2023 April 23-27,
15th IACHEC meeting
@ Pelham, Germany

Verification of XRISM Timing System Using Thermal-vacuum Test Data

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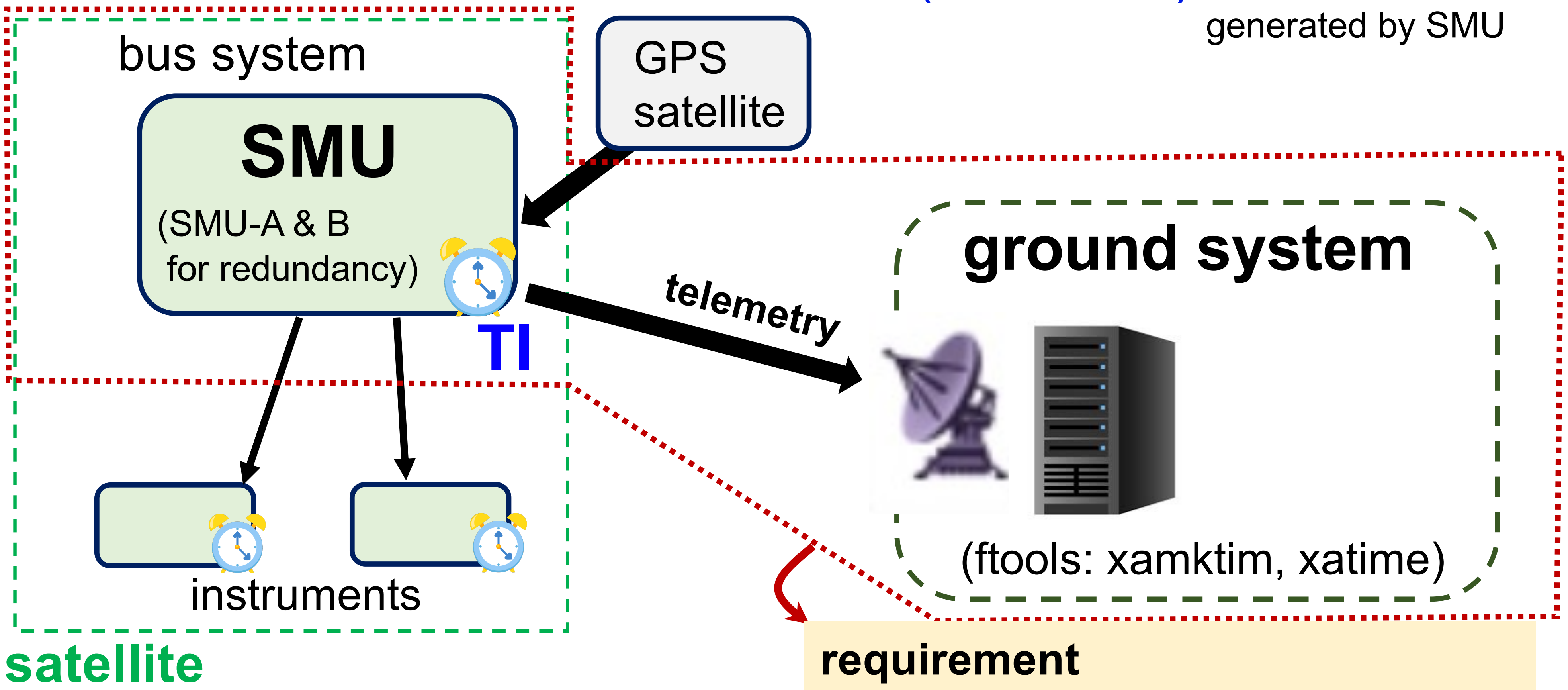
XRISM Timing system

XRISM time assignment system

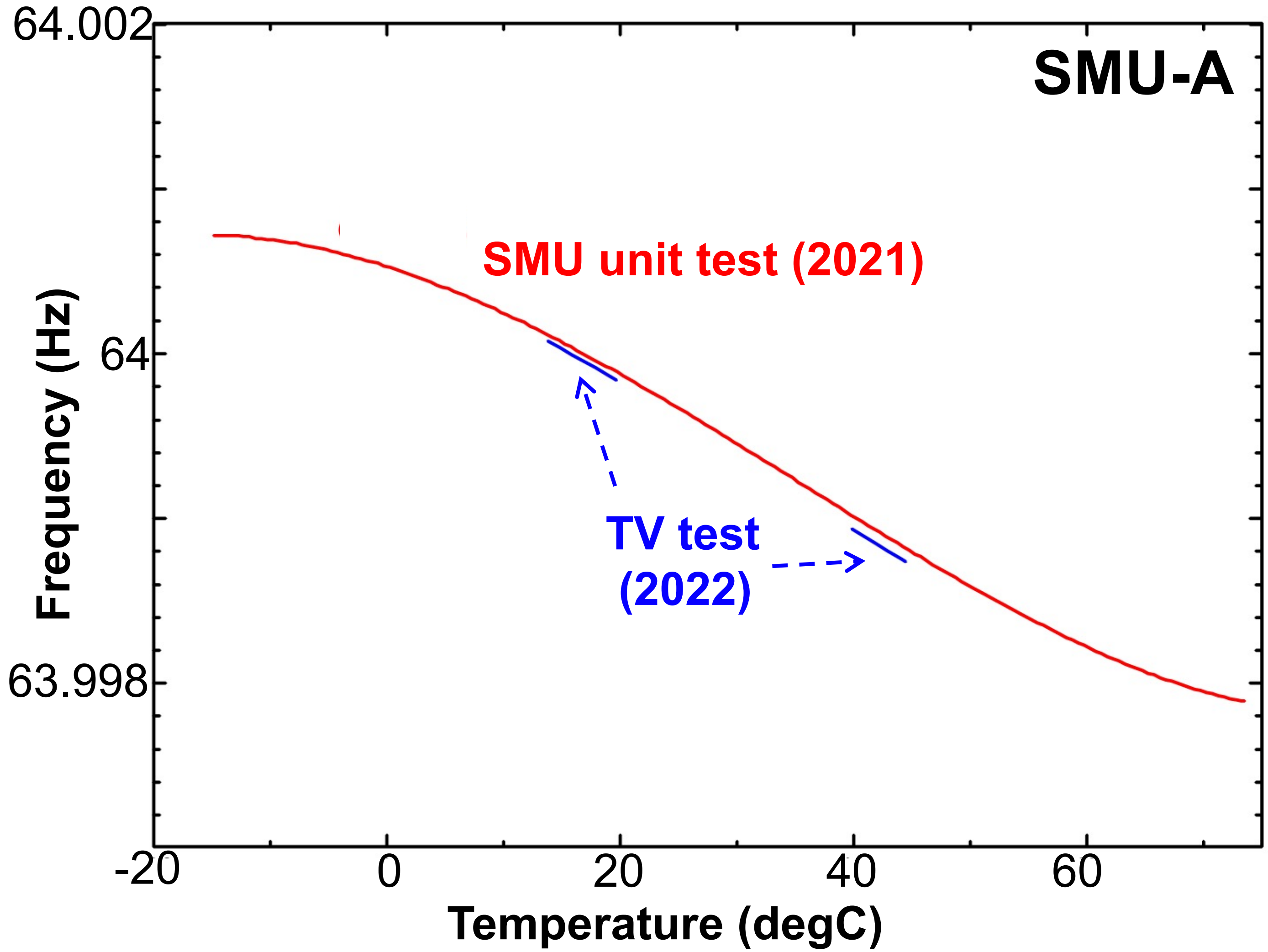
SMU: main computer of the satellite
TI (Time Indicator): satellite time counter generated by SMU



requirement
Error budget: 350 us / 1ms (total)

XRISM has a GPS receiver,
and the quartz clock in SMU is normally synchronized to the GPS time.
In case the satellite fails to receive the GPS signal (expected to rarely happen),
the clock runs freely and its frequency changes with the temperature.

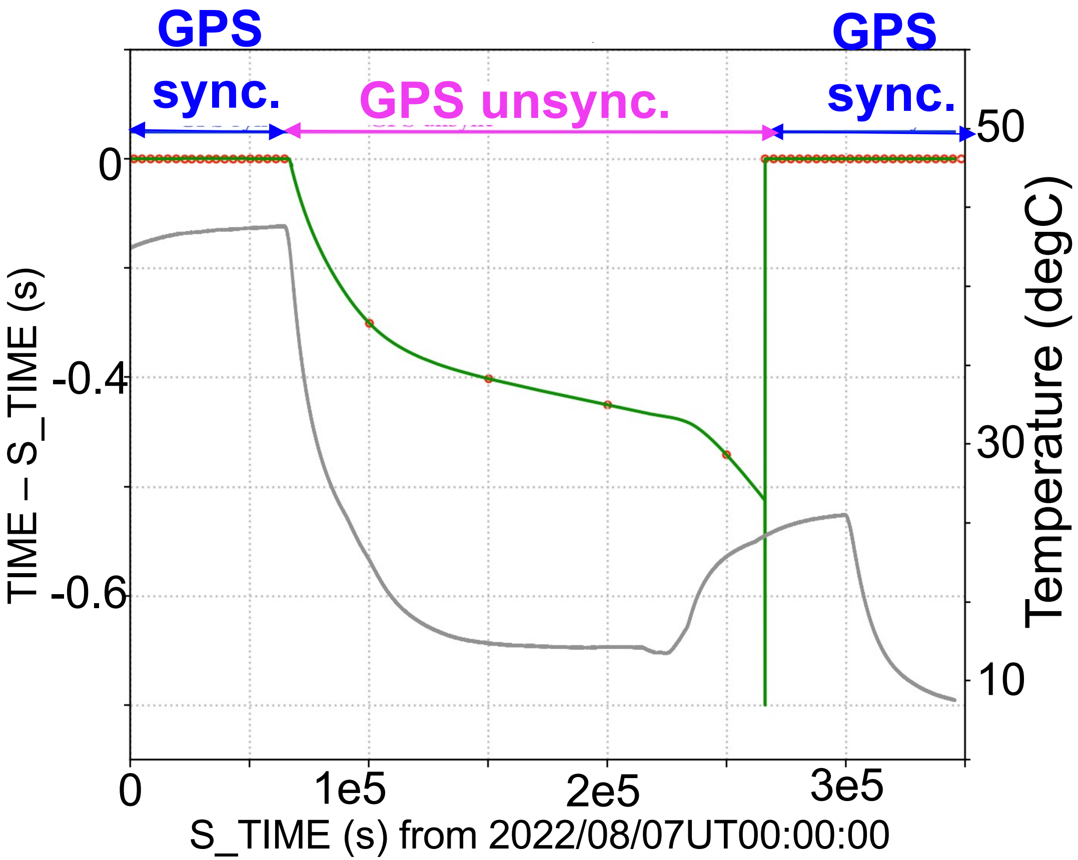
Results from Thermal Vacuum (TV) test: measurement of freq. vs T trend



(similar results were obtained for SMU-B)

The measured freq. vs. T trends are almost consistent but slightly different between the TV test and the unit test

Results from TV test:
Time assignment w/ f-T trend from unit test



- **Input data for time assignment (time telemetry data)**
- **SMU temperature**

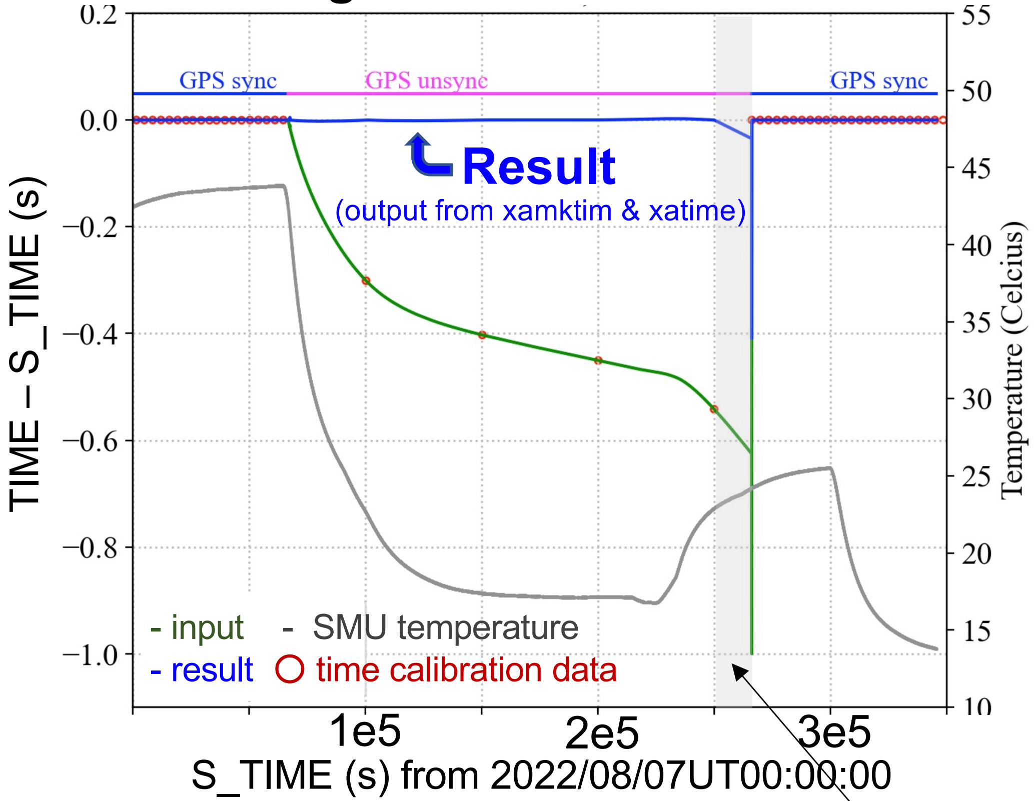
○ **Time calibration data**
(some data points are removed in the GPS unsync. period to simulate the on-orbit case)

S_TIME: the actual time when the TI was sent from SMU (always synchronized to GPS)

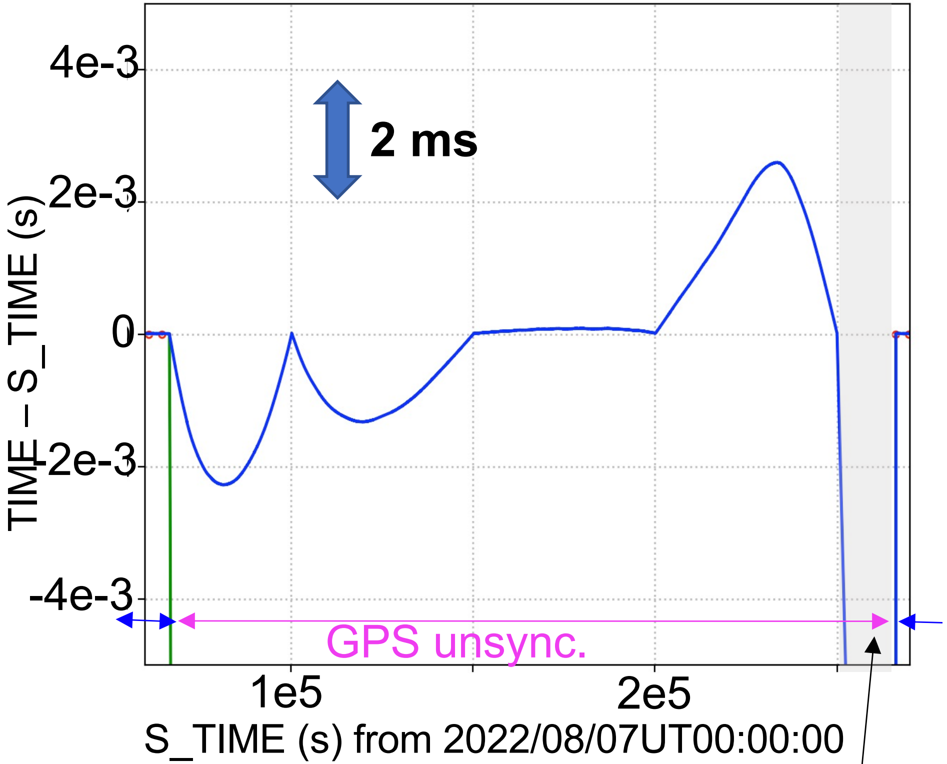
Note: S_TIME values in usual HK and event fits from QL data processing contain jitter so we adopted the **"time telemetry" data** (used to create the time calibration table) that have true S_TIME values, as input data for timing verification.

Results from TV test:
Time assignment w/ f-T trend from unit test

Result of time assignment using CALDB f vs. T trend



Enlarged view in GPS unsync. period



The error can be large because the anchor point for long-term drift correction is unavailable at the transition.
This period is excluded for verification.

The requirement is satisfied in the GPS synchronized period (error < 10 us) but not satisfied in the GPS unsynchronized period (error: up to ~3 ms).

Results from TV test:
Time assignment w/ f-T trend from TV test

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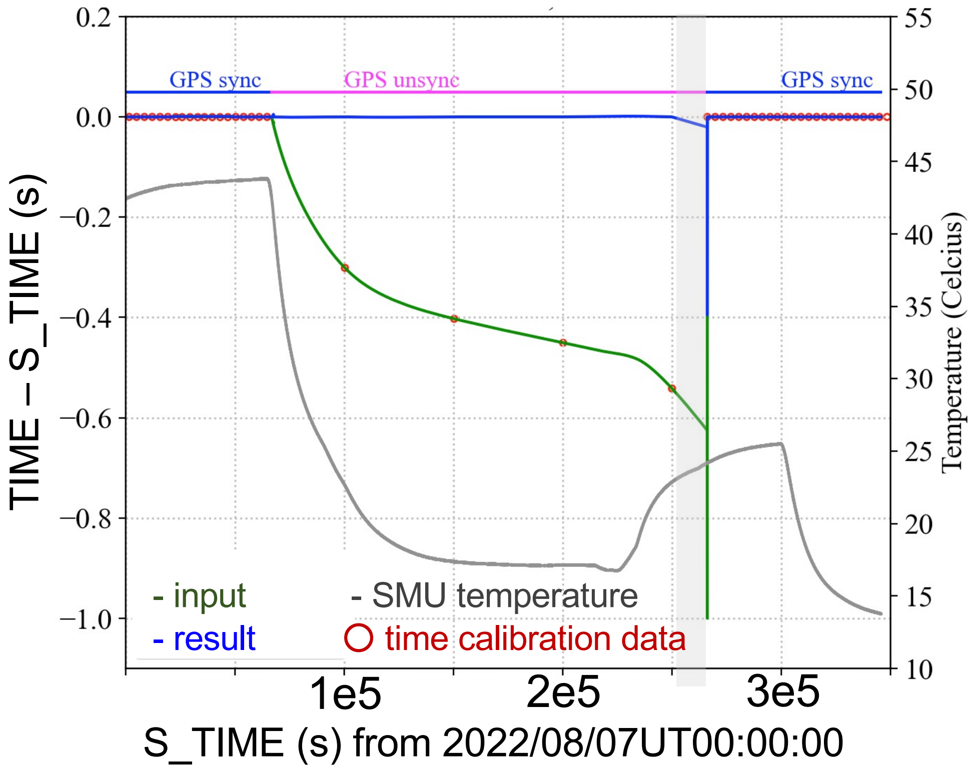
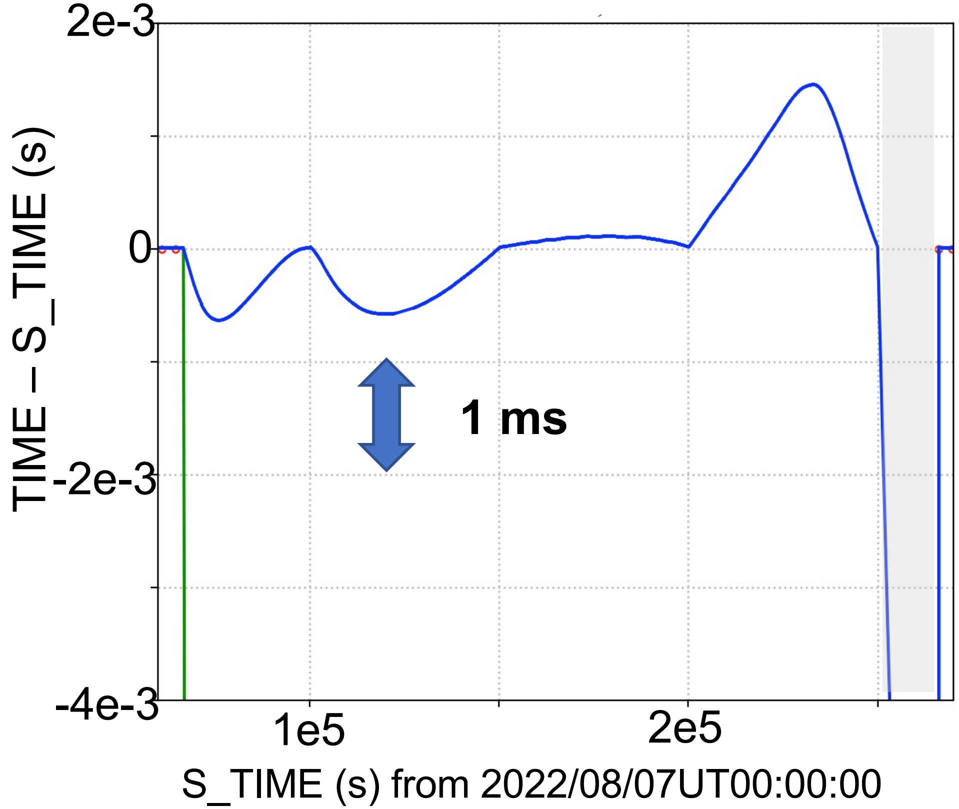
Results of time assignment w/ f vs. T trend from Tvac test



Enlarged view in GPS unsync. period

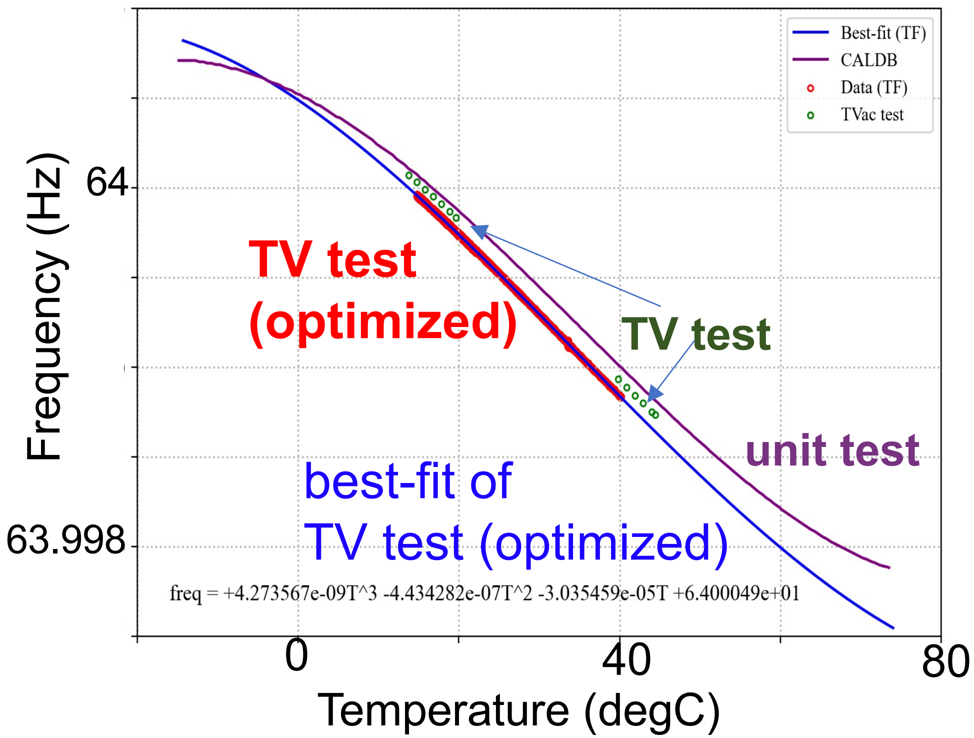


The result is improved when using the f vs. T trend from the TV data, but still beyond the requirement especially when the temperature changes rapidly (up to 1.5 ms).

The accuracy of f vs. T trend is not sufficient in some reasons...?

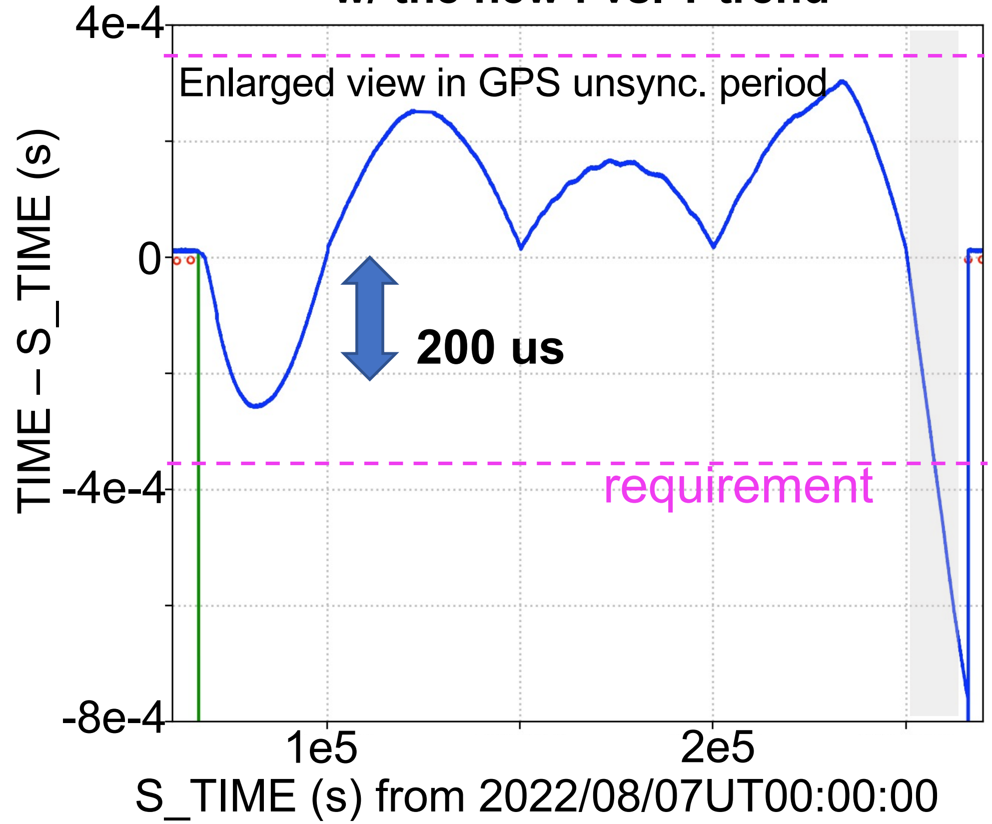
Results from TV test:
Optimization of f-T trend

Using the test data that have TI and the corresponding S_TIME values, we calculated the freq. vs. T trend that make the assigned TIME values always equal to the S_TIME values.



the difference is likely because we do not measure the temperature of the quartz clock itself

Time assignment w/ the new f vs. T trend

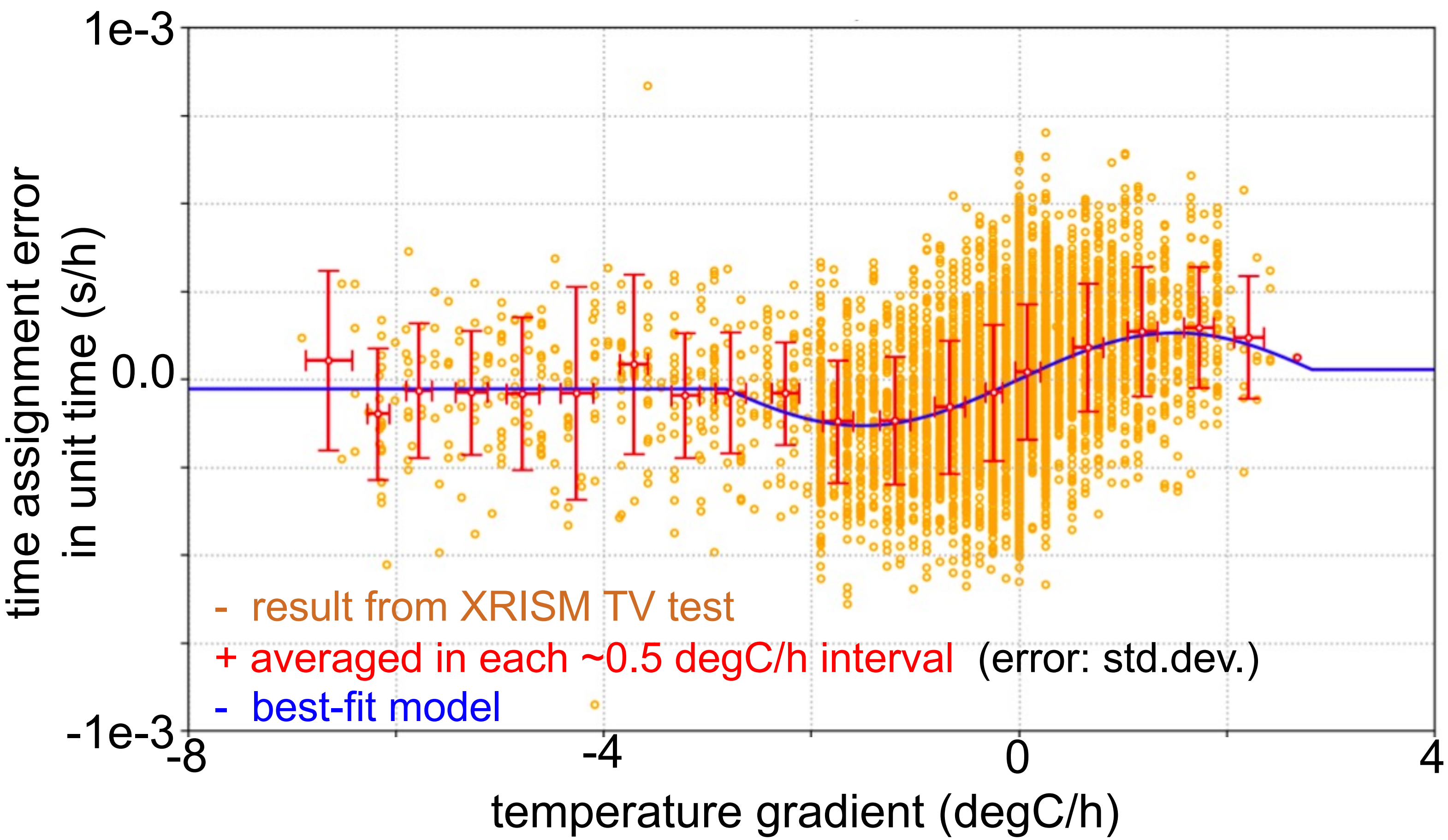


The errors are within ~300 us so the requirement is satisfied!

What about in the actual on-orbit temperature conditions…?

Dependence of the Timing Accuracy on the temperature gradient

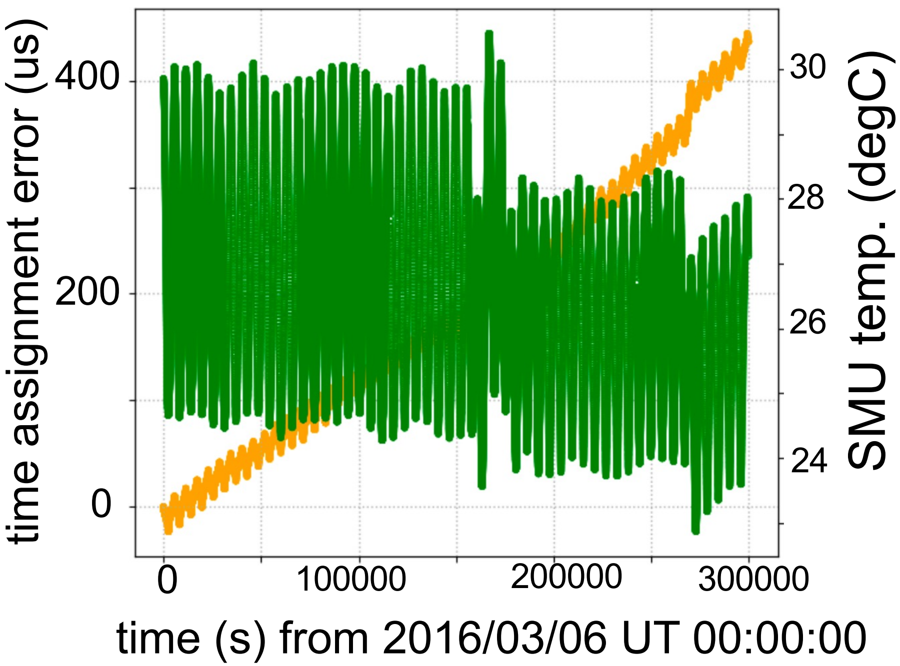
We investigated correlation of the temperature gradient and the time assignment error obtained from TV test data using the optimized f-T trend



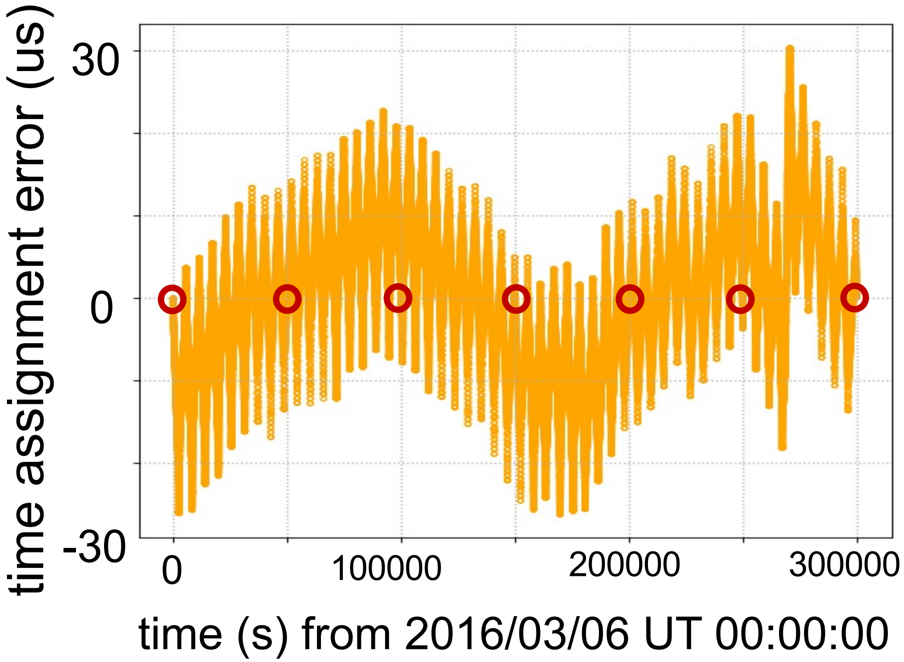
Note: long-term drift correction using time calibration data points is not performed here.

Simulation using Hitomi on-orbit data

We simulated the time variation of timing accuracy in actual on-orbit temperature conditions, using the dependency of time assignment error on temp. gradient and Hitomi on-orbit data of the SMU temperature.



- Hitomi SMU temperature
- time assignment error
  (w/o long-term drift correction using time calibration data)



same as left panel, but long-term drift correction is performed using time calibration data with a 50,000 s interval

We confirmed that the requirement is satisfied for ~300,000 s.

Summary

Requirement
error ≤ 350 us

GPS synchronized period

- The requirement is fully satisfied. (error: <~10 us)

GPS unsynchronized period

- Using the optimized freq. vs T trend derived from time telemetry data in the GPS unsync. period, the requirement is satisfied.
- In the typical on-orbit temperature conditions, the requirement is expected to be satisfied for at least ~300,000 s (~3.5 days).
  Note: this duration is comparable to that of Suzaku (Terada+ 2007, PASJ, Fig. 4).
- The optimized freq. vs. T trend data are included in XRISM official CALDB.