

# INSIGHT-HXMT

## In-Orbit Timing Calibration

*Youli Tuo et al 2022 ApJS 259 14*

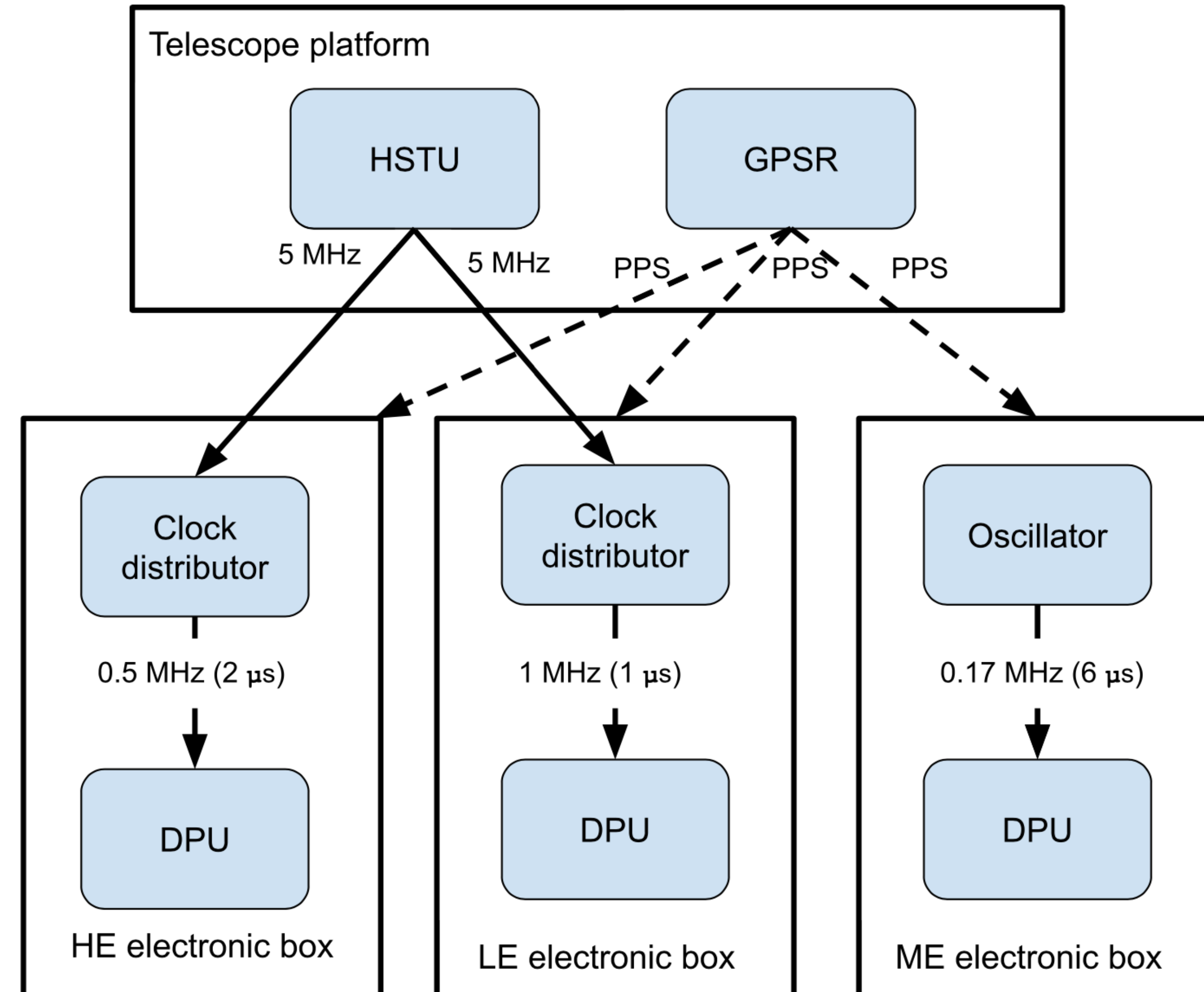
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**University of Tuebingen**

# Time System of HXMT

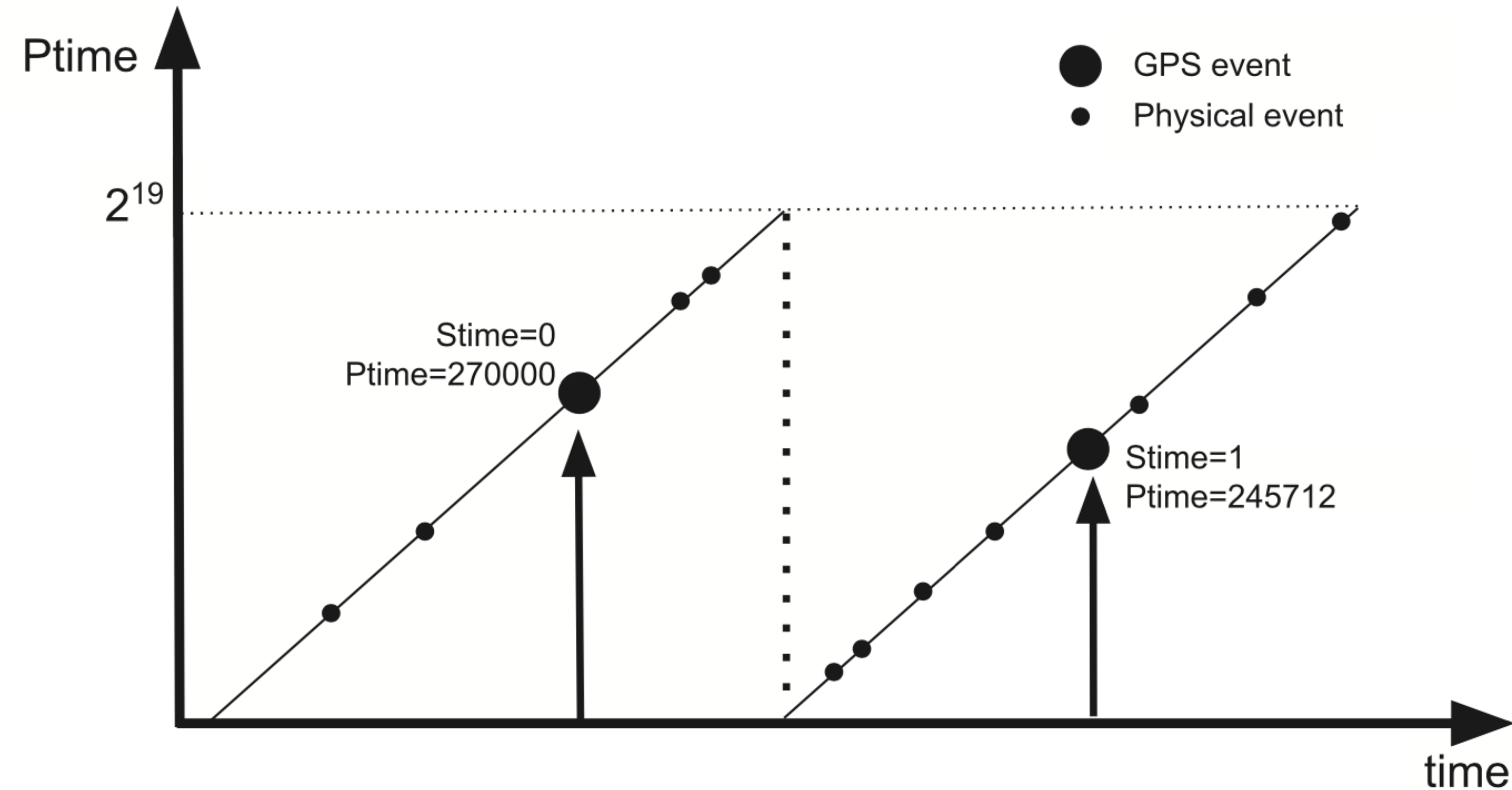
- **High Stability Time Unit (HSTU)**
  - **5 MHz frequency**
- **Quartz Oscillator**
  - **0.17 MHz**





# Time System of HXMT

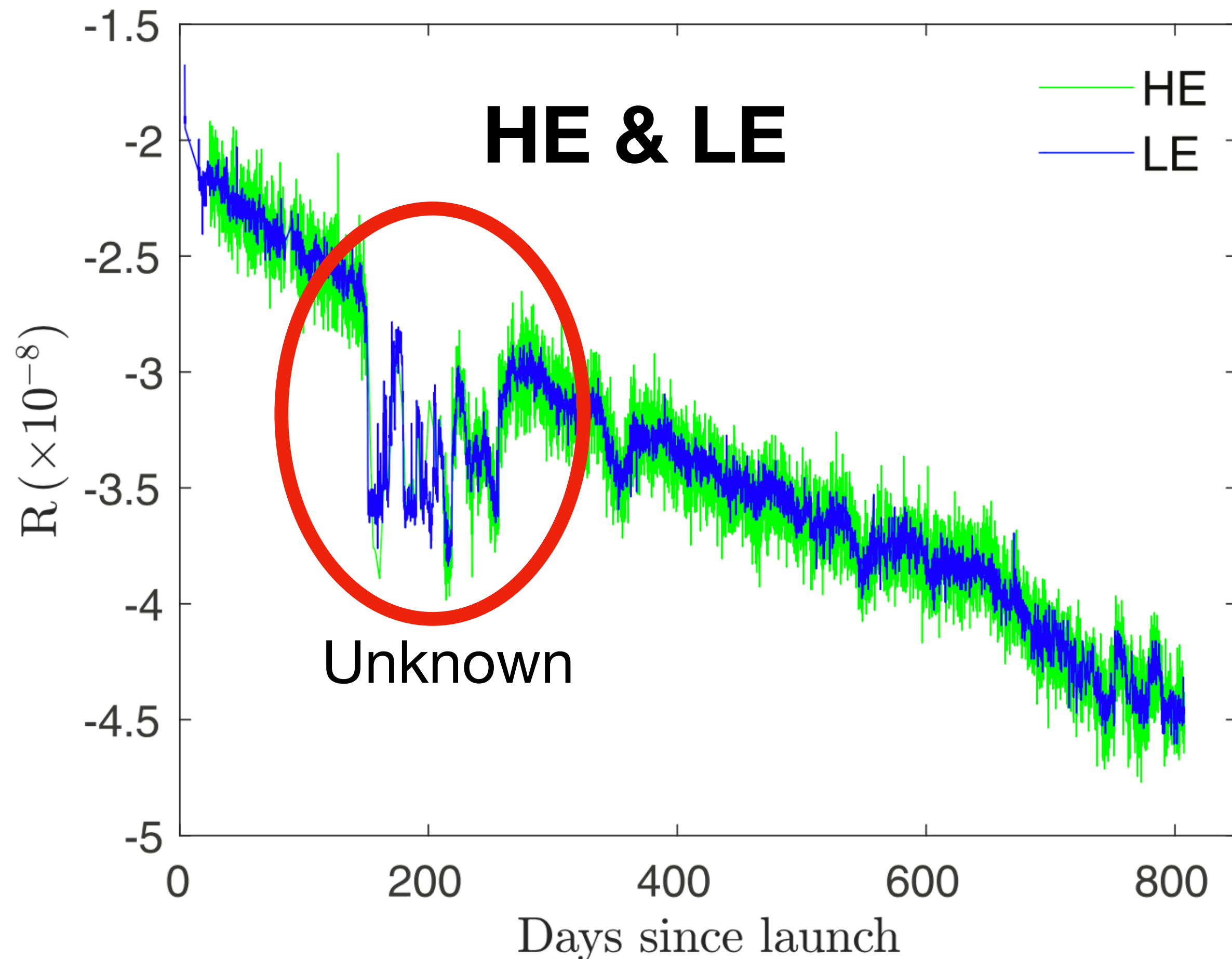
- **High Stability Time Unit (HSTU)**
  - 5 MHz frequency
- **Quartz Oscillator**
  - 0.17 MHz
- **Time assignment of Events**
  - **GPS Receiver --> Pulse per Second**
  - **local clock --> fraction part of time**
  - **Event time = PPS + fraction part**



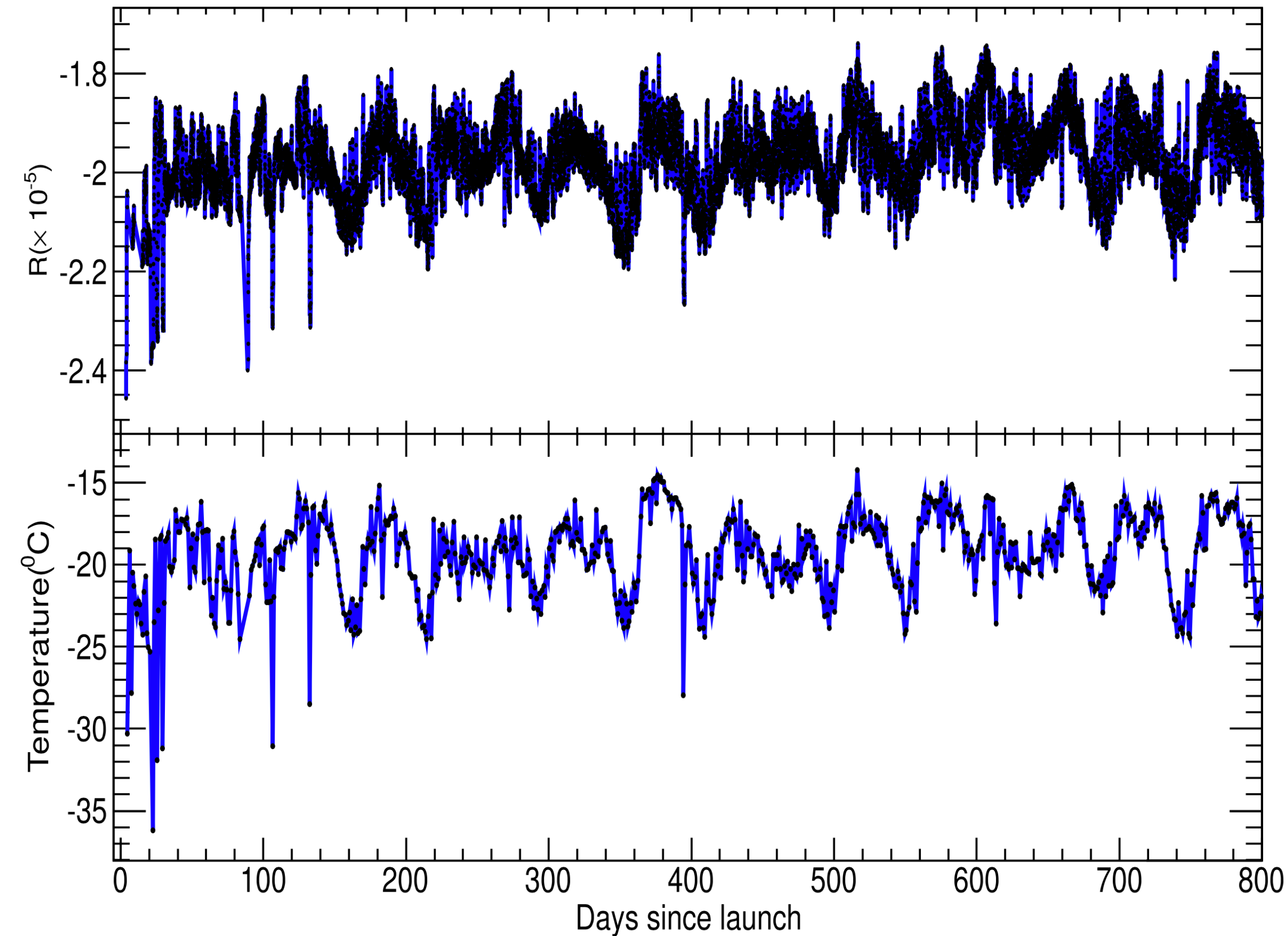
# Correction of the Arrival times of Events

- Long-term variation of local clock
- ME: no temperature-compensated crystal oscillator

$$R = \frac{\tau - \tau_0}{\tau_0}$$



**ME**

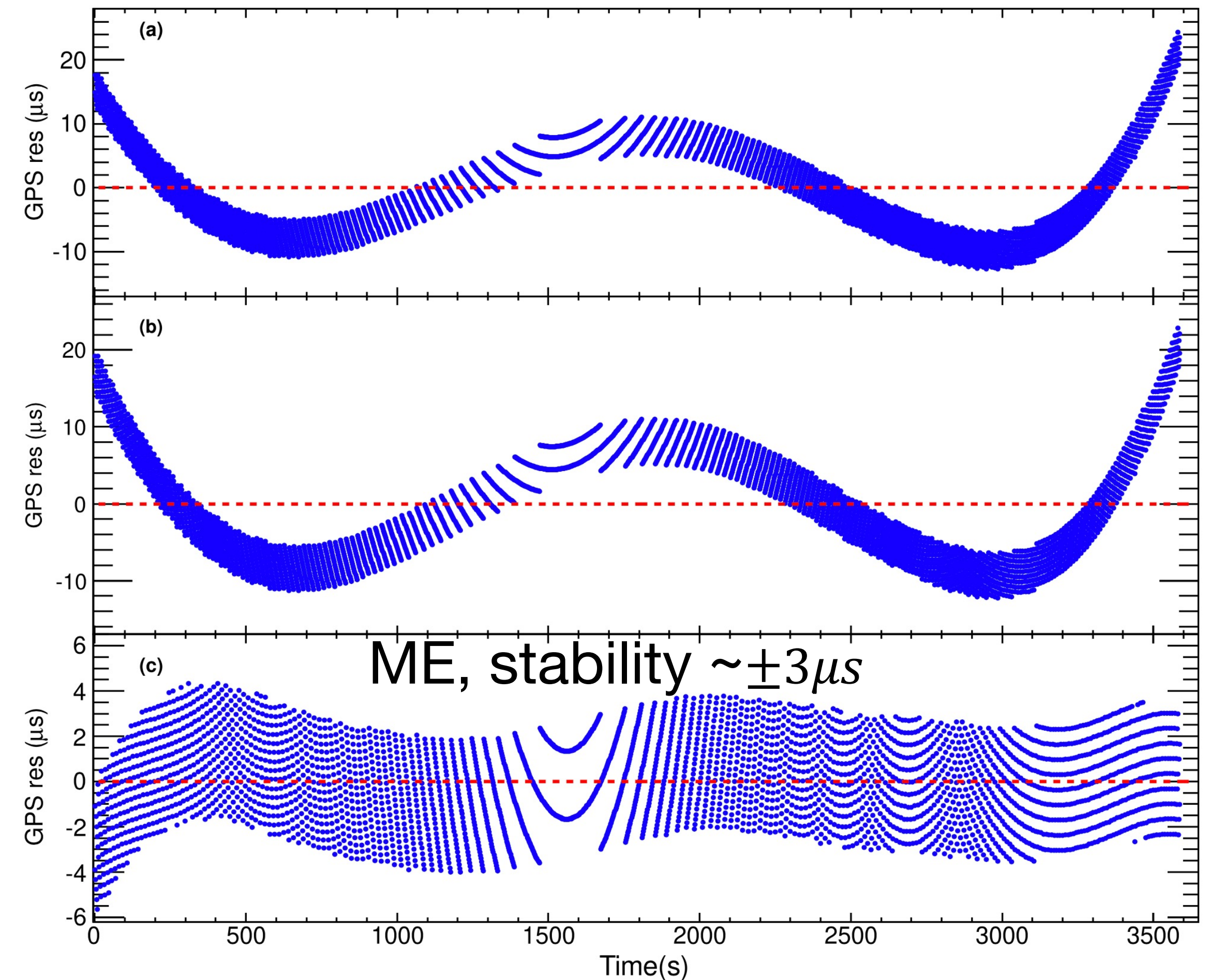
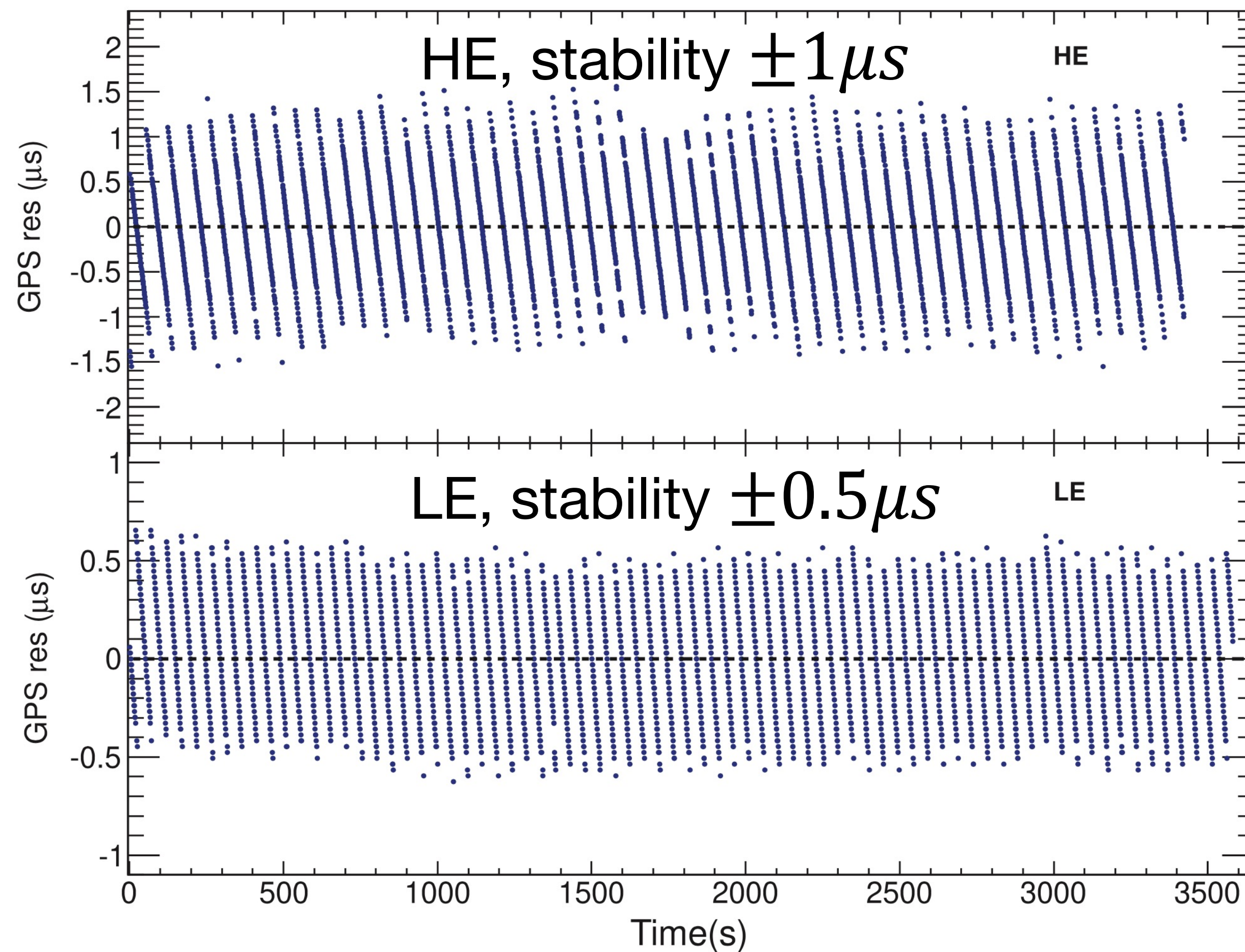




# Correction of the Arrival times of Events

- synchronize the GPS 'pulse per second' with the local clock signal
- introducing the higher order term for local clock evolution

$$S = S_0 + \tau(N - N_0) + \frac{1}{2} \dot{\tau}(N - N_0)^2 + \frac{1}{6} (N - N_0)^3 + \dots$$





# Performance and absolute timing

- Observe the stable pulsar
  - Crab pulsar, ~~PSR B1821-24~~, ~~PSR B1937+21~~ (too faint for HXMT)
- quasi-simultaneous observations with NICER

The Quasi-simultaneous Observations of the Crab by Insight-HXMT and NICER

HXMT-Obs_ID	Start (UTC)	Stop (UTC)	NICER-Obs_ID	Start (UTC)	Stop (UTC)
P0111605001	2017-11-09T04:03:40	2017-11-10T00:55:03	ni1013010109	2017-11-09T10:17:39	2017-11-09T10:21:25
P0111605002	2017-11-10T16:39:27	2017-11-11T00:47:15	ni1013010110	2017-11-10T17:22:06	2017-11-10T20:42:54
P0111605003	2017-11-11T16:31:37	2017-11-12T00:39:35	ni1013010111	2017-11-11T10:27:10	2017-11-11T10:36:03
P0111605004	2017-11-12T16:23:59	2017-11-13T00:32:07	ni1013010112	2017-11-12T14:16:03	2017-11-12T14:23:31
P0111605005	2017-11-13T16:16:35	2017-11-14T00:24:54	ni1013010113	2017-11-13T13:26:45	2017-11-13T23:57:07
P0111605006	2017-11-14T16:09:27	2017-11-15T00:17:59	ni1013010114	2017-11-14T00:13:49	2017-11-14T23:23:31
P0111605007	2017-11-15T16:02:39	2017-11-16T00:11:27	ni1013010115	2017-11-15T00:38:16	2017-11-15T23:49:56
P0111605008	2017-11-16T15:56:18	2017-11-16T20:43:06	ni1013010116	2017-11-16T01:21:04	2017-11-16T23:00:20
P0111605009	2017-11-17T15:50:26	2017-11-17T20:53:02	ni1013010117	2017-11-17T00:30:30	2017-11-17T12:54:22
P0111605010	2017-11-18T15:45:02	2017-11-18T20:41:24	ni1013010118	2017-11-17T14:24:10	2017-11-17T23:43:24
P0111605011	2017-11-19T15:40:00	2017-11-19T20:27:01	ni1013010119	2017-11-18T01:14:29	2017-11-18T22:53:48
P0111605012	2017-11-20T15:34:53	2017-11-20T19:17:12	ni1013010120	2017-11-19T00:24:55	2017-11-19T23:47:12
P0111605013	2017-11-21T17:04:41	2017-11-21T22:06:55	ni1013010121	2017-11-20T01:14:37	2017-11-20T19:51:15
			ni1011010301	2017-11-20T15:28:39	2017-11-20T16:58:08

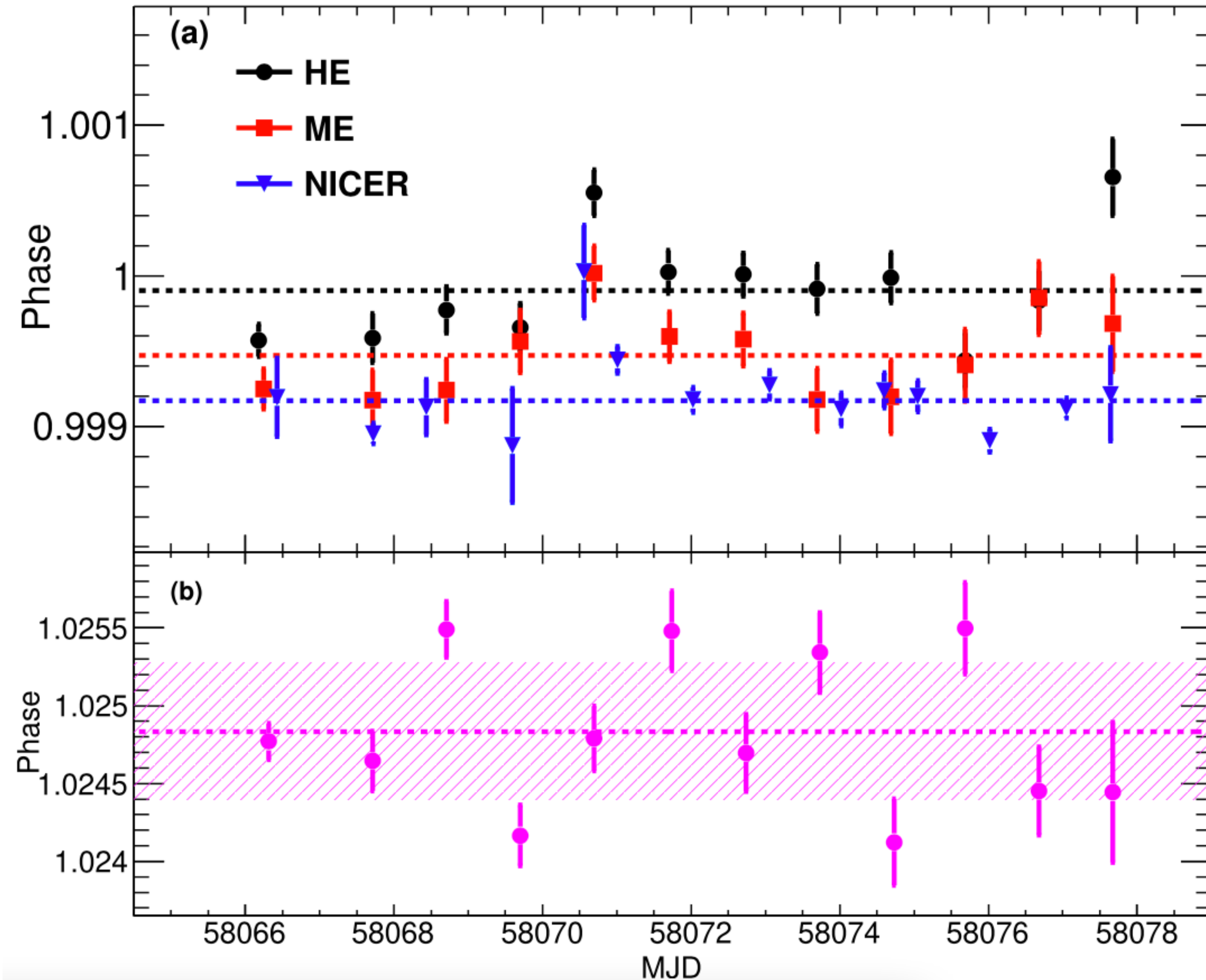
# Performance and absolute timing

- barycentric correction
  - JPL-DE405
- Epoch folded by Jodrell Bank Ephemeris
- Systematic Error by solving
  - $\sum_{i=1}^N \frac{(X_i - \bar{X})^2}{\sigma_i^2} = N - 1$
  - $\sigma_i^2 = \sigma_{\text{sys}}^2 + \sigma_{\text{stat},i}^2$
  - $\bar{X} = \sum_{i=1}^N X_i \times w_i$ ,  $w_i = \frac{1/\sigma_i^2}{\sum_{i=1}^N (1/\sigma_i^2)}$

**Table 4**

The Timing Errors of Insight-HXMT Payloads with Respect to NICER

Payloads	Mean Phase	Systematic Error ( $\mu\text{s}$ )	Statistic Error ( $\mu\text{s}$ )	Offset ( $\mu\text{s}$ )
NICER	0.999172	5.5	0.9	0
HE	0.999904	12.1	1.5	24.7
ME	0.999472	8.6	1.9	10.1
LE	1.02483	15.8	2.1	864.7

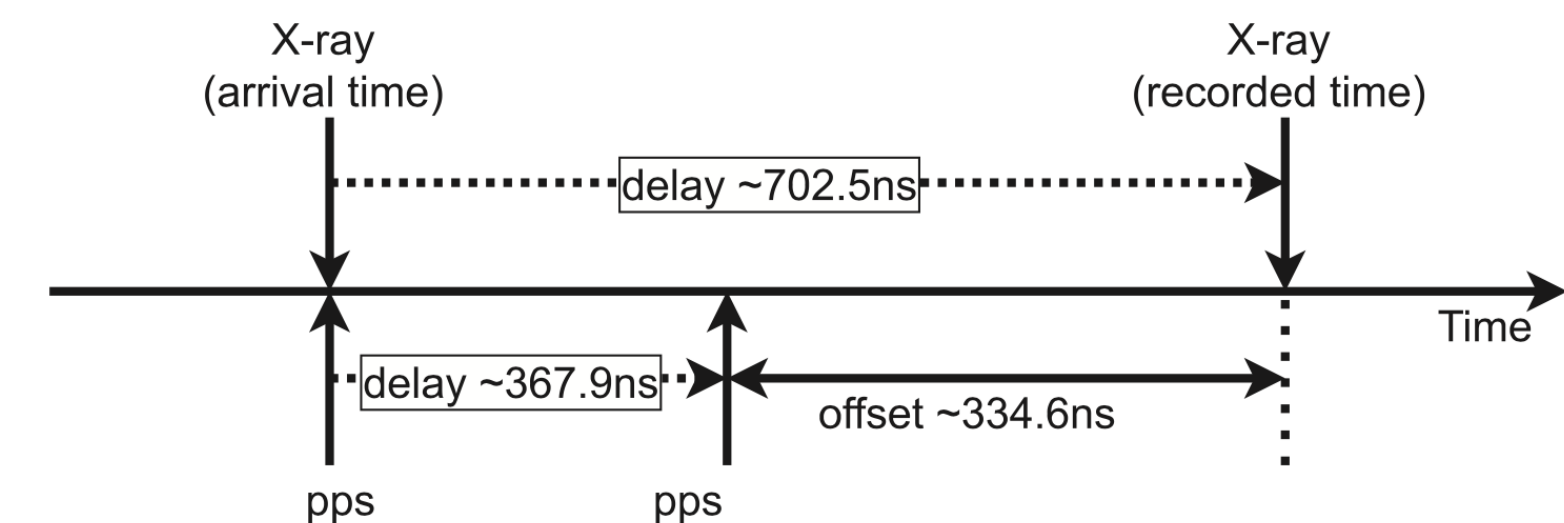
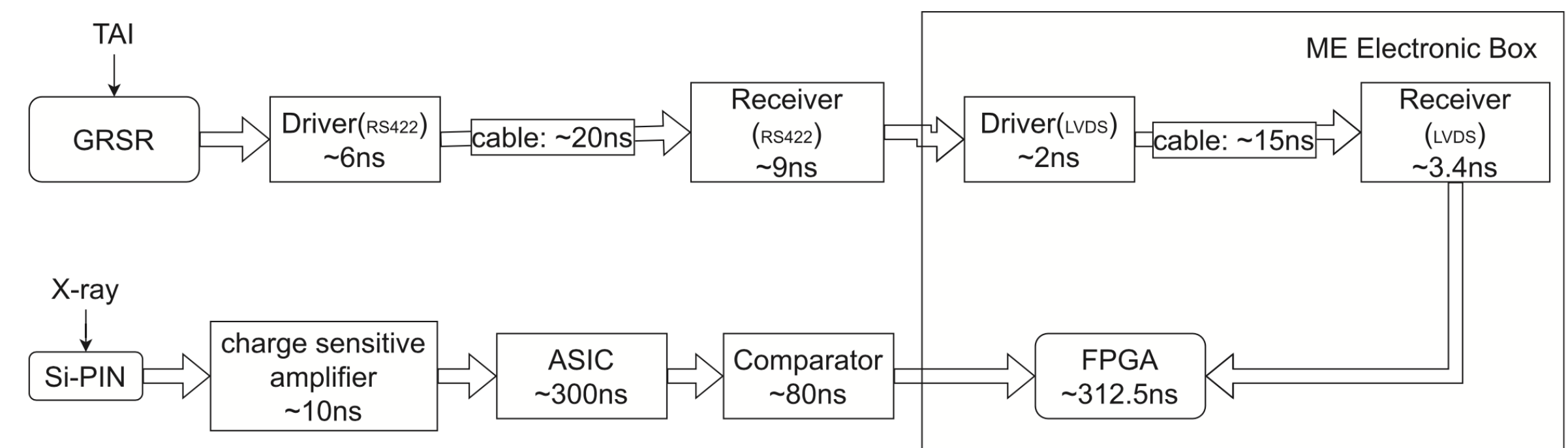
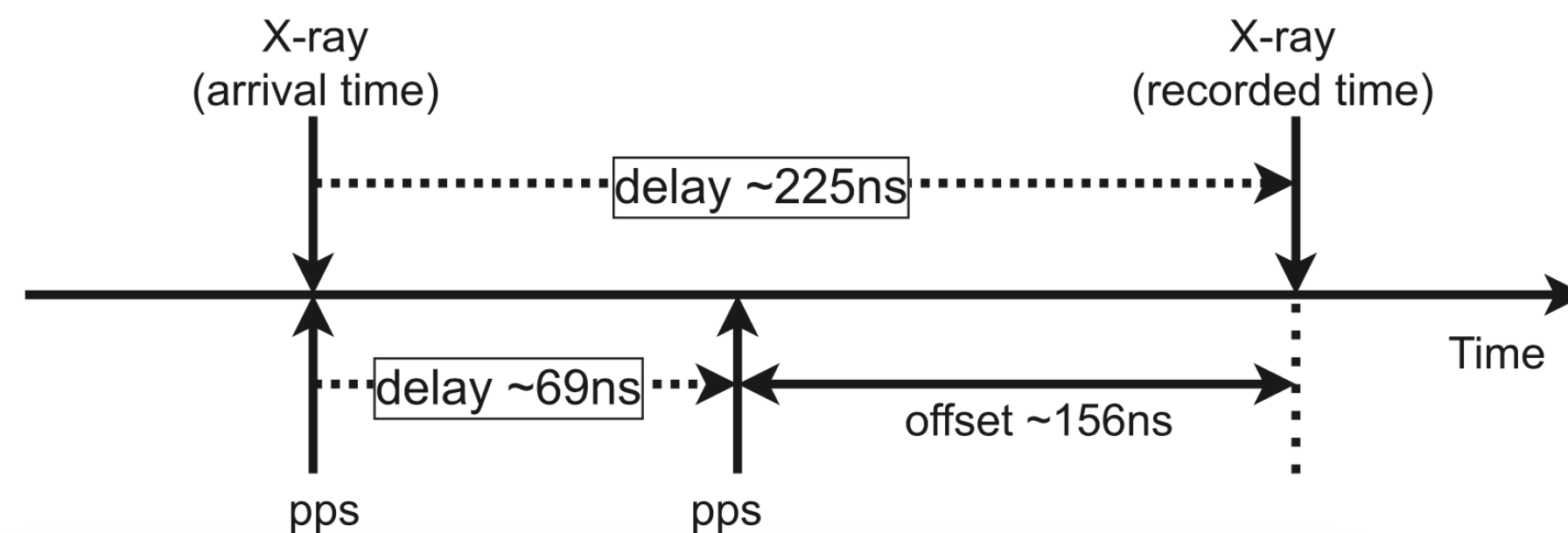
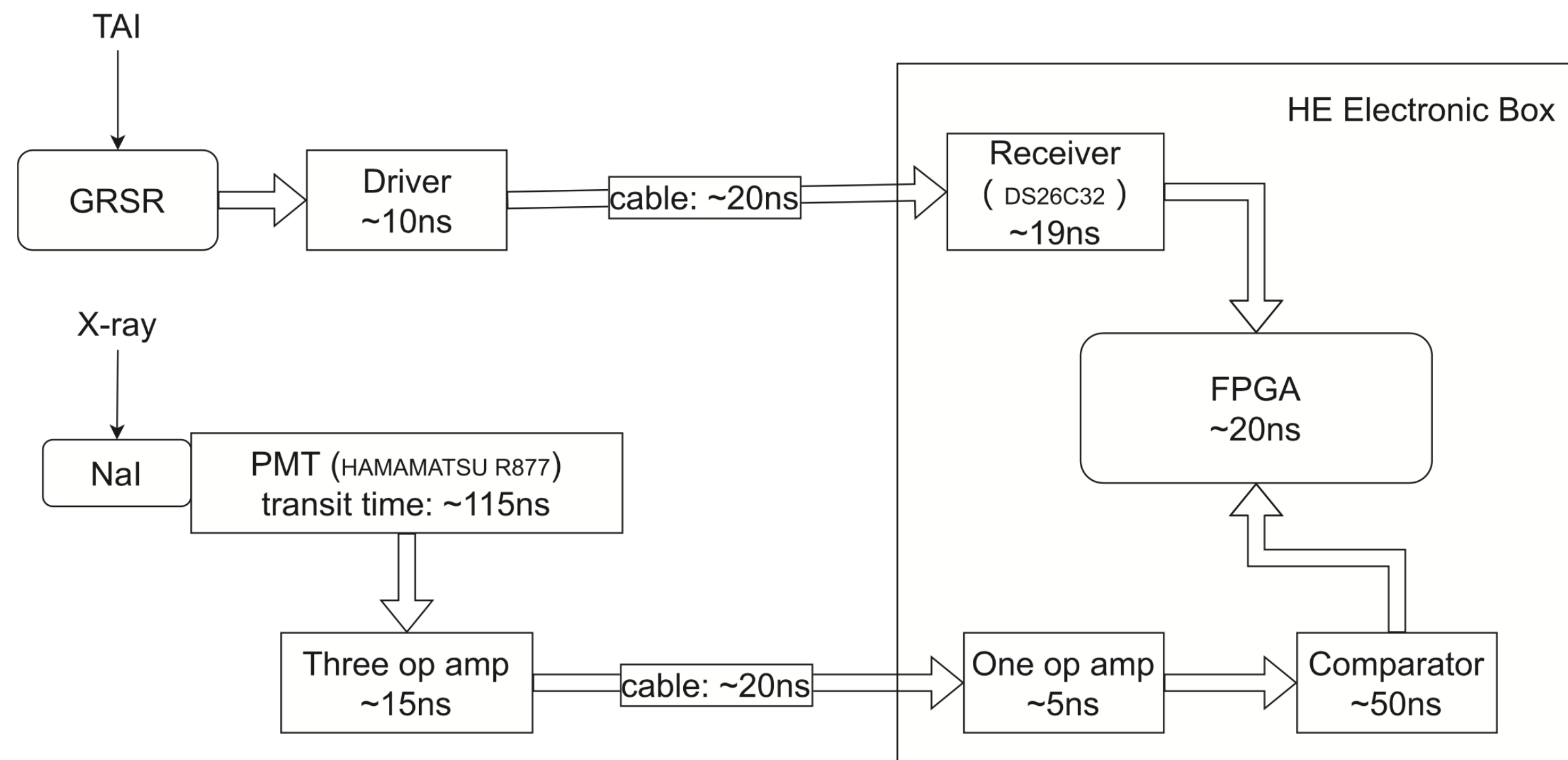


offset is due to instrumental effect or intrinsic of the pulsar?



# Instrumental delay

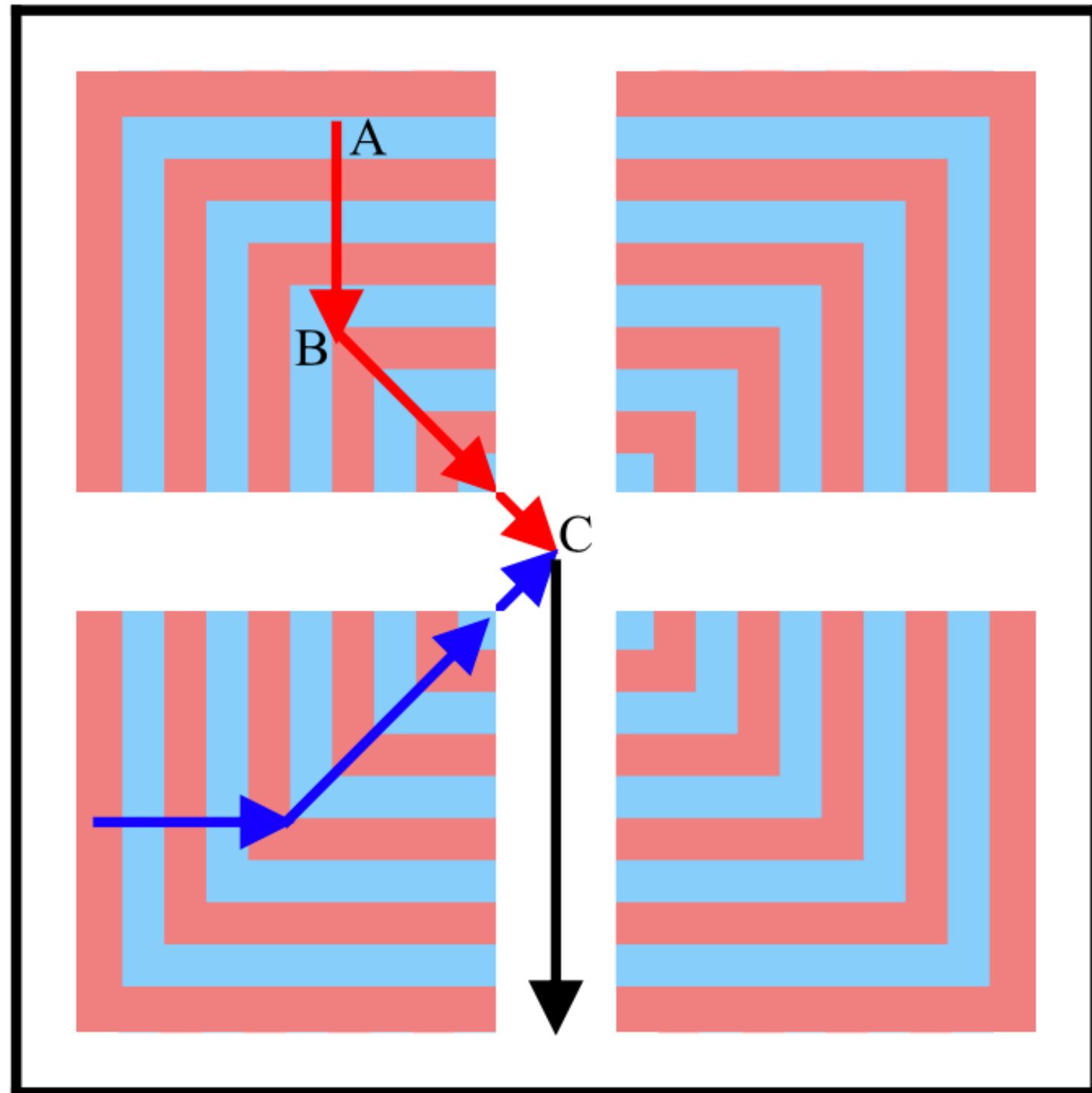
- No ground calibration
- Accumulate each 'typical' response time of each electronic device



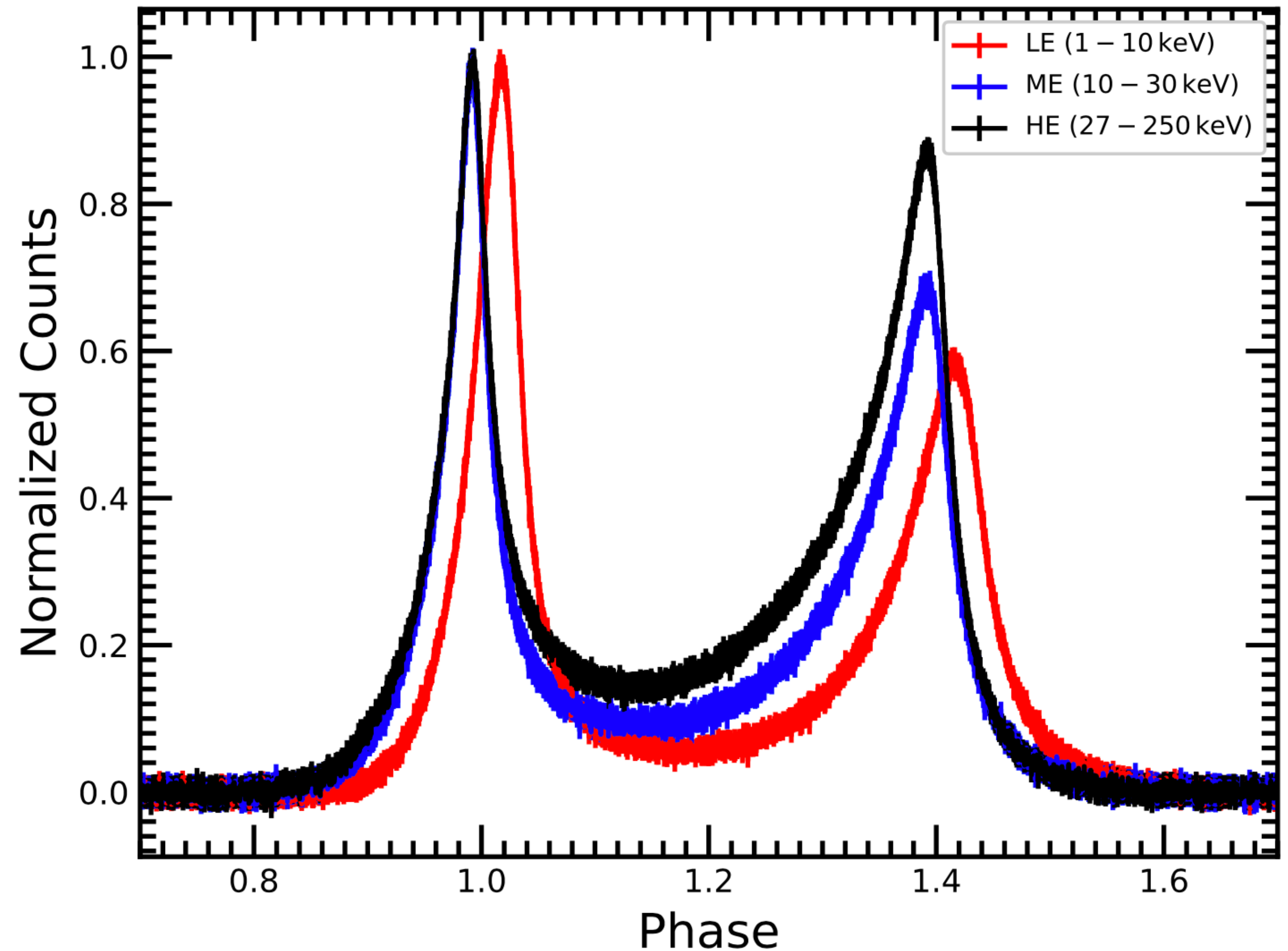


# Instrumental delay

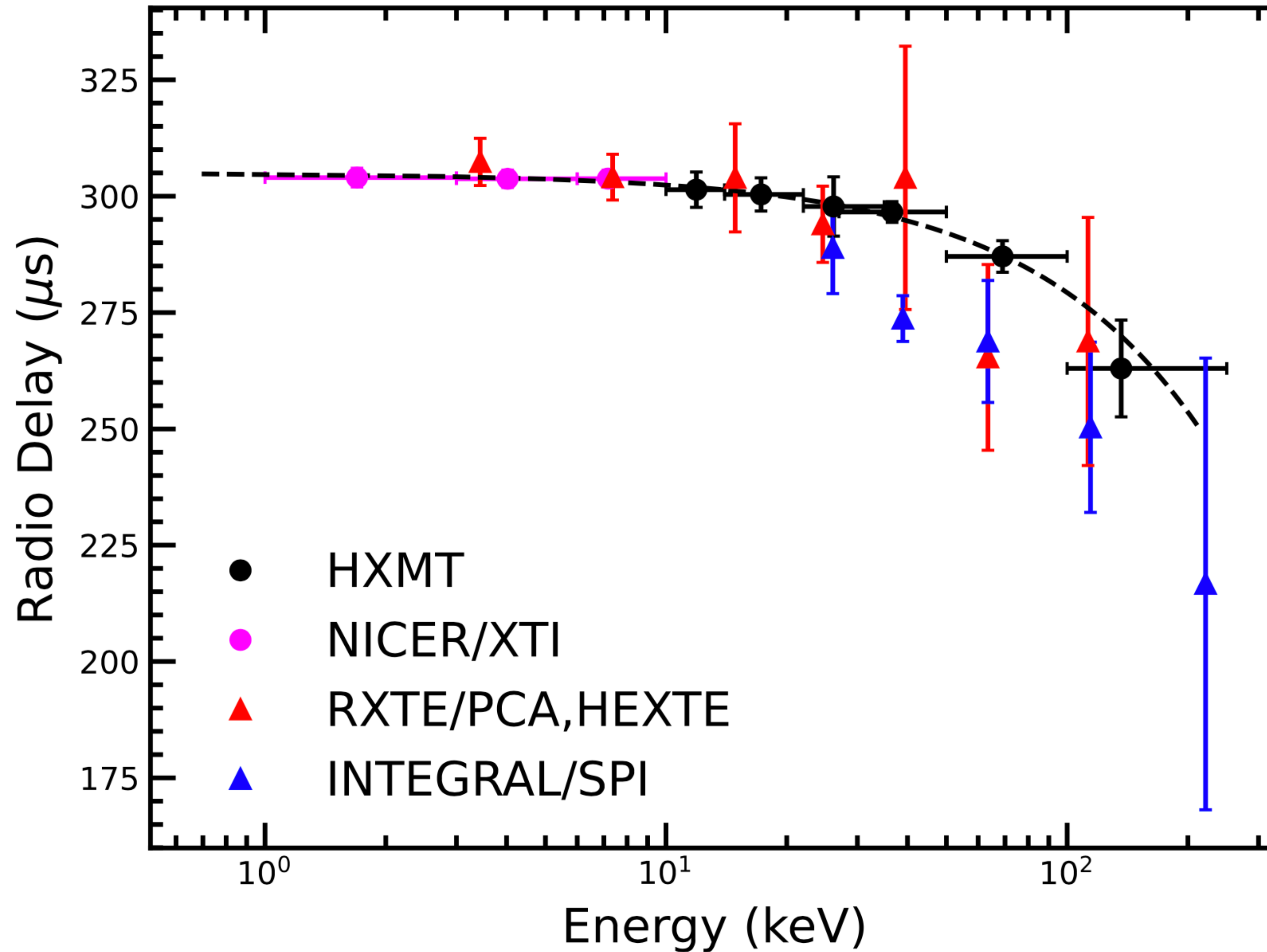
- HXMT/LE Swept charge device (SCD)
  - low pileup effect
  - readout delay  $\sim 856\mu\text{s}$



Effects on timing products, refers to  
Zhao et al. 2019  
Zhou et al. 2021



# Crab Main peak delay





# Summary

- systematic error of HXMT timing system
  - HE:  $12.1\mu s$
  - ME:  $8.6\mu s$
  - LE:  $15.8\mu s$
- Instrumental offset with respect to NICER
  - HE:  $24.7\mu s$ , ME:  $10.1\mu s$ , LE:  $864.7\mu s$
- Lessons we learned
  - on-ground timing calibration was not sufficient for HXMT





# Backup



- JPL-DE200
- Position -- Radio measurement

