IACHEC Timing WG report

Presented by

Yukikatsu Terada (Saitama U. & JAXA)

Timing WG members (Nov 2021)

Update from May 2021

Yukikatsu Terada (Suzaku,Hitomi, XRISM),
Craig Markwardt (NICER),
Teruaki Enoto (NICER),
Matteo Bachetti (NuSTAR),
Katja Pottschmidt (NuSTAR),
Felix Fuerst (XMM-Newton),
Simon Rosen (XMM-Newton),
Vinay Kashyap (Chandra),
Arnold Rots (Chandra),
Amy Lien (Swift),
Giancarlo Cusumano (Swift),
Guillaume Belanger(INTEGRAL),
Volodymyr SAVCHENKO(INTEGRAL),
Lucien Kuiper(INTEGRAL)
Xiaobo LI (HXMT),
Gulab Dewangan (Astrosat),
Dipankar Bhattacharya(Astrosat)
Michael Freyberg (eROSITA),
Makoto Sawada(XRISM),
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Minami Sakama (XRISM)

Timing WG communication

No Update

ML: iachec-time@heal.phy.saitama-u.ac.jp
SLAC: iachec.slack.com #timing
Wiki: https://wikis.mit.edu/confluence/display/iachec/Timing

→ Please contact Yuki to join ML; terada@mail.saitama-u.ac.jp

Goal of the Timing WG

No Update (remind)

1. **Share information on Timing calibration methods/protocol, lessons learned (to enhance timing capability)**
   - Suzaku, Hitomi (2017, 2018, 2019)
   - NuSTAR(2019), NICER (2018)
   - HXMT(2018), Astrosat
   - eROSITA
   - Future missions (XRISM, Athena, etc)

14th IACHEC in Shonan Japan

2. **In-orbit timing calibration plan/observations/studies**
   - Discussion on calibration plans for near future missions
   - Perform timing coordinated observations // Coordinated Observation WG
   - Analyses of GO coordinated observations (using archive data) // with Cal. Stat. WG
3. **Studies on Timing products**
   - Systematic studies on the effects fot timing products (power spectrum, light curve etc) by the detector’ s behavior (dead time, grade selection of calorimeter etc)
   - Timing Tool // collaboration with Cal. Stat. WG

Update from May 2021

Activities in 2020-2021

Timing WG telecom

- 28 April 2020
- 15 Sep 2020
- 20 April 2021
- 12 May 2021
- 13 Oct 2021
  - Meeting notes (PDF) are available on the timing WG wiki page https://wikis.mit.edu/confluence/display/iachec/Timing

Major activities

1. Summary of timing calibration/performance of multiple missions (Goal 1)
   update
2. Systematic study of Crab timing using archive data among instruments (Goal 2)
   update
3. Effects of dead time / grade selection etc on timing products (Goal 3)
   new/to be active soon

Update from May 2021

#1. Summary of timing calibration/performance

Organizer: Yuki Terada
Output: see https://wikis.mit.edu/confluence/display/iachec/Timing
Instruments:

- RXTE PCA, HEXTE (calibration target ; updated)
- Chandra ACIS, HRC
- XMM-Newton EPIC-PN , ~~EPIC-MOS~~
- INTEGRAL SPI, IBIS
- Swift BAT, XRT
- Suzaku XIS, HXD
- NuSTAR FPM
- Fermi LAT, GBM
- AstroSat LAXPC, CZTI
- Insight-HXMT (Newly added)
- Hitomi SXS, SXI, HXI, SGD
- NICER XTI
- SRG eROSITA
- XRISM Resolve, Xtend

#1. Summary of timing calibration/performance

Discussed

Columns on the table:

- Science Requirement Absolute Time (Requirement & Goal)
- Timing System Design (GPS yes/no, Clock Stability)
- Timing Calibration Status (Timing offset, deviation, notes)
- In-orbit Timing Calibration Targets
- Reported Issues
- Reference

Note:

- The values on the table comes from the various published papers;
  i.e., they do not come from a systematic study like item #2.
  → The definition of the timing accuracy and offset are different among instruments.
  For example, some instruments refer the radio arrival time,
  but others refer the absolute timing.
- The detail description is available in the "note" column.
  (we are gathering information, still)

- We plan to keep maintenance of this summary table.

Update from May 2021

The Table (1/3) https://wikis.mit.edu/confluence/display/iachec/Timing

Mission/Instruments	Science Requirement Absolute Time		Timing System Design		Timing Calibration Status			In-orbit Timing Calibration Targets	Reported Issues	Reference
	Requirement	Goal	GPS Receiver	Clock Stability	Offset	Deviation, sigma	Notes			
RXTE/PCA ⭐	10μsec	none	No		Calibrated: < 3.4 μsec Uncalibrated: < 100 usec (Absolute, not relative to radio)	Calibrated: 3.4 μsec Uncalibrated: ~50 usec	Calibration: Spline-based calibration against ground timing standards, including ground time assignment error. Uncalibrated: Mission operations maintained on-board clock to within 100 usec of UTC using clock frequency steering	PSR B1821-24 60 μsec	Before 1997-04-29, increased timing jitter 8 μsec	rxte_time.html Timing Budget Jahoda et al. 2006 (10.1086/500659) PSR B1821 Rots et al. 1998 (10.1086/305836) Crab Rots et al. 2001 (10.1086/420842)
RXTE/HEXTE⭐	10 μsec	none			See above	See above	Event by event has 7.6 μsec resolution. "the HEXTE absolute time reference is accurate within a fraction of a millisecond. (10.1086/305377)"	delay 0-1 μsec (corrected?)	None	HXTE Timing (10.1086/305377)
Chandra/ACIS	0.25625 s (one minor frame start time)	0.001 s (synchronize minor frame starts)	No (sync DSN)	3.2 μsec	285 ± 6 μsec				None at present	Davis et al. 2003 (davis.pdf)
Chandra/HRC		16 μsec			4 ± 4 μsec			Crab PSR B1821-24	Note: Precision relative to RXTE. Due to a wiring problem, photon time tag gets attached to next event; correctable under special mode for HRC-S which telemeters all events and then reassigns times on the ground.	Davis et al. 2003 (davis.pdf) Rots 2006 (CXOClock.pdf)
XMM-Newtion/EPIC-PN	1 ms	none	No	-	-354±11 μsec	108 μsec (1 sigma)	Note: Timing = -306 +/- 16 μsec, Burst = -387+/-13 μsec. Timing mode is affected by pile up. Note: XMM-Newton EPIC-MOS was deleted from the table.	Crab pulsar (bi-annual)	None currently	Kirsch et al, SPIE, 5165, 85 (10.1117/12.503559) Martin-Carrillo et al, A&A, 545, A126 (2012) (10.1051/0004-6361/201116576) ~~CAL-TN-0220-1-4.pdf (Limited access)~~ CAL-TN-0220-1-5.pdf

Continue.

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The Table (2/3) https://wikis.mit.edu/confluence/display/iachec/Timing

INTEGRAL/SPI										L.Kuiper 2003 (10.1051/0004-6361:20031353) L.Kuiper 2019 (13th IACHEC PDF)
INTEGRAL/IBIS					-248±2 μsec	61 μsec	Offset is w.r.t. radio main-pulse using ISGRI 20-100 keV data collected during INTEGRAL Revolutions 47 - 1877 (last date Oct. 23, 2017); Jodrell Bank radio eph. folding			same above
Swift/BAT	100 ms	100 usec	No	~ 6.572 x 10^-8 s/s	Uncalibrated: tens of seconds Calibrated: ~50 μs	Uncalibrated: N/A Calibrated: ~ 50 μs	BAT instrument has 100 usec time-stamping quantization, which is dominant term in uncertainty. Offset is found by comparing RXTE PCA and Swift BAT observations of Crab (Cusumano et al 2012) Clock measurements made by mission operations & ground station, and applied as calibration when barycentering.	Crab pulsar (annual)	None at present	G. Cusumano et al 2012 (10.1051/0004-6361/201219968) BAT team wiki page; private communication with Michael Tripicco see BAT Wiki: Pre-launch Timing, BAT Wiki (410.4-SPEC-0005F.pdf) (Limited Access)
Swift/XRT	~ 10 ms		No			~ 270 μs	Clock measurements made by mission operations & ground station, and applied as calibration when barycentering.	Crab pulsar	None at present	G. Cusumano et al 2012 (10.1051/0004-6361/201219968) D. Burrows et al. 2005 (10.1007/s11214-005-5097-2)
Suzaku/XIS⭐	No science requirement defined.		No (sync. ground)	1.9 x 10^-9 s/s (measured)	Not confirmed.	N/A		A0535+262, Her X-1, etc	N/A	Y.Terada et al 2008 (10.1093/pasj/60.sp1.S25)
Suzaku/HXD⭐					~ 70 μsec	360±150 μsec (90%) (270±130 μsec in condition)	"offset" is defined from the difference from the average arrival time of Crab among X-ray missions and the HXD in the simultaneous observation of Crab.	Crab for coordinated PSR1509-58	Timing shift by a failure in time stamp at the ground station during 2012-2014 (Shu Koyama, Fixed)	
NuSTAR/FPM	Should be 100 ms	none	No	Freely drifting by ~3 ms/day. Reduced to 20 us/day using the clock correction file		65 μs (1-sigma)		Crab B1821-24A B1937+21	~5ms offset using millisecond pulsars (Lucien Kuiper) Corrected through clock correction file v108+	Bachetti+ in prep (can distribute early copy)
Fermi/LAT					-111 ±4μs	57 μs	9 years of LAT data; see also Sci. 334, 69 (2011) for 9 months after launch value of -138 us +/- 12 us +/- 21 us; Jodrell Bank radio eph. folding			
Fermi/GBM (BGO)					-222 ±4μs	56 μs	100-300 keV band; data from Nov-2012 up to incl. Jan-2018; Jodrell Bank radio eph. folding			

Continue.

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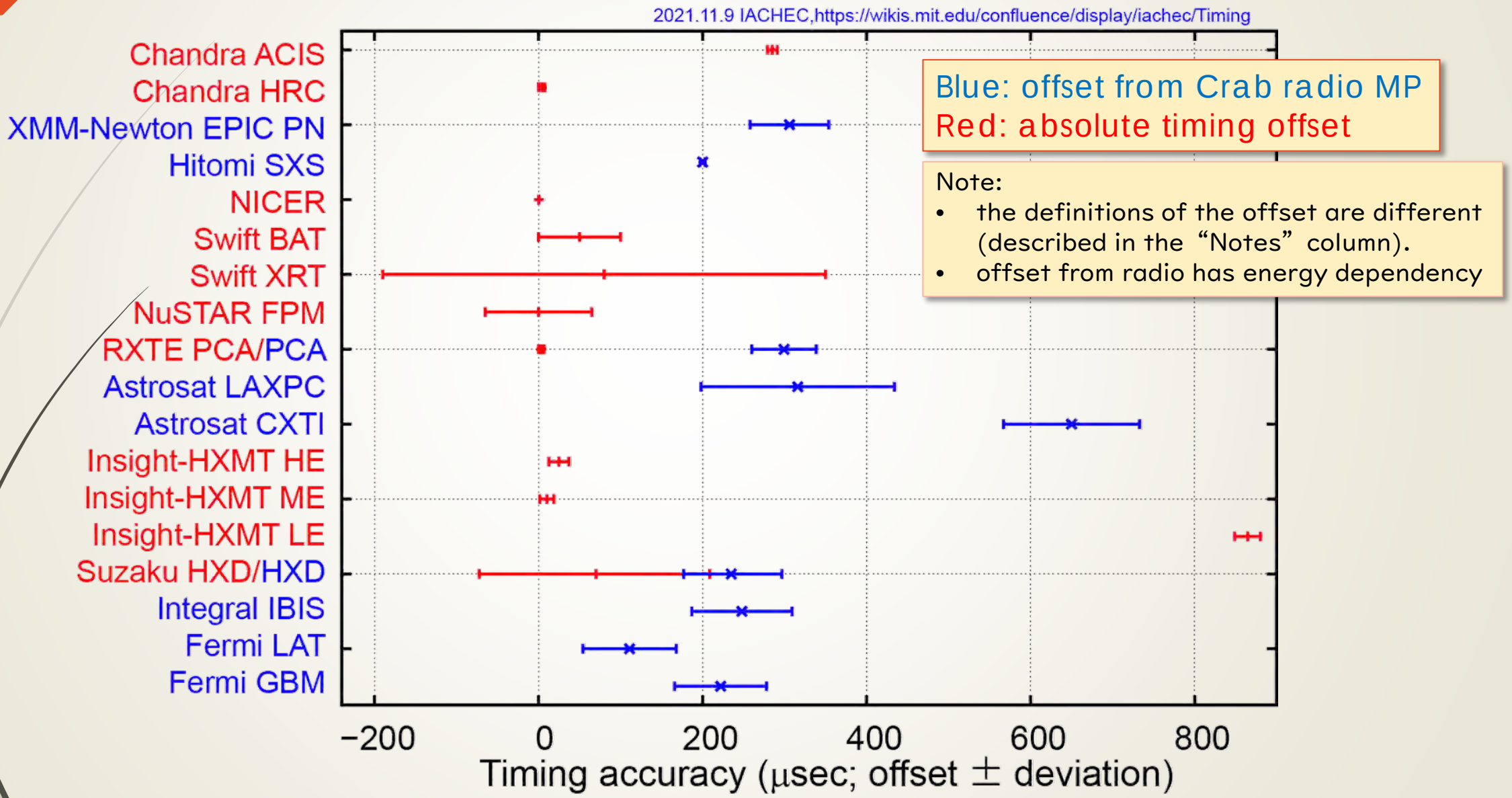
The Table (3/3) https://wikis.mit.edu/confluence/display/iachec/Timing

Fermi/GBM (NaI)										
AstroSat/LAXPC	None defined		Yes (offline referral)	4 μsec rms after GPS synchronization	316 ±70μs	118 μs (rms)	The offset is with respect to Fermi-LAT ephemeris	Crab Pulsar (with Radio)	None at present	D. Bhattacharya 2017 (10.1007/s12036-017-9461-x) Basu et al (in prep)
AstroSat/CZTI	None defined		Yes (offline referral)	3 μsec rms after GPS synchronization	-650 ±70μs	83 μs (rms)	The offset is with respect to Fermi-LAT ephemeris	Crab Pulsar (with Radio) GRBs	None at present	D. Bhattacharya 2017 (10.1007/s12036-017-9461-x) Basu et al 2018 (10.1051/0004-6361/201832913) Basu et al (in prep)
Insight-HXMT/HE			Yes	3 x 10^-8 s/s	24.7 μs	12.1 μs	The offset is with respect to NICER	Crab (with NICER)		Youli Tuo et al 2021 (https://arxiv.org/abs/2109.04709)
Insight-HXMT/ME					10.1 μs	8.6 μs	The offset is with respect to NICER			
Insight-HXMT/LE					864.7 μs	15.8 μs	The offset is with respect to NICER			
Hitomi/SXS, SXI, HXI, SGD⭐	350 μsec	35 μsec	Yes	0.01μsec(GPSR) <3.0 μsec(SpW) 0.3 ns (orbit)	~ 120-230 μsec	<3.0 usec (3 sigma)		Crab (with radio) note: using out-of-time event for SXI	absolute timing accuracy is much larger than expected on ground (3 μsec)	Y.Terada et al 2018 (10.1117/1.JATIS.4.1.011206)
NICER/XTI	100 ns (RMS)	none	Yes	N/A	Uncalibrated: 1 second Calibrated: Approx <3 us based on Crab Calibrated: Measured <400 ns based on ground cal (Absolute, not relative to radio)	100 ns (RMS) [requirement]	The NICER XTI timing system was calibrated on ground using an end-to-end system, with GPS simulator and precision X-ray pulse generator. Detector + system time delays of ~400 ns are included in the calibration. Combined error / noise terms designed to be < 100 ns (including GPS, X-ray detection, barycentering) Absolute timing offset values depend on the definition of absolute timing. See supplementary material of this paper(https://science.sciencemag.org/content/372/6538/187), Figure S12 and S13 [p.33-34] for the NICER Crab X-ray main peak monitoring. At this stage, it is not clear whether the fluctuation of the peak phase is due to the instrumental effects or due to intrinsic of the pulsar.	Crab Pulsar PSR B1821-24A PSR B1937+21	Precise 1-second offset in on-board timestamps due to flight software bug; corrected using TIMEZERO keyword in pipeline-processed FITS data files. (see HEASARC page for detail)	Markwardt et al. (in prep.)
eROSITA										
XRISM/Resolve ★	1 msec	none	Yes	same as Hitomi	<1 ms	<1 ms	the values (1 msec) are the requirement including both offset and deviation.	(under discussion)		See In-flight Calibration Plan in IACHEC 2021 virtual meeting; xrism_ifcp_iachec_20210416.pdf
XRISM/Xtend ★	10 msec	none	Yes		< 10 ms	< 10 ms	the mission requirement values.	(under discussion)		

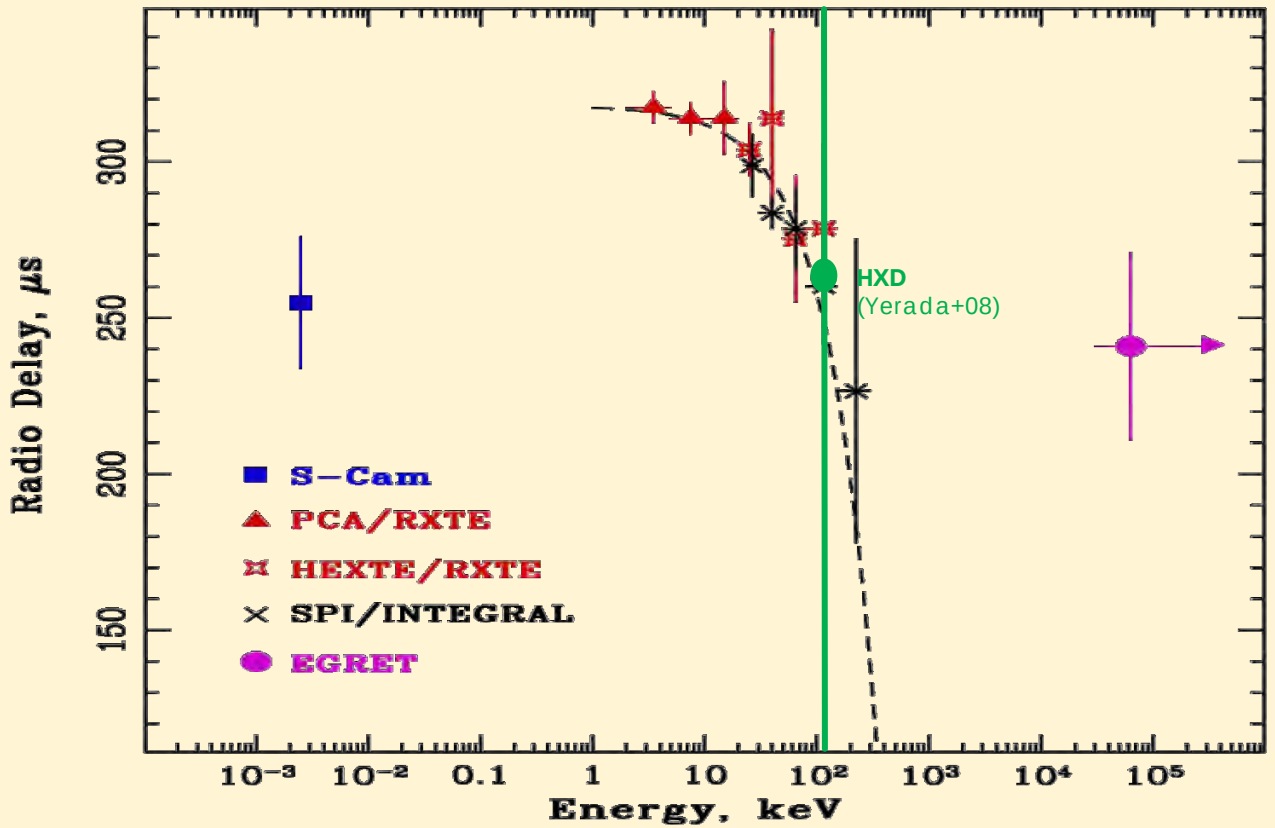
Update from May 2021

Fig. Timing Calibration status (offset ± deviation)



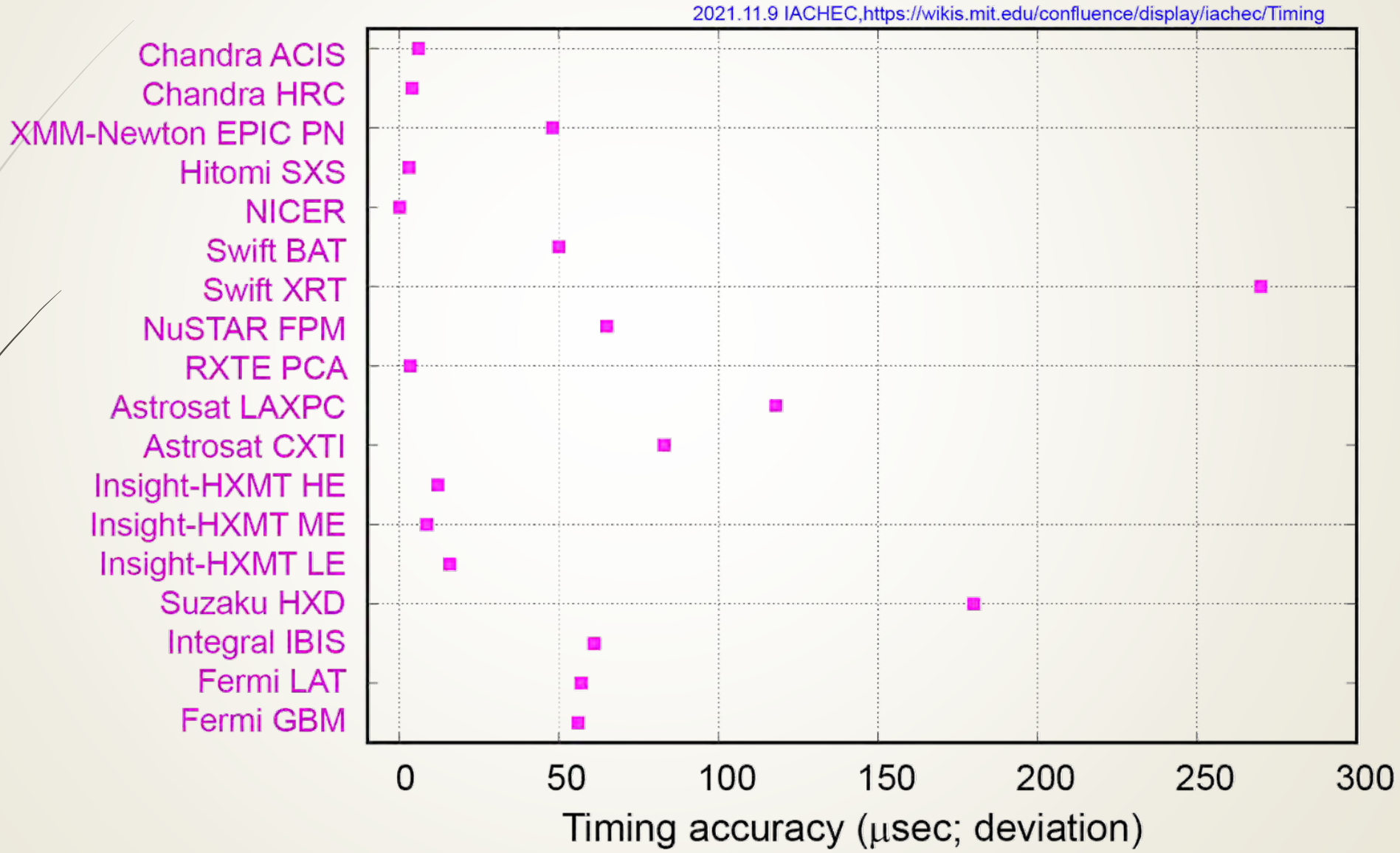
Ref) The energy dependency of the intrinsic timing delay from the radio main pulse of Crab

Molkov, Jourdain, Roques 2010



Update from May 2021

Fig. Timing Calibration status (deviation) ;



Update from May 2021

Summary of Timing Calibration Objects

In-orbit calibration objects	Mission
Crab	Chandra/HRC, XMM-Newtion/EPIC-PN, Swift/BAT, Swift/XRT, Suzaku HXD, NuSTAR/FPM, AstroSat/LAXPC , AstroSat/CZTI, Hitomi/SXS, Hitomi/HXI, Hitomi/SGD, NICER/XTI, HXMT
PSR B1937+21	Chandra/HRC, NuSTAR/FPM, NICER/XTI
PSR B1821-24A	RXTE/PCA NuSTAR/FPM, NICER/XTI
PSR B1509-58	Suzaku/HXD
GRB	AstroSat/CZTI
A0535+262, Her X-1, etc	Suzaku/XIS

Update from May 2021

#2. Comparison of Crab ephemeris

Organizer: Matteo Bachetti

Purpose:

1. Systematic-timing cross-calibration of instruments using archive data.
2. Systematic check of Timing delay of the Crab main pulse between the X-ray and Radio.
   Note: please see also the presentation by L.Kuiper in 13th IACHEC 2018.

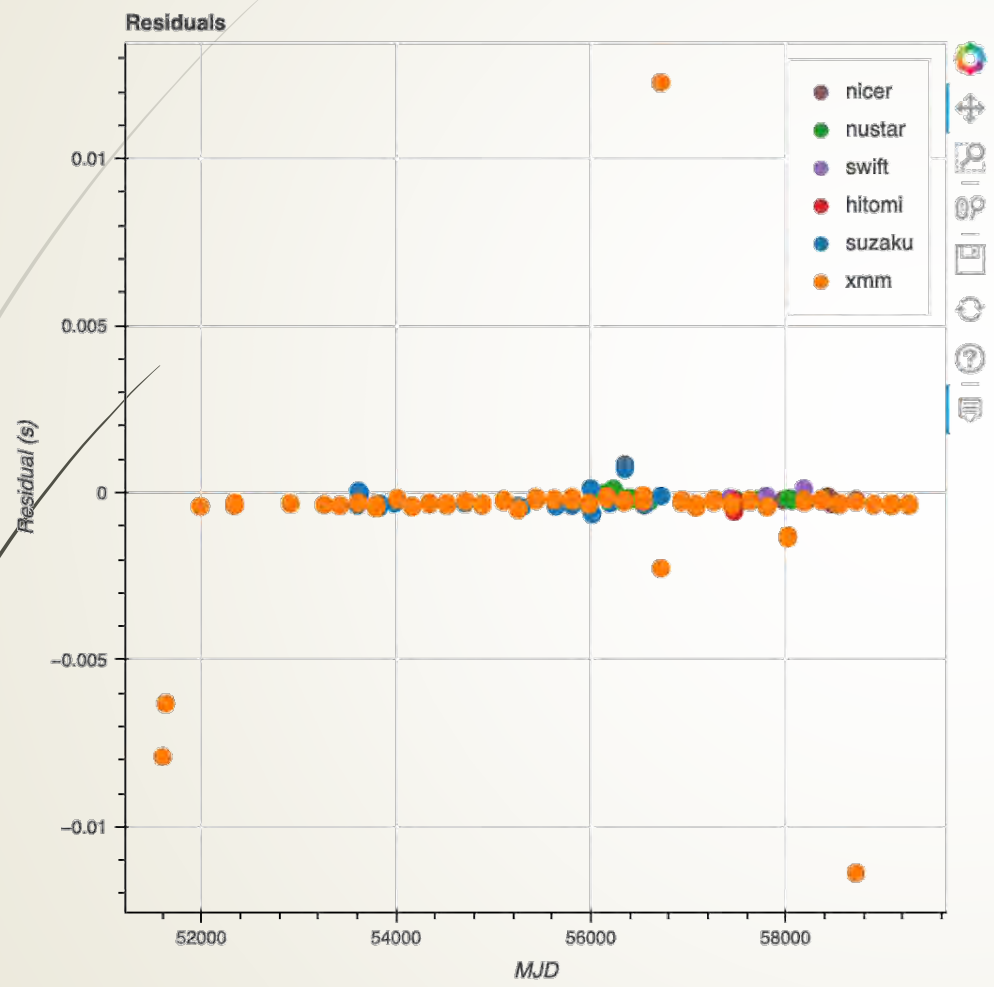
Status:

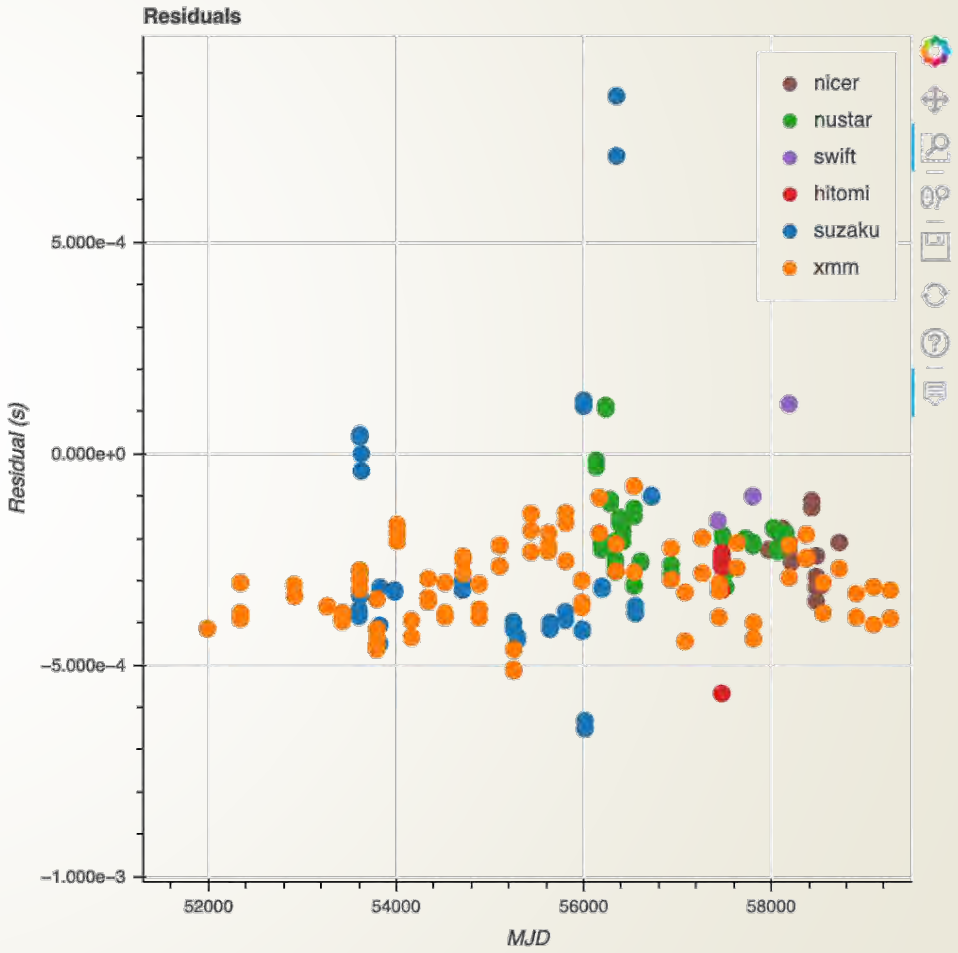
1. We start gathering barycenter event files of the missions;
   - XMM-Newton
   - Suzaku
   - NuSTAR
   - Astrosat
   - Hitomi
   - Swift

   more missions/instruments will be added.
2. Matteo prepared the code to check ephemeris of multiple missions.
   Quick-look result was updated (next page).
   We still gather the event files (or folded light curve) for the study.
3. We see several outliers, which may be due to ground station issues;
   "Known issues" will be also listed ← we are gathering the information.

Update from May 2021

Quick-look results of systematic timing study with Crab © Matteo Bachetti





Plot on 15 Oct 2021

New/Future work

#3 Effects of DAQ behavior on timing products

Organizer: TBA (Yuki)

Purpose:

- check the effect of the following detector's behavior on folded light curve/power spectrum, delta-time spectrum, etc
  a. Time resolution of instruments
  b. Absolute timing accuracy
  c. Dead time (and/or grade selection for calorimeter)
  d. Background events
  e. Good time interval etc

Notes:

Previous works exist on pile-up (Chandra, Suzaku), dead time (NICER, NuSTAR), and time resolution (Hitomi) etc.

Status:

To be active soon!

Please join the WG if you are interested in.

Mail: iachec-time@heal.phy.saitama-u.ac.jp