XRISM X-Ray Imaging and Spectroscopy Mission

2024 May 15, 16th IACHEC meeting
@ Parador de La Granja (Spain)

Challenges to Keep the Timing Accuracy of XRISM Timing System in GPS Failure Mode

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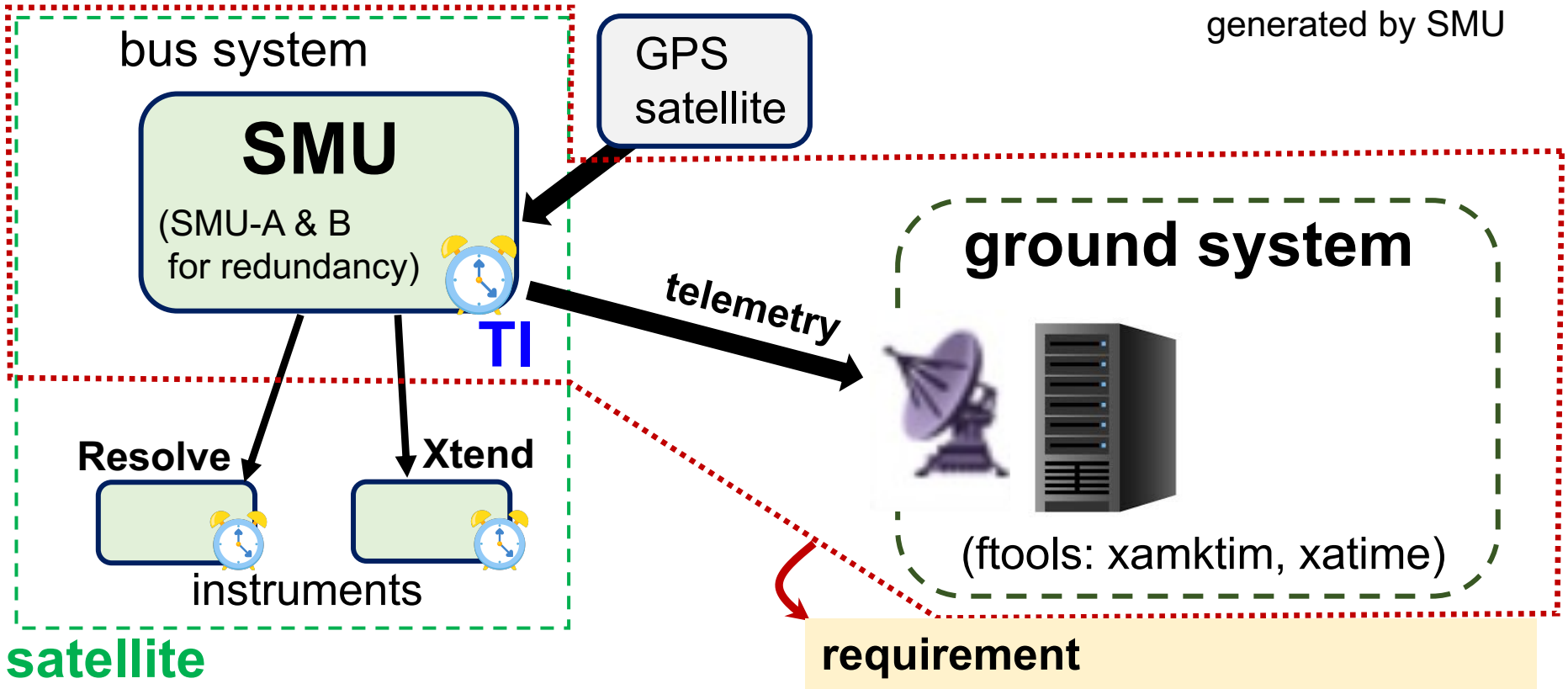
and the XRISM Science Operations Team

XRISM Timing system

XRISM time assignment system

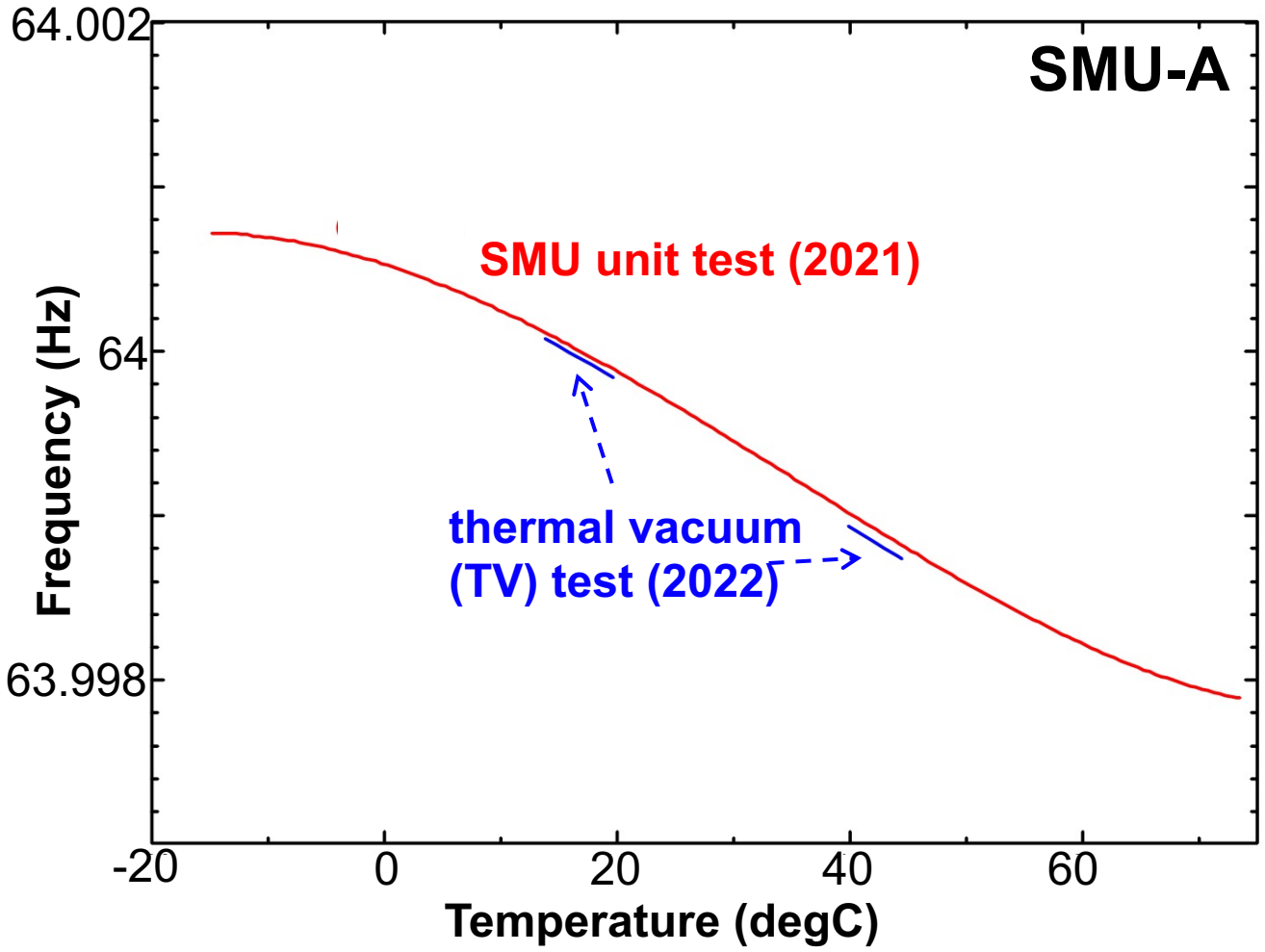
SMU: main computer of the satellite
TI (Time Indicator): satellite time counter generated by SMU



requirement
Error budget: 350 us / 1 ms (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 (**Suzaku mode**).

freq. vs T trend obtained in ground tests

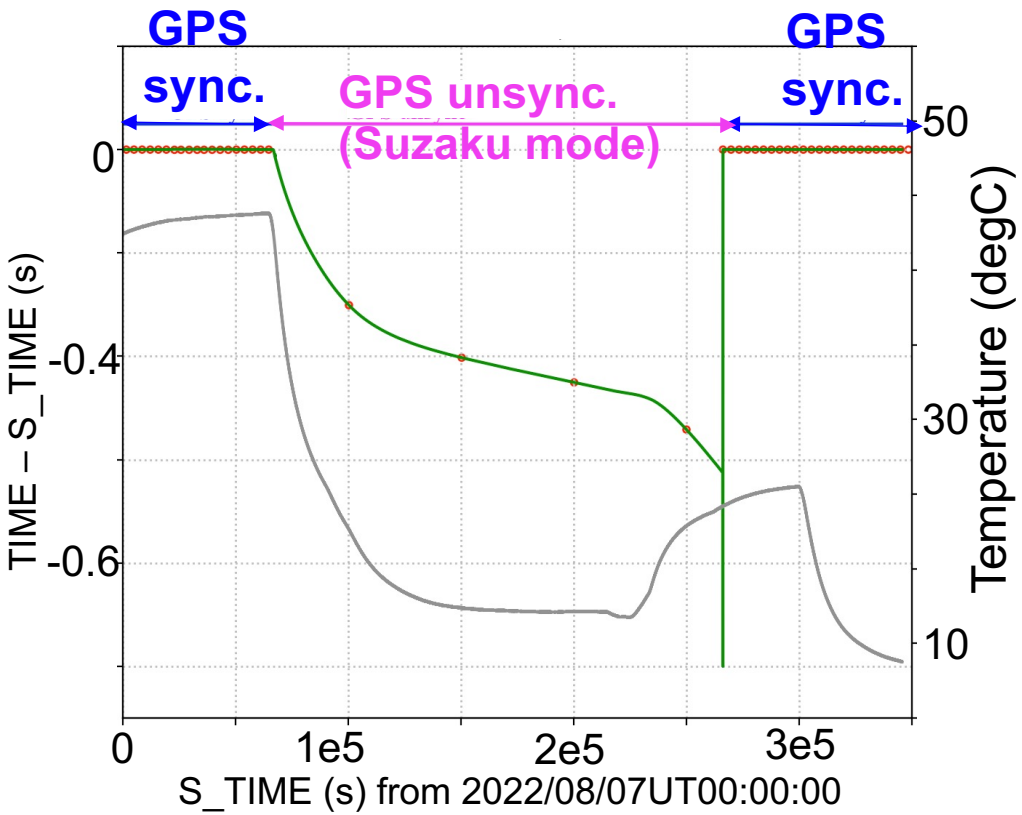


(similar results were obtained for SMU-B)

Using this Frequency vs. Temperature (FvT) trend we can correct the time drift in the Suzaku mode!

But it was not so simple
as we had expected…

Timing verification in thermal vacuum (TV) 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 the GPS time)

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/ fvT trend from the unit test

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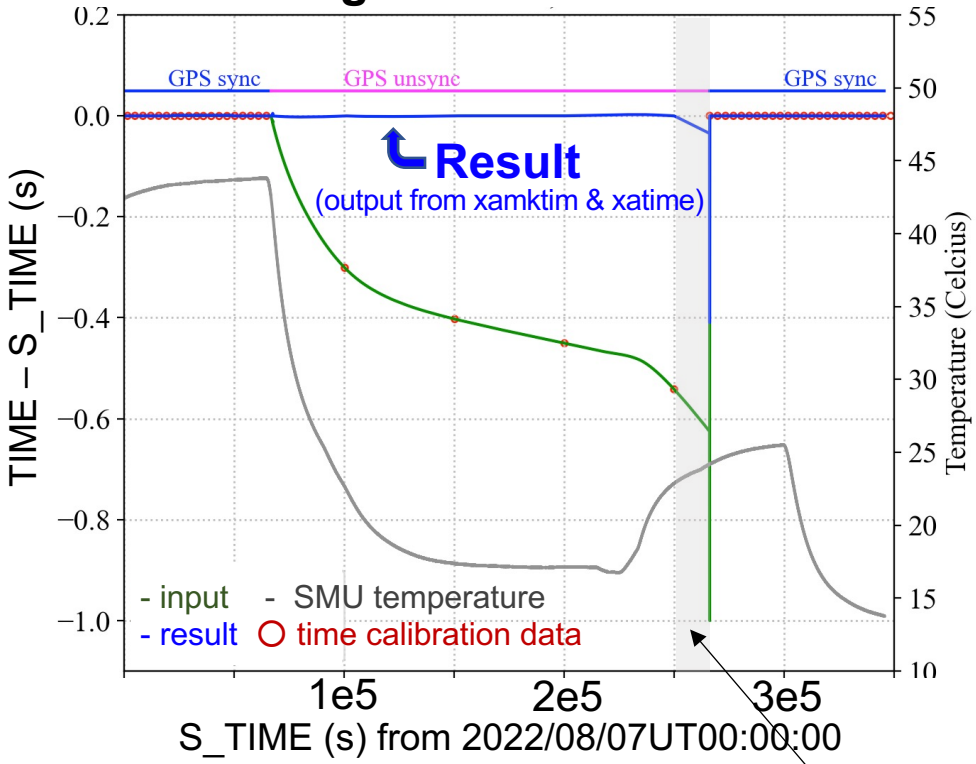
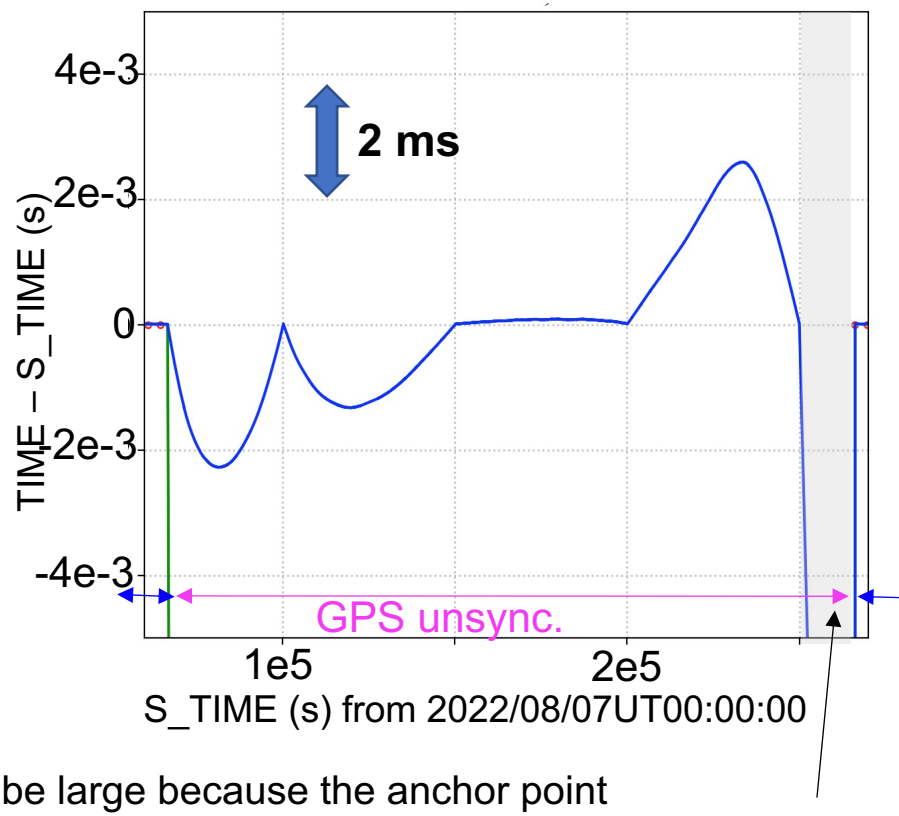
Result of time assignment using CALDB fvT trend



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/ fvT trend from TV test

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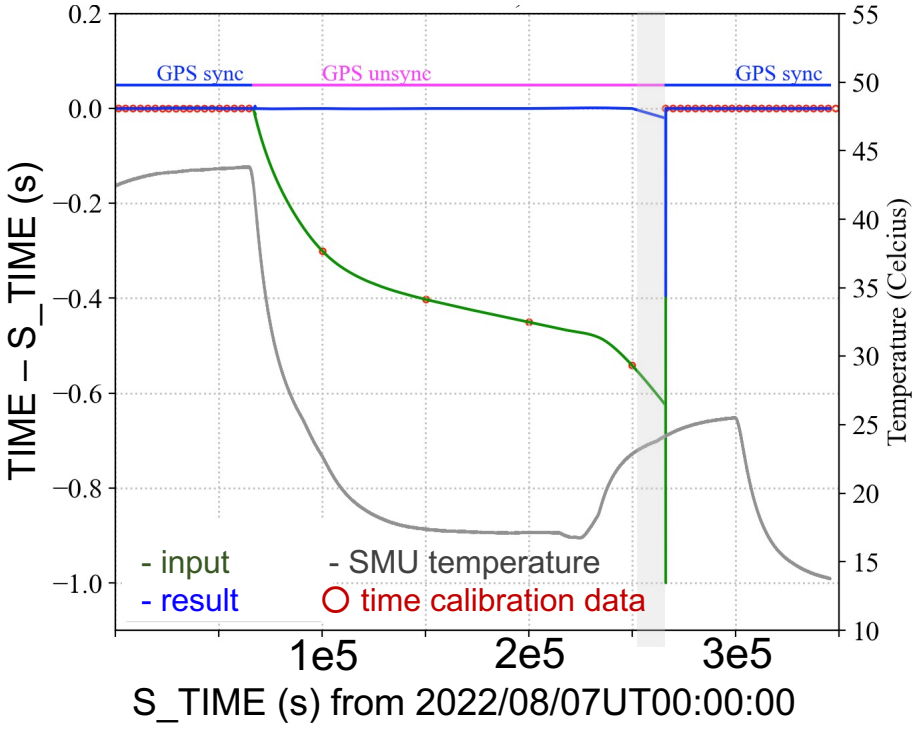
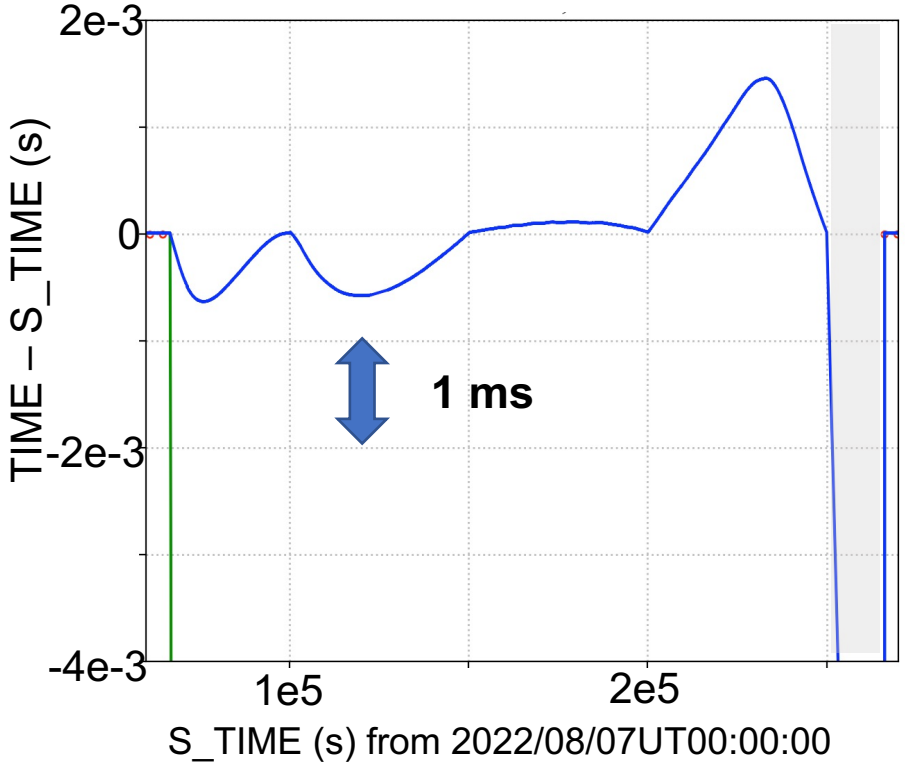
Results of time assignment w/ fvT trend from Tvac test



Enlarged view in GPS unsync. period



The result is improved when using the fvT 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

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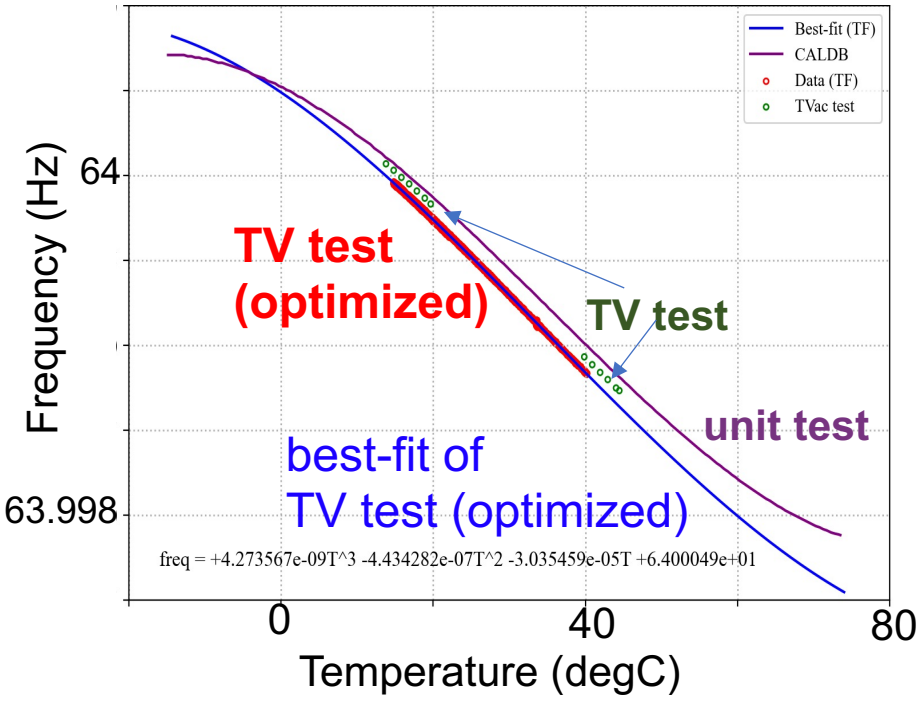
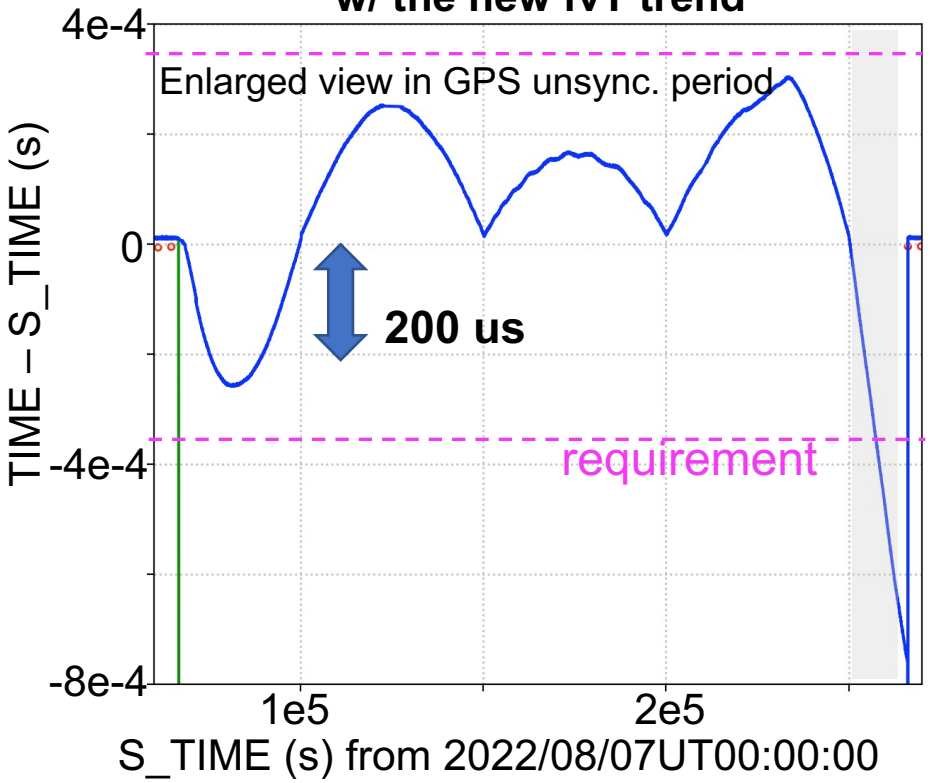
Using the test data that have TI and the corresponding S_TIME values, we calculated the freq. vs. T trend that make the assigned TIME values always equal to the S_TIME values.



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

Time assignment w/ the new fvT trend

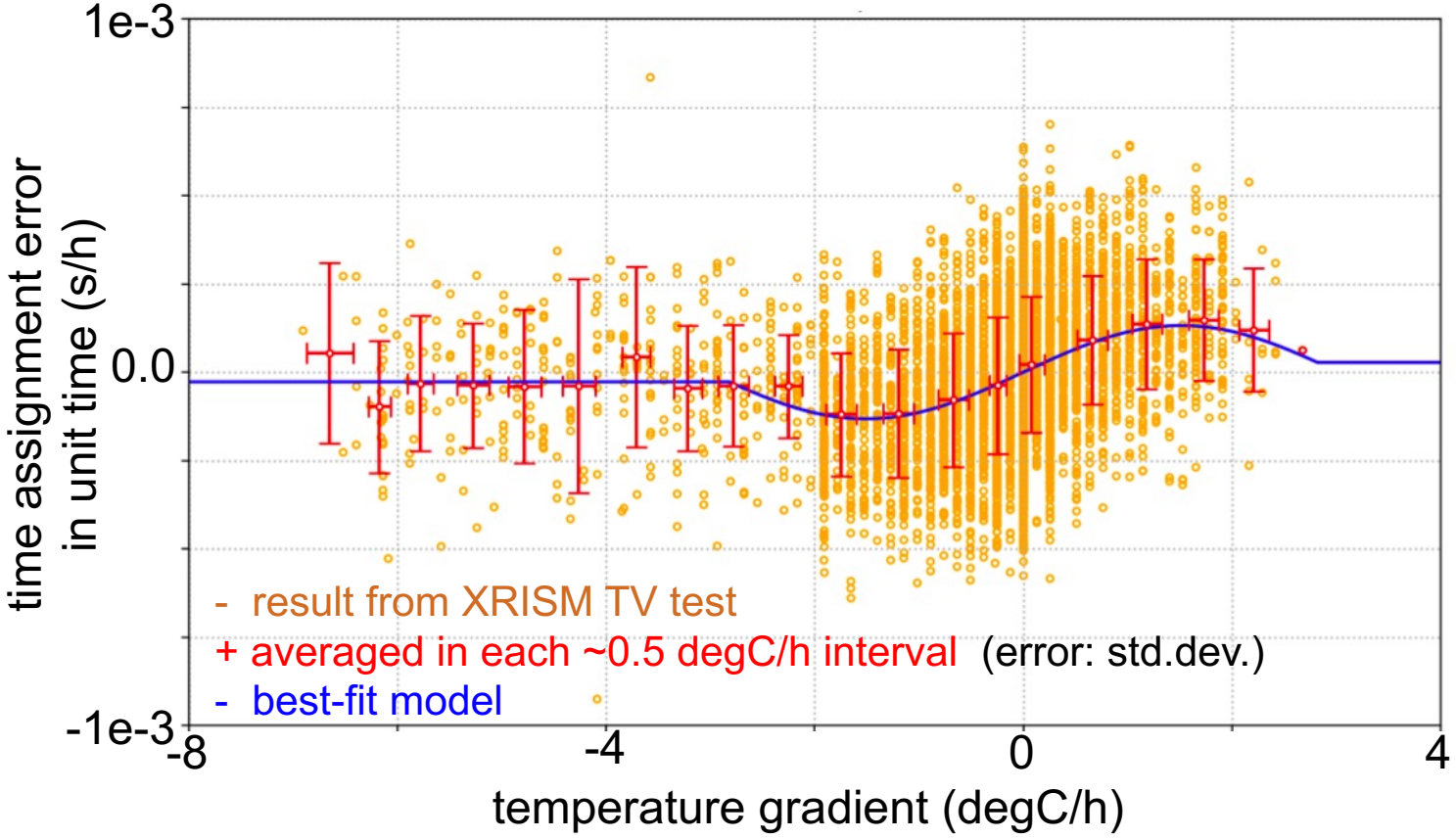


The errors are within ~300 us so the requirement is satisfied!

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

Dependence of the Timing Accuracy on the temperature gradient

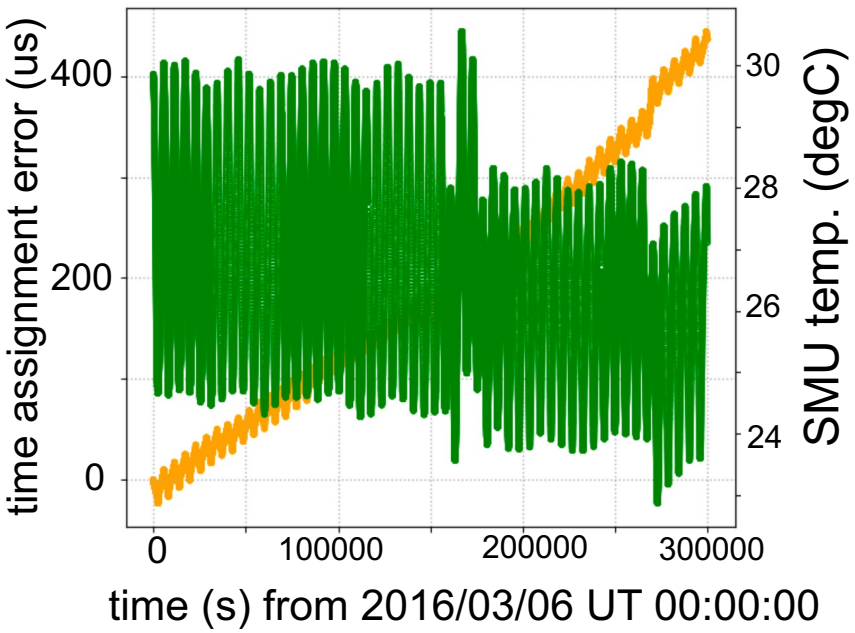
We investigated correlation of the temperature gradient and the time assignment error obtained from TV test data using the optimized fvT trend



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

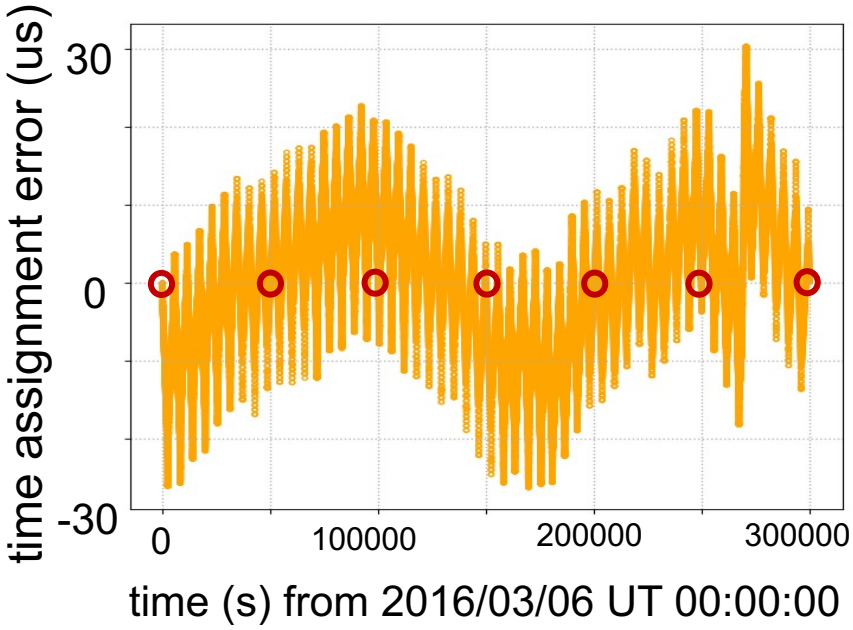
Simulation using Hitomi on-orbit data

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.

On-orbit verification

On-orbit commissioning

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(done in bus system checkout period)

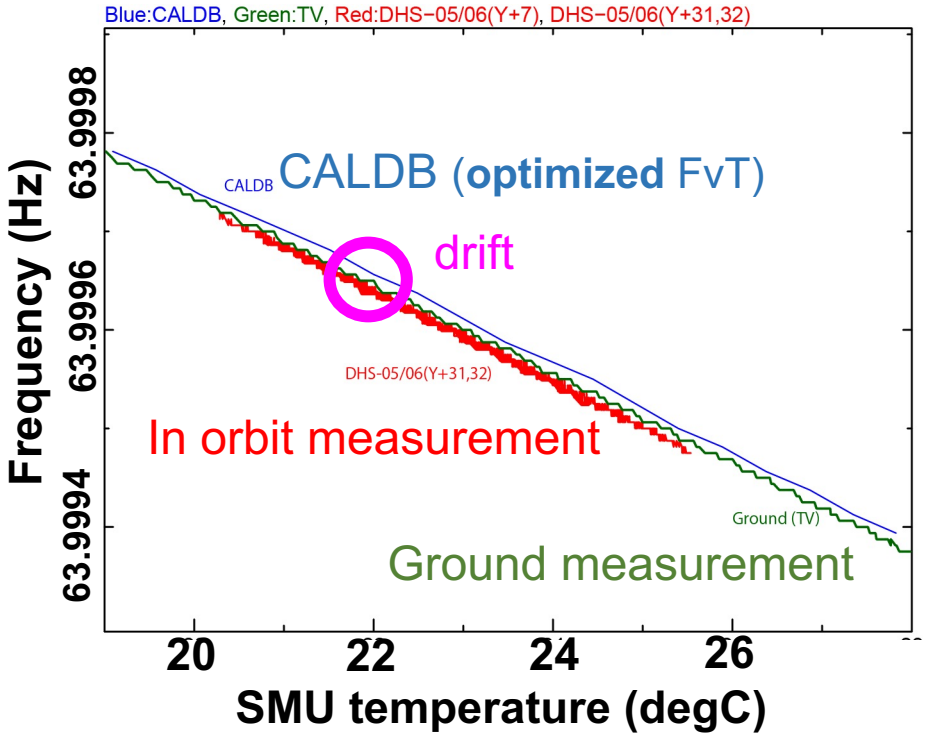
With NEC and SOT

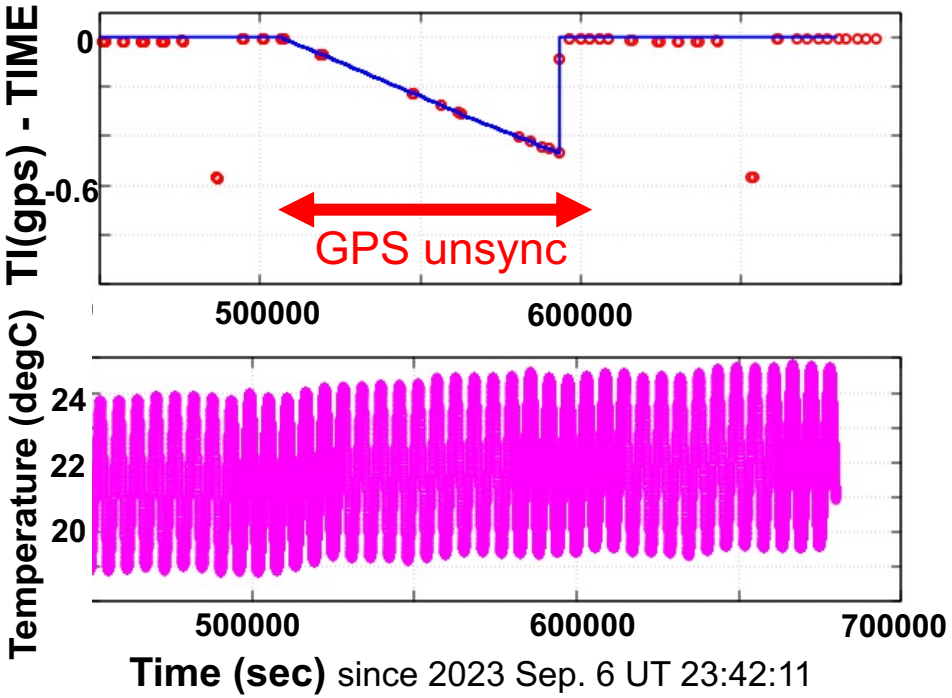
Day	Main Goal
Y+0~Y+7	To confirm that switching between the Suzaku mode and the GPS synch. mode works properly
Y+31, 32	To confirm that the SMU clock produces proper TI values in the Suzaku mode following the temperature versus clock frequency trend

(Y: days from launch)

note:
after the launch, the Suzaku mode was not observed, except during these commissioning activities.

On-orbit commissioning





Frequency drift is consistent with the ground measurement
– OK / passed (13 Oct 2023)

Summary

Requirement
error ≤ 350 us

Verification before launch

- Using the optimized f vs T trend derived from the time telemetry data, the requirement is satisfied.
- The optimized freq. vs. T trend data have been included in the XRISM CALDB.
- 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).

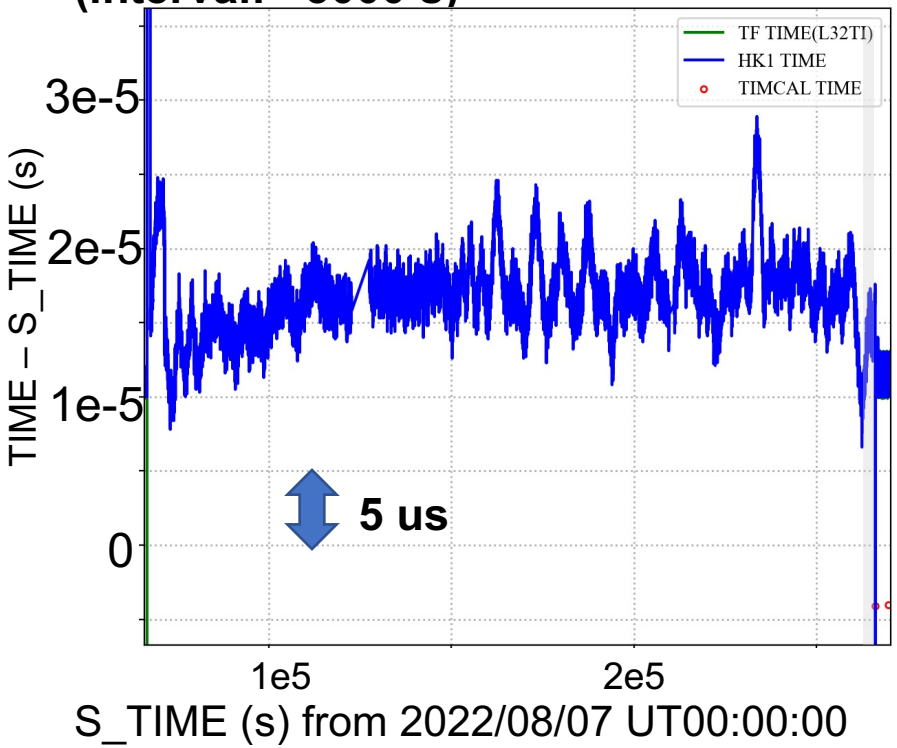
On-orbit Commissioning

- The Suzaku mode works properly!
- The f vs T trend does not change significantly after launch

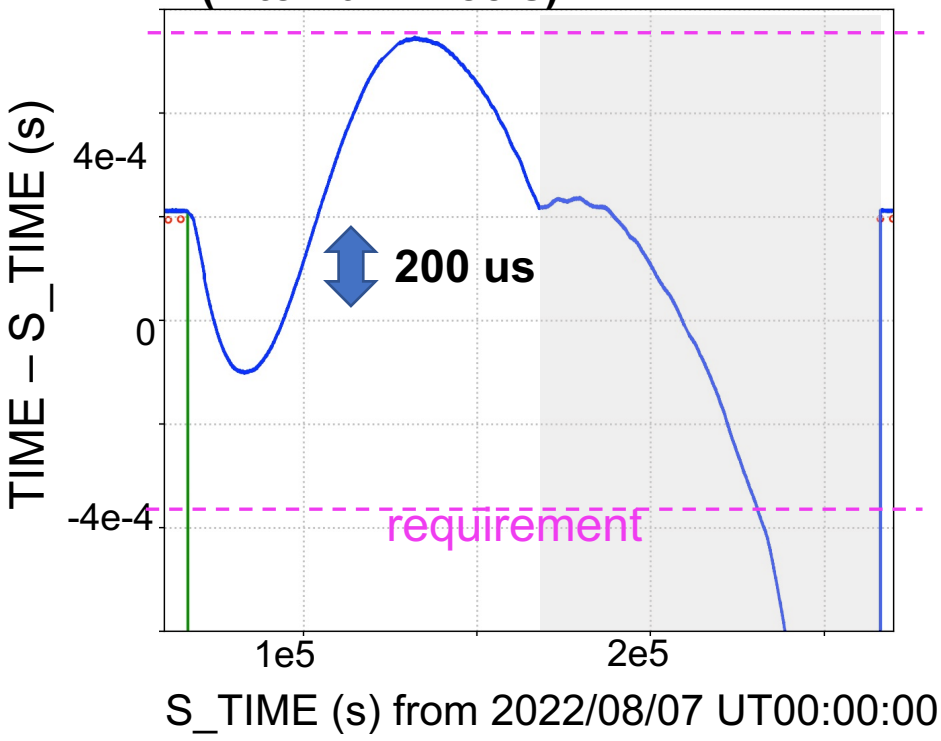
Appendix.

w/ a different number of TIMCAL points using the optimized f vs. T trend

all the time cal. data points are used (interval: ~3000 s)

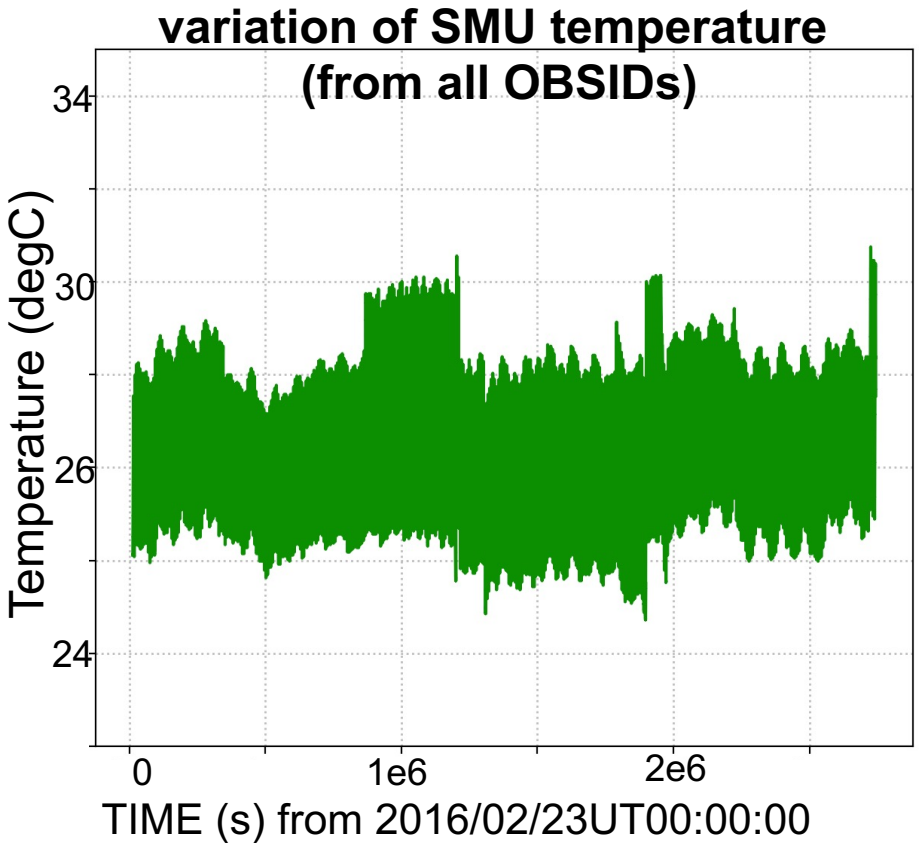


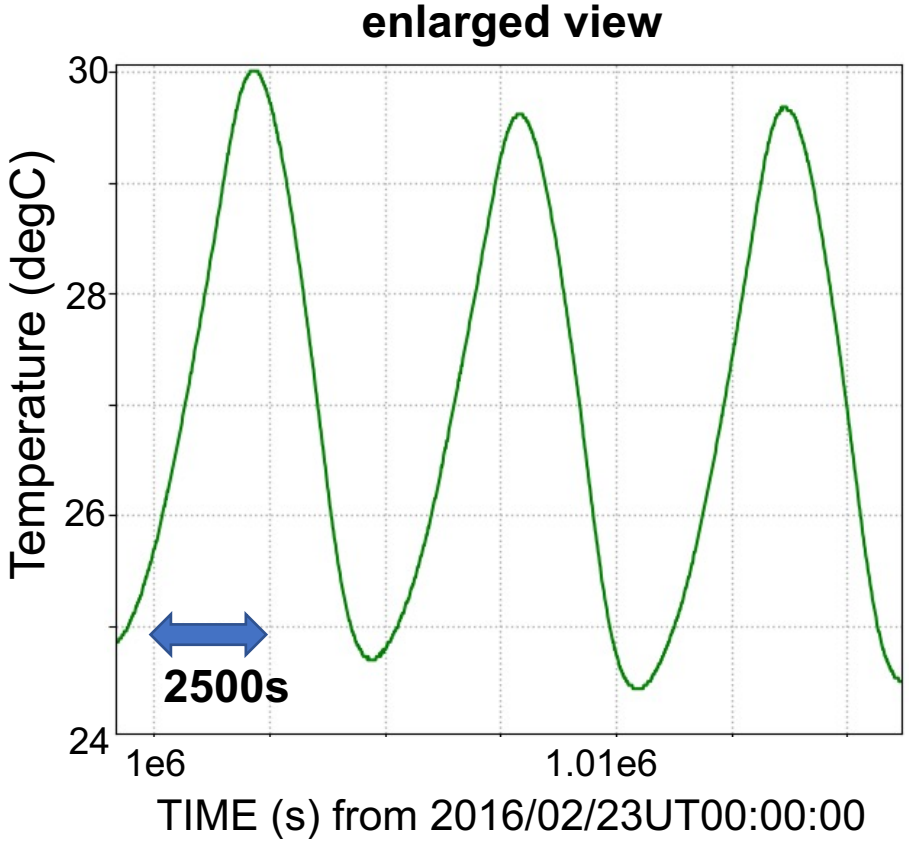
only 1 time cal. point is used (interval: ~1e5 s)



Appendix.
trend in SMU temperature: Hitomi case

MS (with NEC)





maximum rate of change:
~ +12 degC/h, -9 degC/h