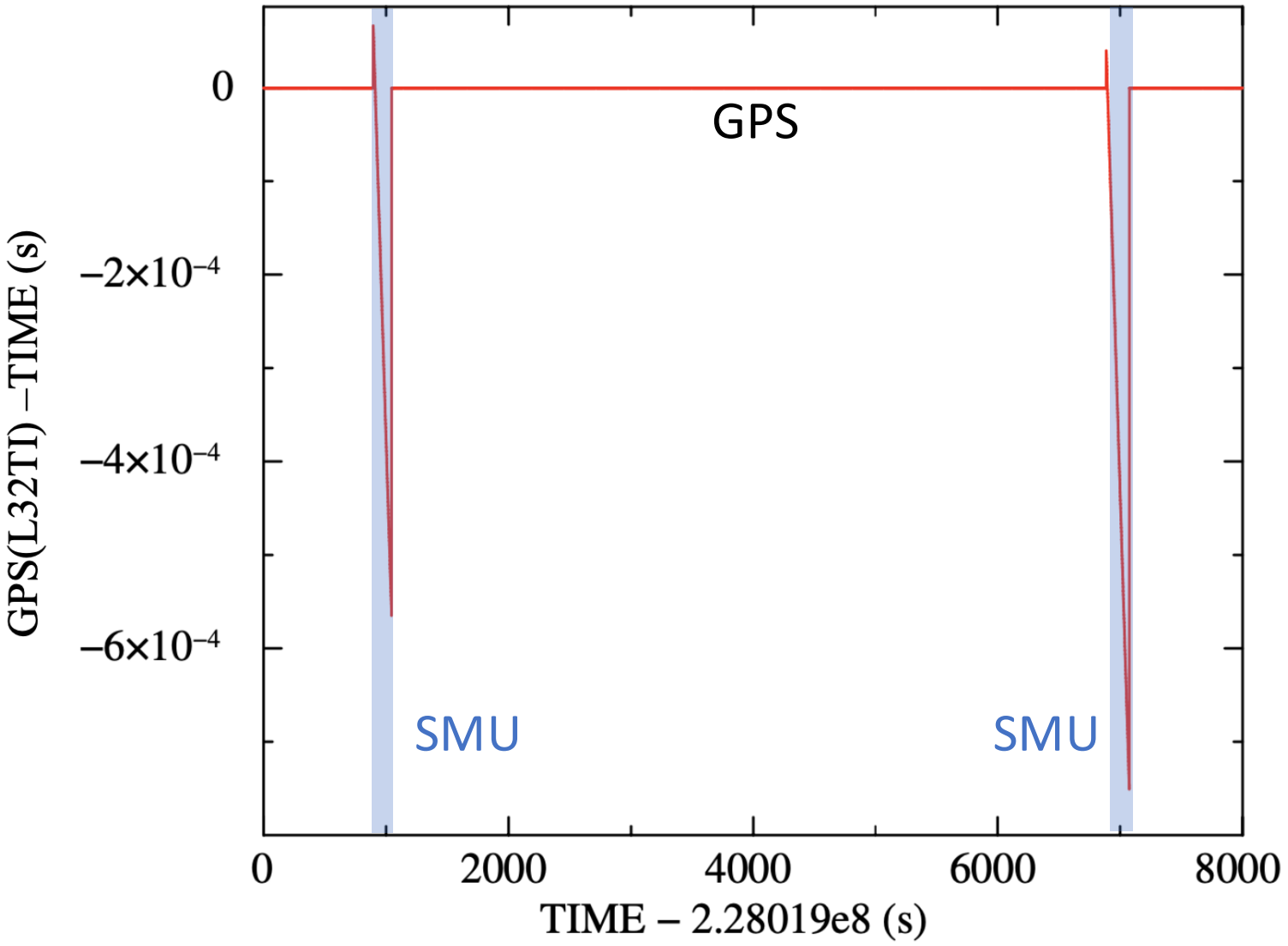




Consistent with the CALDB trend

The dependency remains unchanged for about two years after launch

GPS → SMU → GPS Transition in March 2026



Two short GPS unlock periods occurred on 2026/03/24 UT.

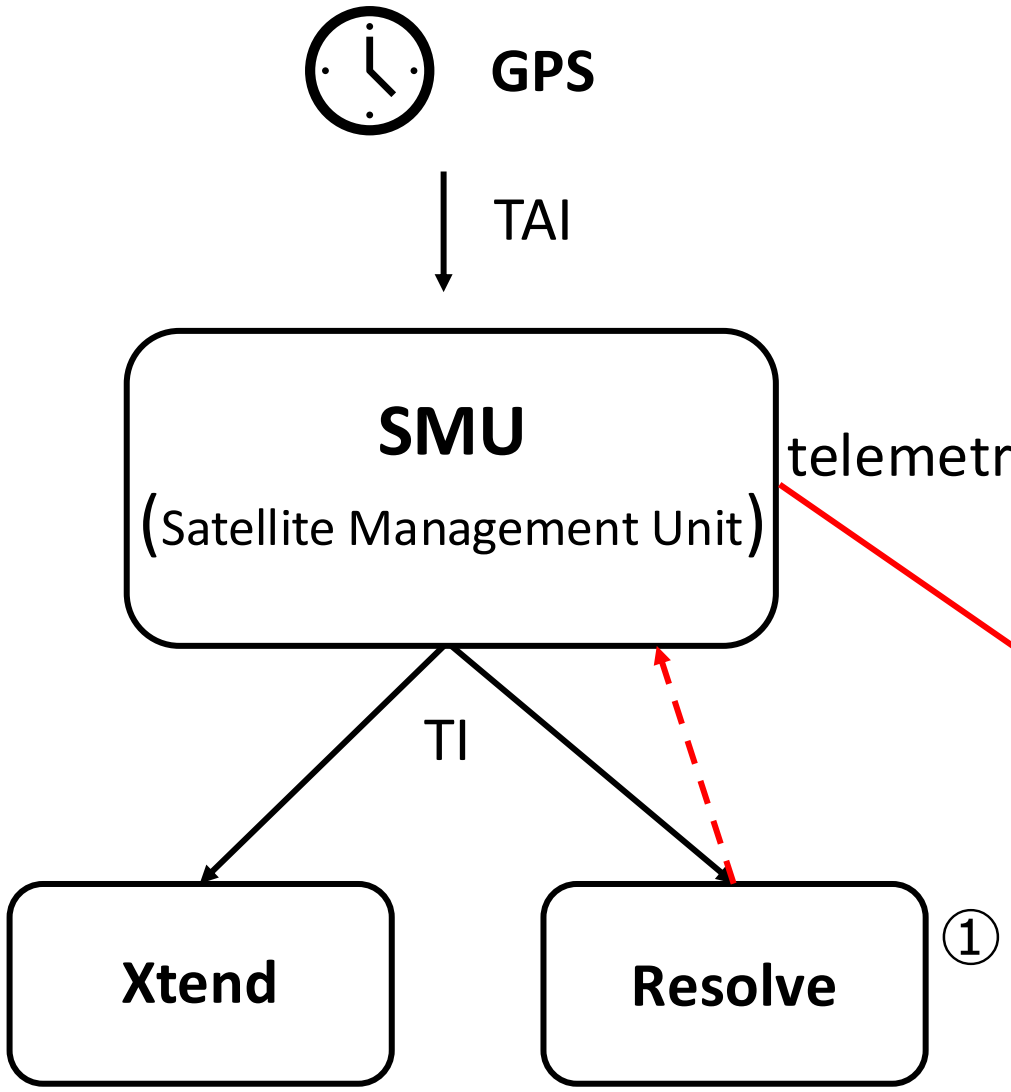
Successful switchback from SMU to GPS

No timing issue outside the GPS-unlocked period

GPS(L32TI): TIME value converted from L32TI assuming GPS sync.

Overview of the XRISM/Resolve Timing System

Timing System of XRISM/Resolve



① Record event information (Resolve local time)

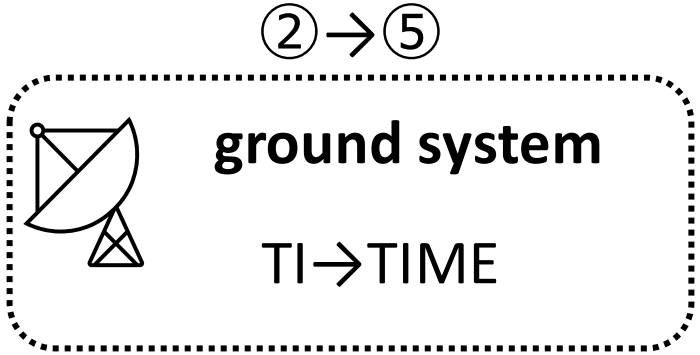
TRIG_LP	**TIME_VERNIER**
1 sample=80 μs	1/16 sample= 5 μs for H/M grade

② Reconstruct the trigger time on the ground as **SAMPLECNTTRIG** (Resolve local time)

③ **Convert it to the calibrated event time SAMPLECNT** (Resolve local time)

④ Convert to **L32TI** (the lower 32 bits of TI)

⑤ Reconstruct **TI** and convert to **TIME**



Event-time correction using the CalDB

$$\mathrm{SAMPLECNT} = \mathrm{SAMPLECNTTRIG} - \left(\frac{A_{\mathrm{g,p}}}{4} \mathrm{RISE\_TIME} + B_{\mathrm{g,p}} \mathrm{DERIV\_MAX} + \boldsymbol{C_{\mathrm{g,p}}} \right)$$

- $A_{\mathrm{g,p}}, B_{\mathrm{g,p}}$: event-parameter-dependent coefficients, determined in the pre-launch ground calibration
- $C_{\mathrm{g,p}}$: event-parameter-independent coefficient for a constant offset, refinable using in-orbit calibration data

◆ **This CALDB update**

- $C_{\mathrm{g,p}}$ updated (grade only)
- $C_{\mathrm{g,p}}$ further subdivided

Previous

Shared $C_{\mathrm{g,p}}$
for Hp, Mp/Ms, and Lp/Ls

New

Independent $C_{\mathrm{g,p}}$
for Hp, Mp, Ms, Lp, and Ls

At Last Year's IACHEC: Correction of Relative Timing Offsets with Respect to NICER

Summary of the 2024 Simultaneous Crab Observations with NICER

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

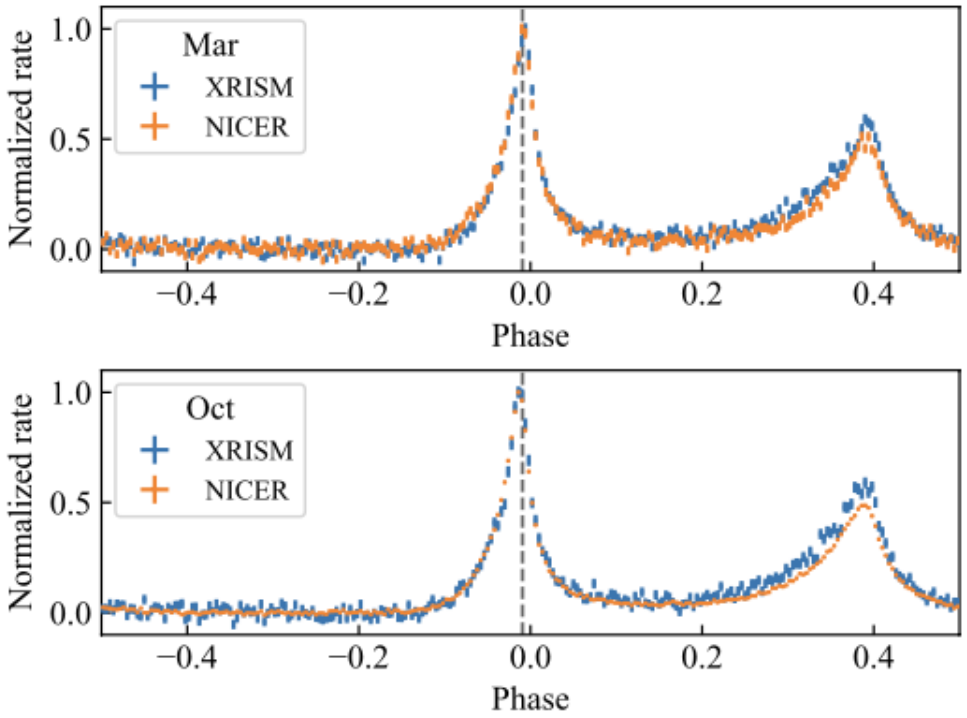
Table 2:Observation log of the Crab pulsar

Simultaneous observations with NICER twice

Total XRISM exposure: 95.8 ks

Determination of X-ray Peak Phase

phase 0 = radio pulse peak



Crab pulse profiles
(XRSIM using Hp and Mp events)
Sawada et al., 2025

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

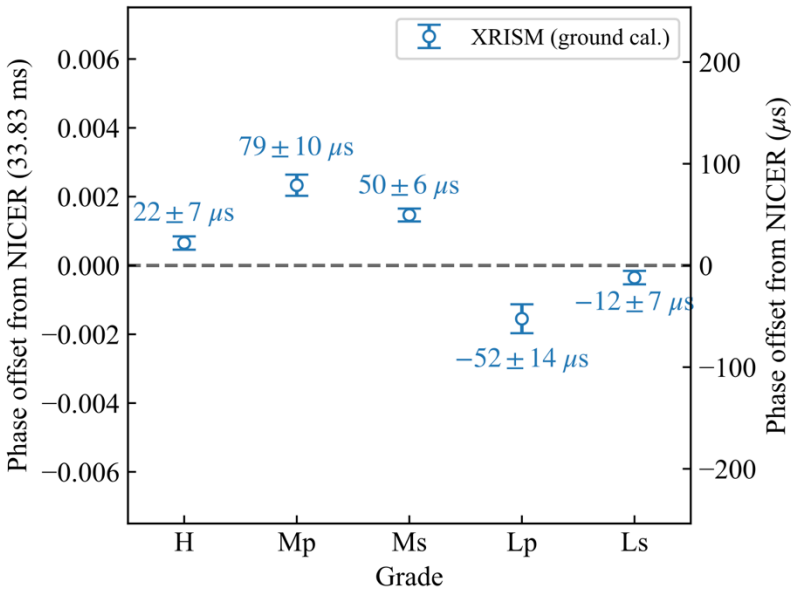
$$L(\phi) = N \frac{1 + a(\phi - \phi_0) + b(\phi - \phi_0)^2}{1 + c(\phi - \phi_0) + d(\phi - \phi_0)^2} \exp\left(-f(\phi - \phi_0)^2\right) + l,$$

$L(\phi)$: 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)

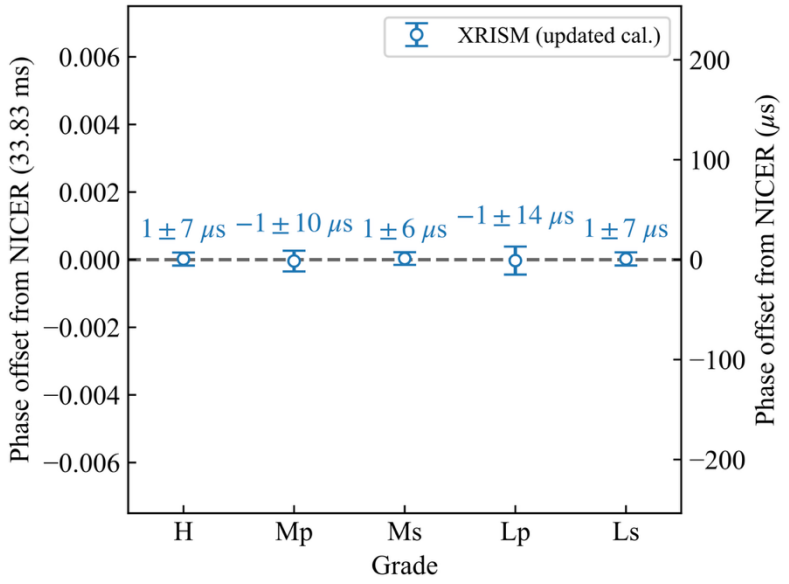
fitting range : $\phi = -0.075\ to + 0.0355$
Statistics: C-statistics

Numerical comparison of ϕ_0 values between NICER and XRISM for each grade

After Applying In-orbit Parameters



$C_{g,p}$ corrected



The 1 ms requirement was already satisfied with the ground calibration

Timing error reduced to ~200 μs

We would like to verify this correction effect using an independent observation

Grade-to-Grade Scatter
After the In-orbit Calibration
Sawada et al., 2025

Verification of the Correction Effect Using the 2025 Crab Observation

Summary of the 2025 Crab Observation

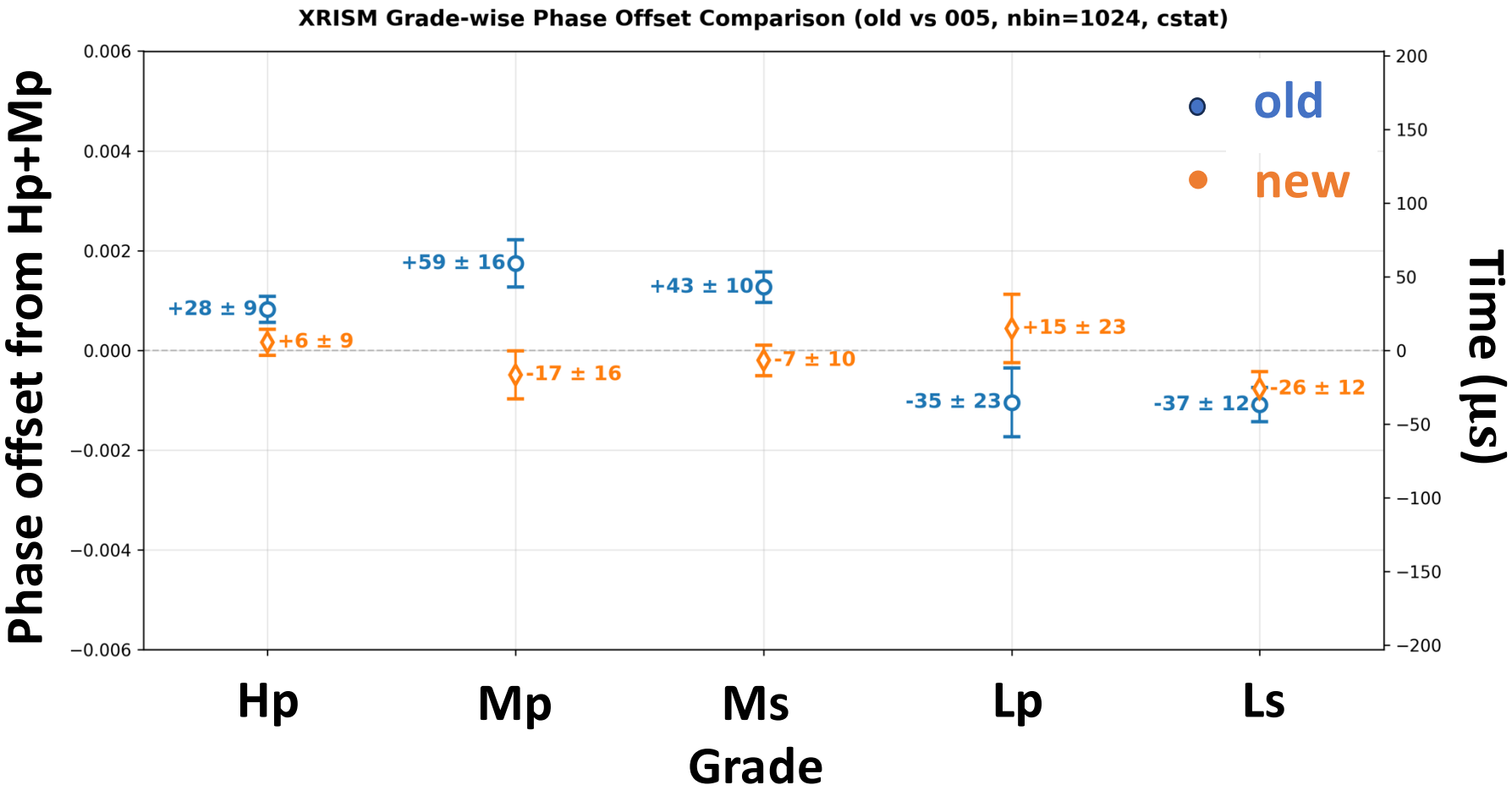
Obs. ID	R.A. (°)	Dec. (°)	Start time	Exposure (ks)
102000010	83.64525	+22.001944	2025-10-08 08:53:04.0	10.86
102001010	83.617833	+22.001667	2025-10-08 17:33:04.0	9.46
102002010	83.645083	+22.027083	2025-10-08 22:18:04.0	10.67
102003010	83.617917	+22.027417	2025-10-09 04:39:04.0	14.34

No simultaneous observation with NICER

Total XRISM exposure: 45.3 ks (95.8 ks in 2024)

The scatter among grades was evaluated by taking the XRISM all-pixel Hp+Mp result as the reference.

Verification Results



Caldb ver.	standard deviation (μs)
old	44.7
new	16.4

The correction effect is confirmed

summary

◆ No long-term change is seen in the SMU quartz Temperature–Frequency Trend.

◆ The GPS → SMU → GPS transition during the GPS unlock period was also normal.

◆ Last year's presentation: Relative timing offsets were corrected using the 2024 simultaneous Crab observations with NICER.

◆ **CalDB update**

- $C_{\mathrm{g,p}}$ updated (grade only)
- Independent $C_{\mathrm{g,p}}$ were introduced for H, Mp, Ms, Lp, and Ls

◆ **This presentation: The correction effect was examined using the 2025 XRISM Crab observation.**

- **The correction effect on the grade-dependent scatter was confirmed.**

backup

Introduction3. XRISM/Resolve timing system

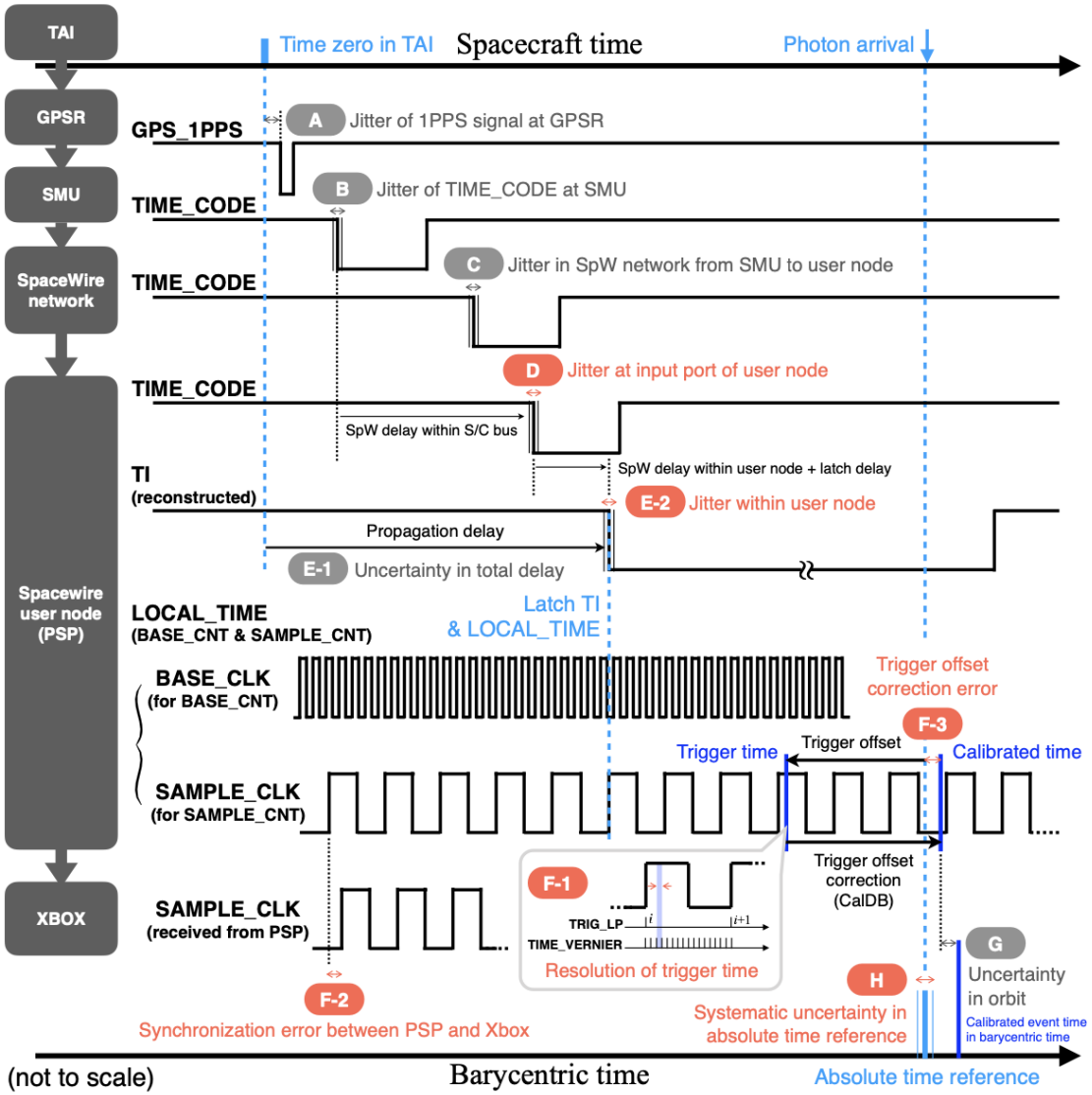


Fig.2:Timing diagram of XRISM/Resolve
Sawada et al., 2025

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

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

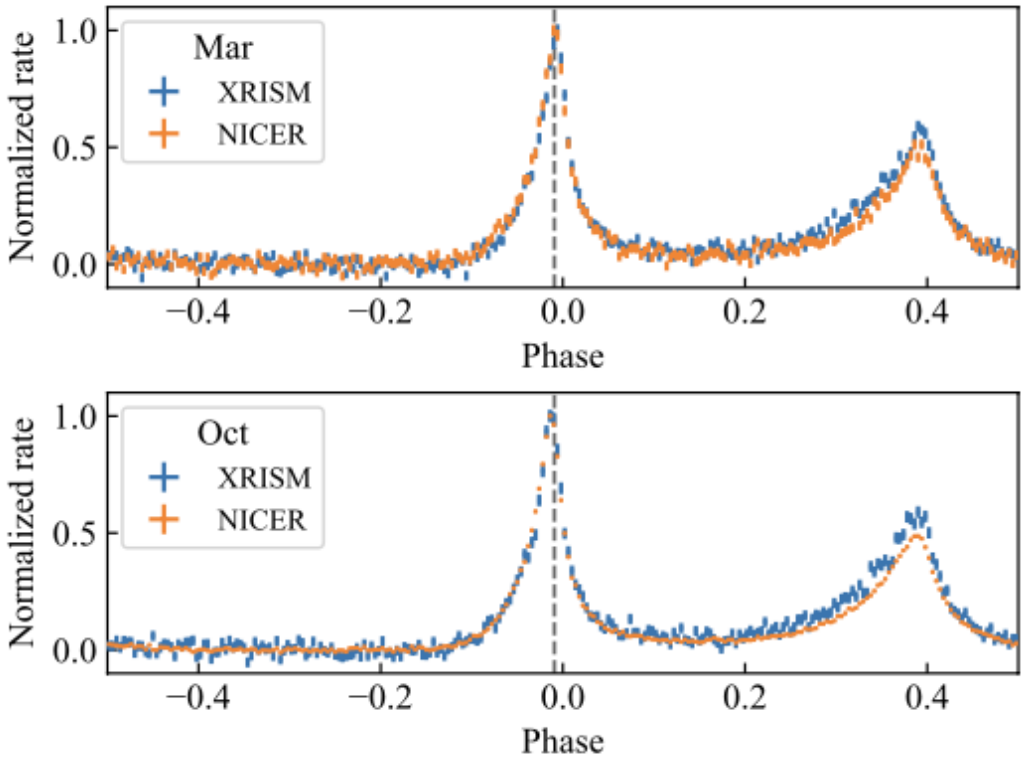


Fig.5: Crab pulse profiles
(XRSIM using H and Mp events)
Sawada et al., 2025

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

Result1. Timing Offset Relative to NICER for H+Mp

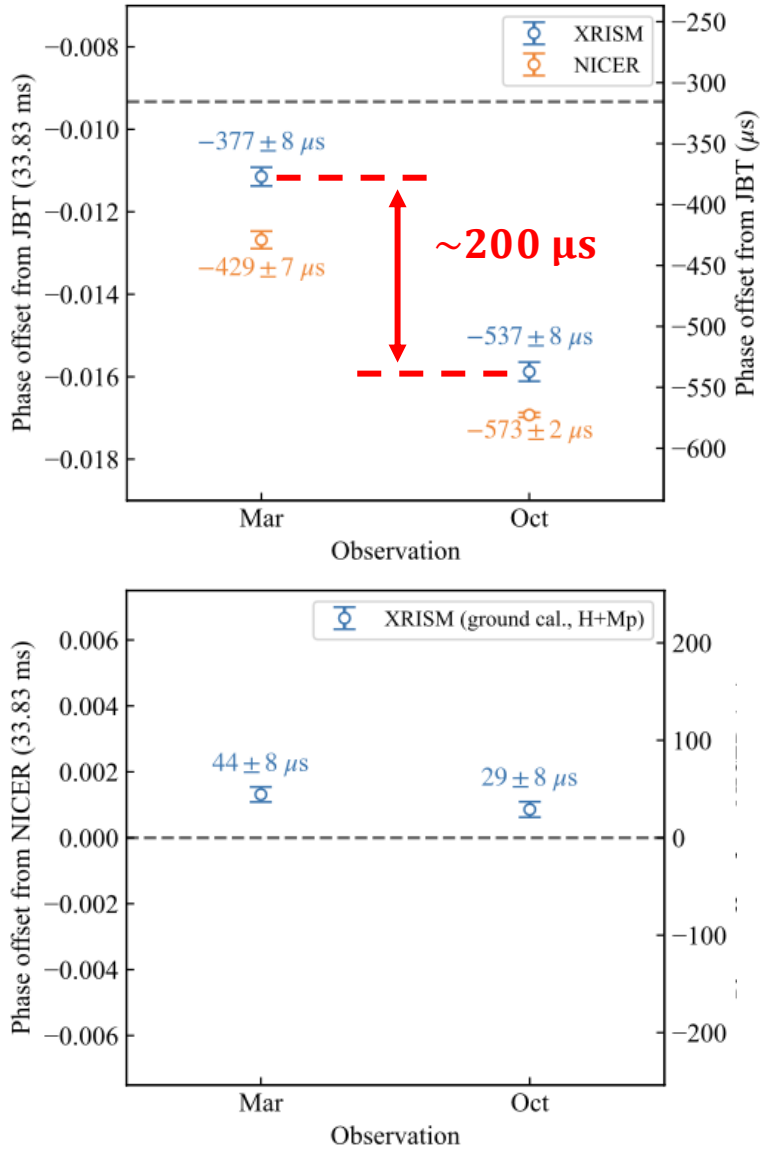


Fig.6: Phase offset using ground calibration
Sawada et al., 2025

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

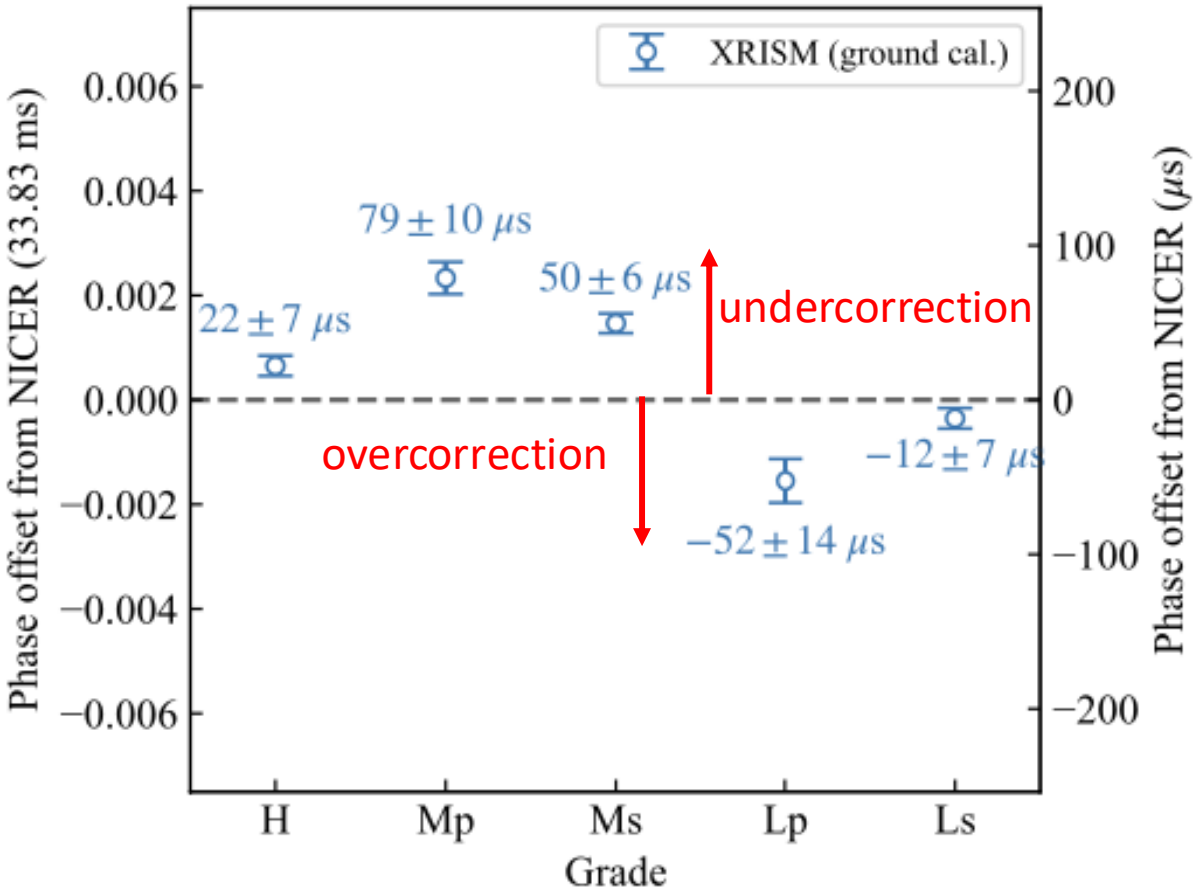


Fig.7: Phase offset using ground calibration(grade differences)
Sawada et al., 2025

We combined data from two calibration epochs to reduce statistical error

◆ **Summary of result**

- ✓ H: ~20 μs
  (comparable to the statistical error in the absolute timing calibration on the ground)
- ✓ The other grades: $-50\ to\ +80$ μs

This grade variance can be recalibrated in the CALDB

Result3. Pixel Dependence on timing offset

Further classification by pixel

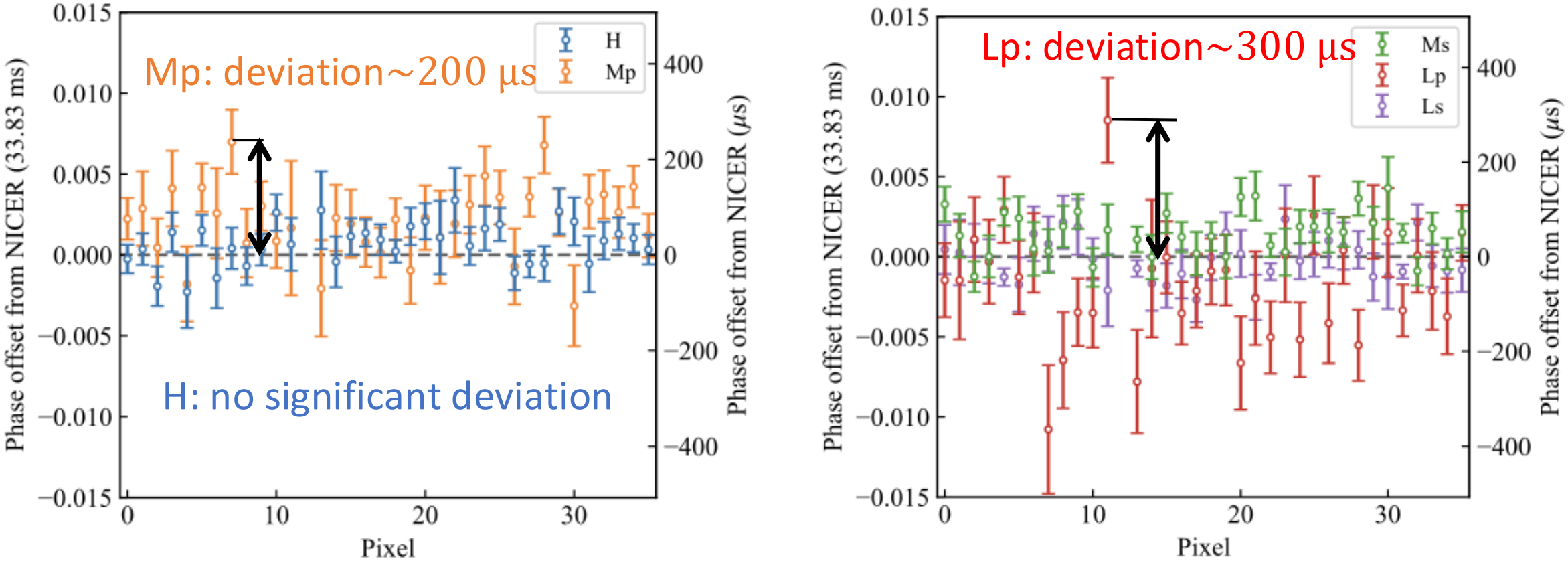
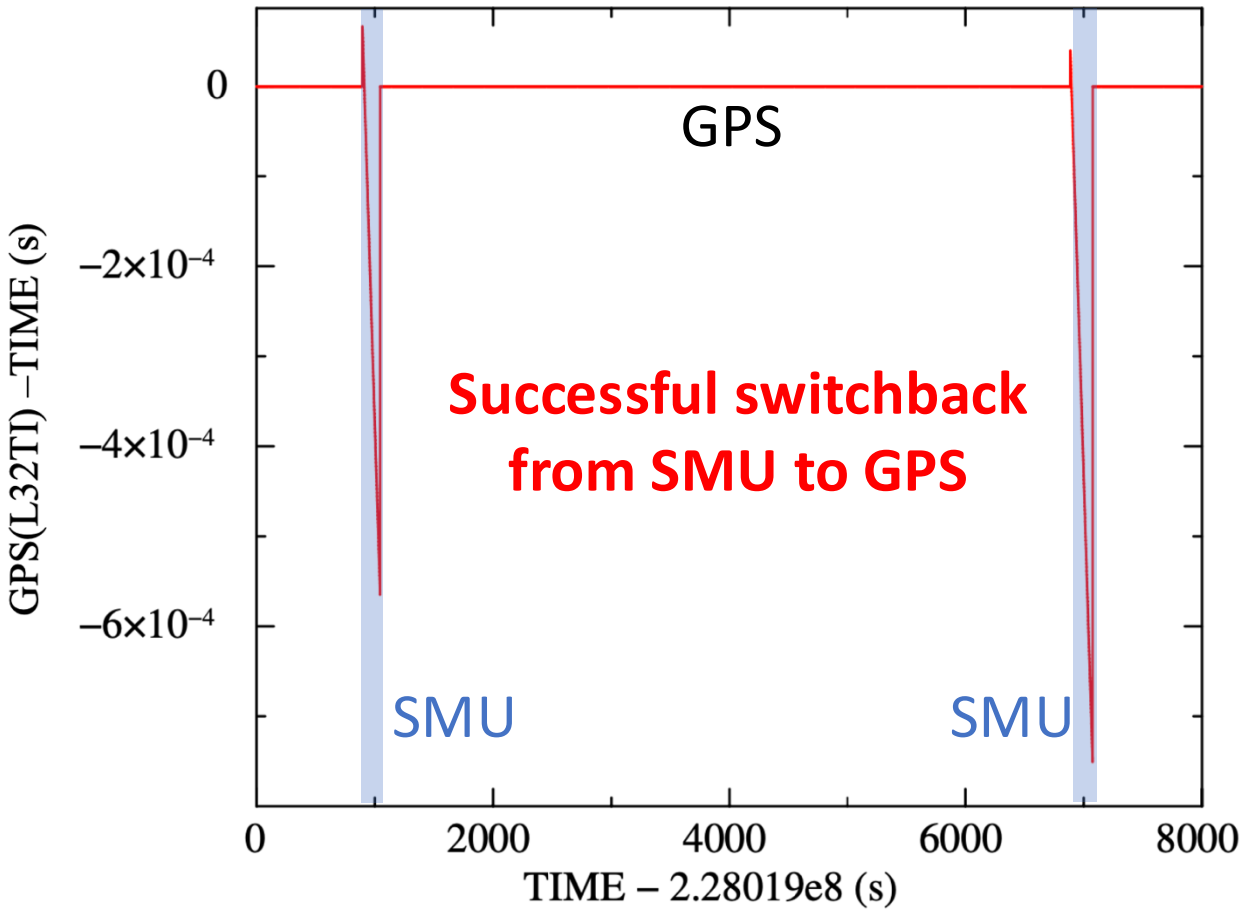


Fig.8: Phase offset using ground calibration(grade differences)
Sawada et al., 2025

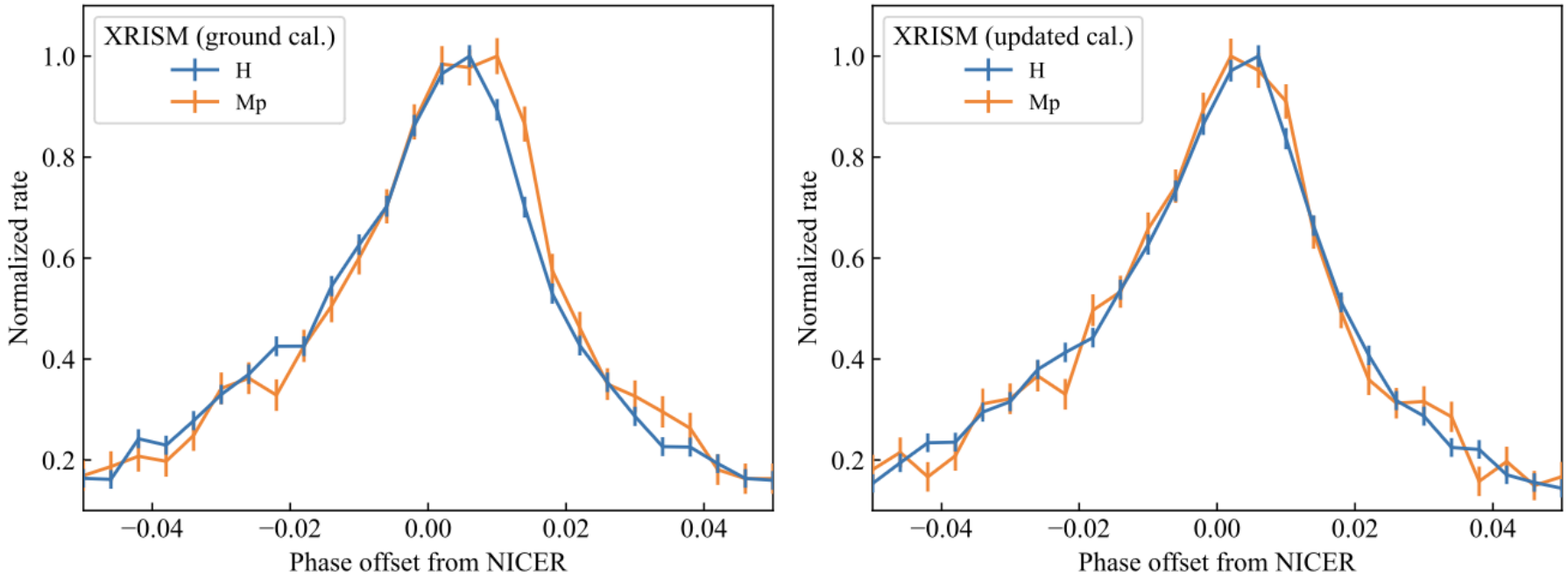
GPS → SMU → GPS Transition in March 2026



GPS(L32TI): TIME value converted from L32TI assuming GPS sync.

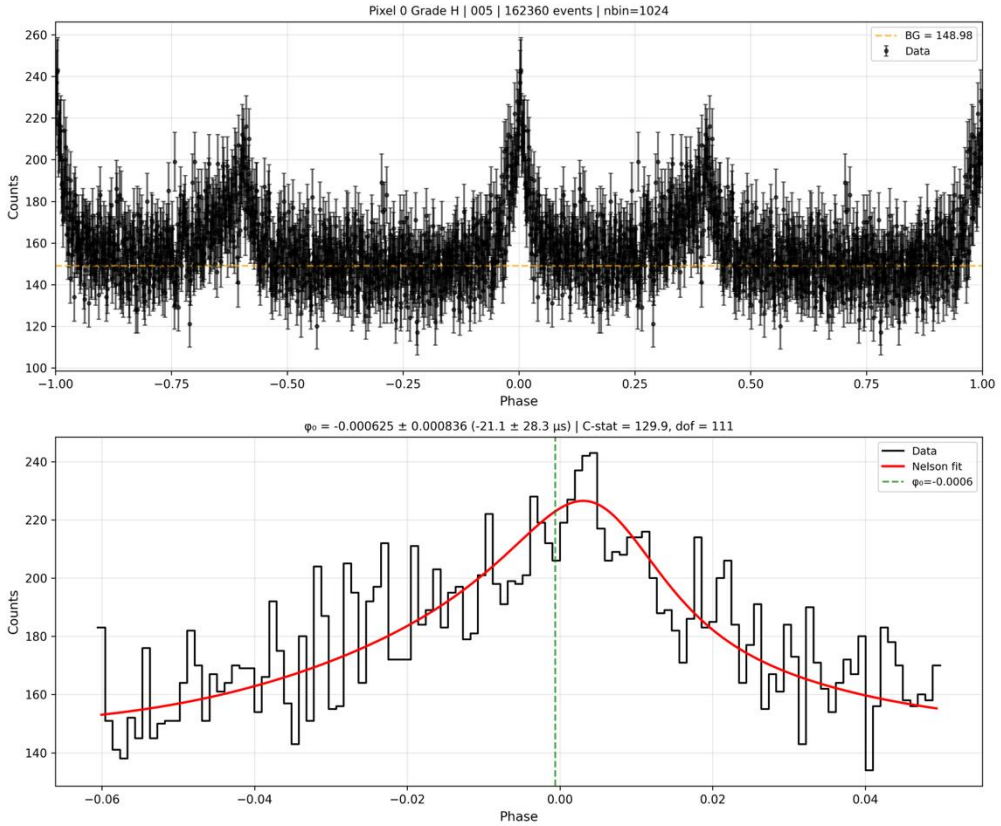
GPS status	Start time (S_TIME)	Start time (UT, 2026 Mar. 24)
GPS Synchronized	2.279250602343780E+08	(Mar. 23) 00:31:00.234378
Error (not defined)	**2.280198952343040E+08**	**02:51:35.234304**
Transition (GPS)	**2.280200142343050E+08**	**02:53:34.234305**
GPS Synchronized	2.280200462343050E+08	02:54:06.234305
Error (not defined)	**2.280258872343310E+08**	**04:31:27.234331**
Transition (GPS)	**2.280260442343320E+08**	**04:34:04.234332**
GPS Synchronized	2.280260762343320E+08	04:34:36.234332

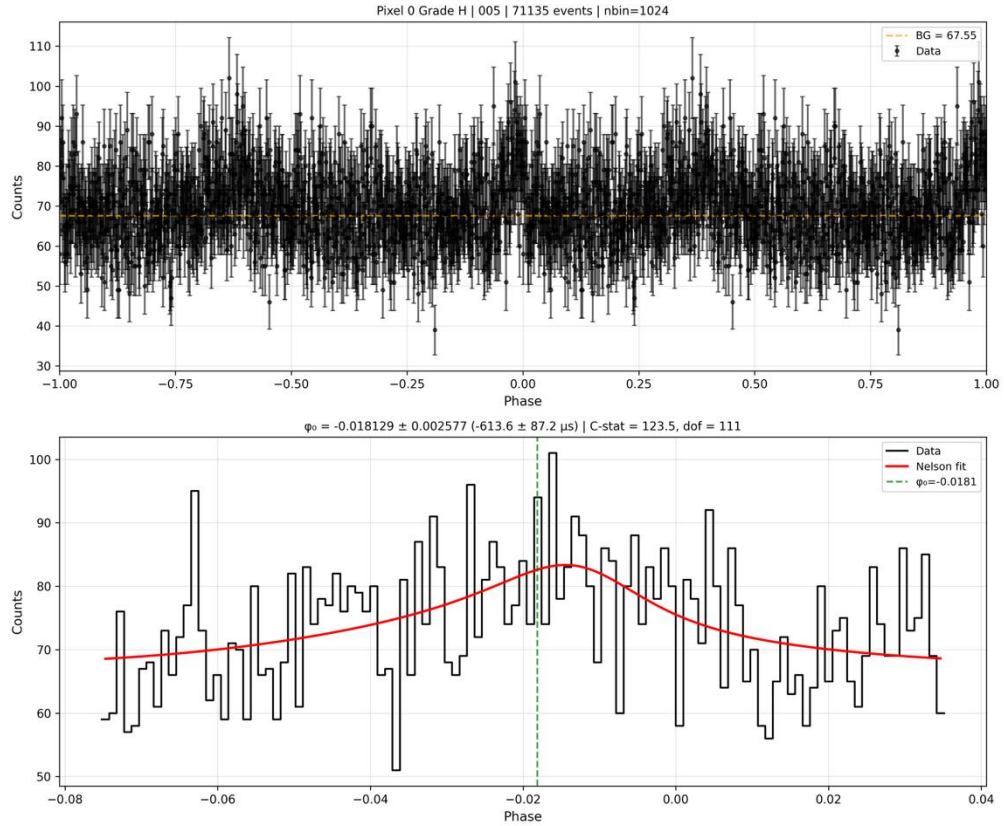
No timing issue outside the GPS-unlocked period


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

Why the correction effect for the pixel-to-pixel scatter is not seen

Pulse Profile and Fit for Pixel 0, Hp Grade





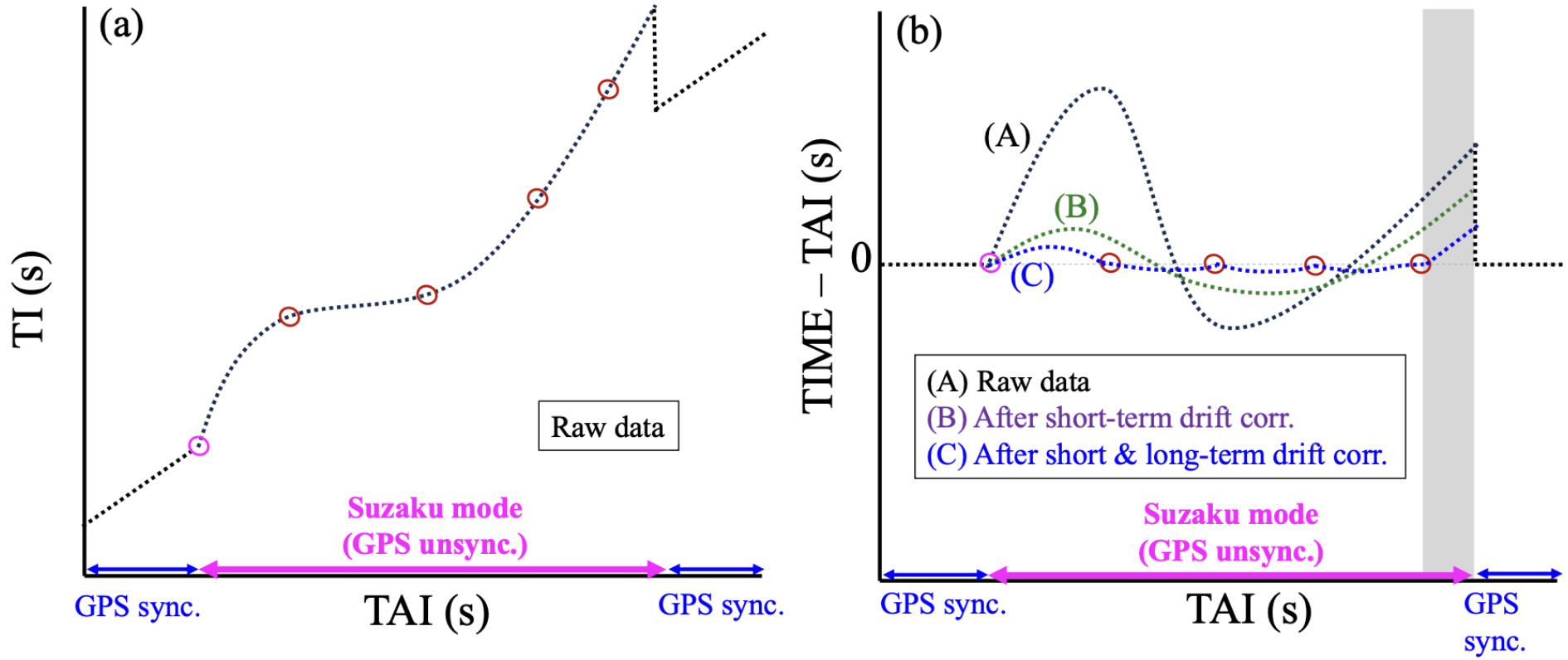
2024 observations (sum of two observations): 95.8 ks

2025 observation：45.3 ks

~50 ks is not enough to obtain sufficient statistics for pixel-by-pixel analysis

~100 ks is required for pixel-by-pixel timing verification using Crab observations

Q&A



Shidatsu et al., 2025