IACHEC Timing WG report

Presented by

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Timing WG members

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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

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)
2. **In-orbit timing calibration plan/observations**
   - 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**
   - effects on timing products (power spec, light curve etc) by the detector's behavior (dead time, grade selection of calorimeter etc)
   - Others.

14th IACHEC in Shonan Japan

Activities in 2020-2021

Timing WG telecom

- 28 April 2020
- 15 Sep 2020
- 20 April 2021
- 12 May 2021

Major activities

1. Summary of timing calibration/performance of multiple missions (Goal 1)
2. Systematic study of Crab timing using archive data among instruments (Goal 2)

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#1. Summary of timing calibration/performance

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

- RXTE PCA, HEXTE
- 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
- HXMT
- Hitomi SXS, SXI, HXI, SGD
- NICER XTI
- SRG eROSITA
- XRISM Resolve, Xtend

#1. Summary of timing calibration/performance

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

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		< 3.4 μsec	3.4 μsec	Spline-based calibration against ground timing standards	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 ★	μsec	none						delay 0-1 μsec (corrected?)	None	see above
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, Burst = -387+/-13. 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)

Continue.

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

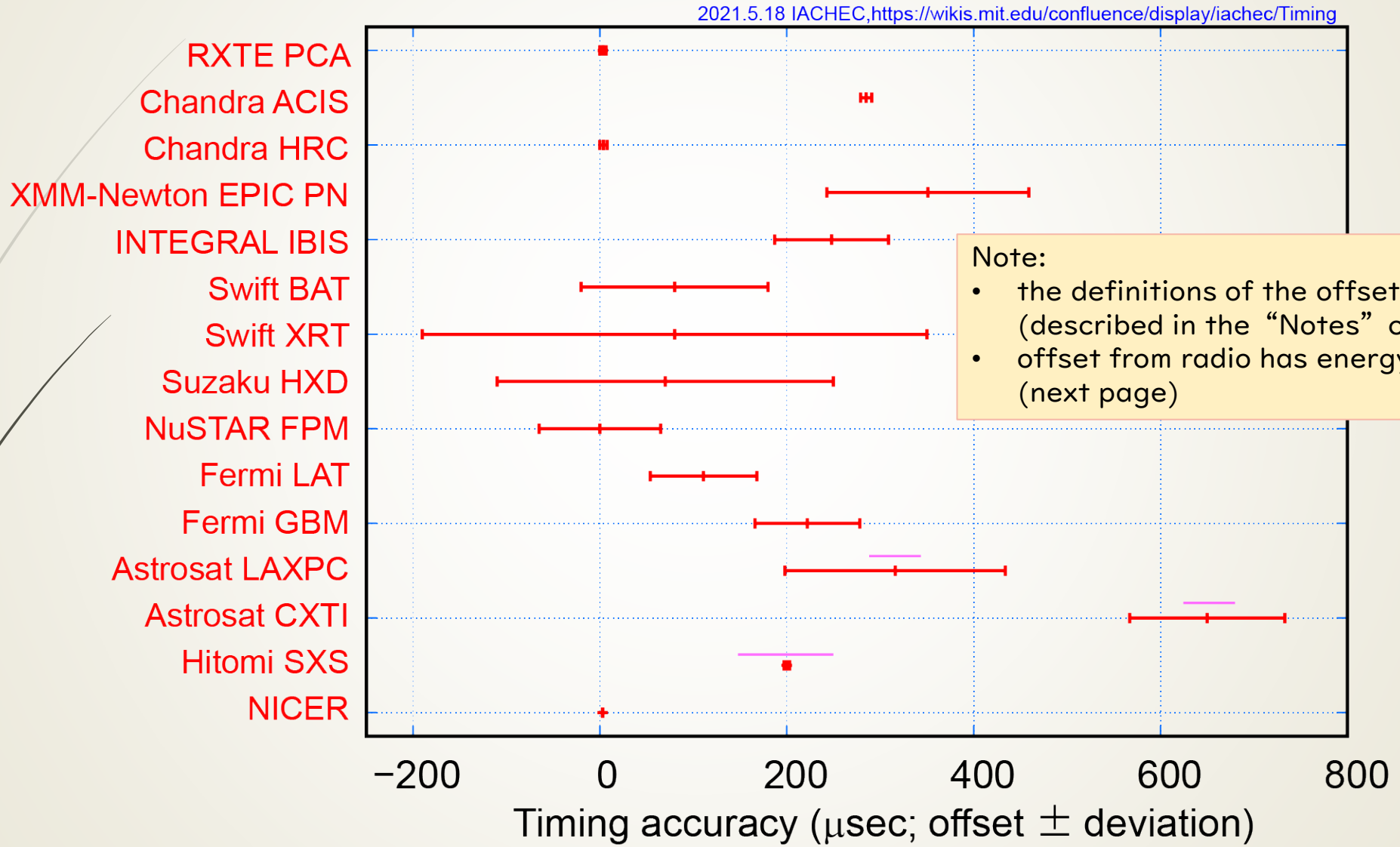
Mission/Instruments	Science Requirement Absolute Time		Timing System Design		Timing Calibration Status			In-orbit Timing Calibration Targets	Reported Issues	Reference
	Requirement	Goal	GPS Receiver	Clock Stability	Offset	Deviation, sigma	Notes			
INTEGRAL/SPI										L.Kuiper 2003 (10.1051/0004-6361:20031353) 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	~ 0.3 ms	GRB light curves	Yes	~ 6.572 x 10^-8 s/s	~ 80 μs	~ 100 μs		Crab pulsar (anual)	None at present	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					~ 270 μs		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			
Fermi/GBM (NaI)										

Continue.

The Table (3/3) 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			
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)
HXMT										
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	Approx <3 us [from wiki, but adding < mark here]	100 ns (RMS) [requirement]	These 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)		

Fig. Timing Calibration status (offset ± deviation)



Note:
- the definitions of the offset are different (described in the "Notes" column).
- offset from radio has energy dependency (next page)

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

Molkov, Jourdain, Roques 2010

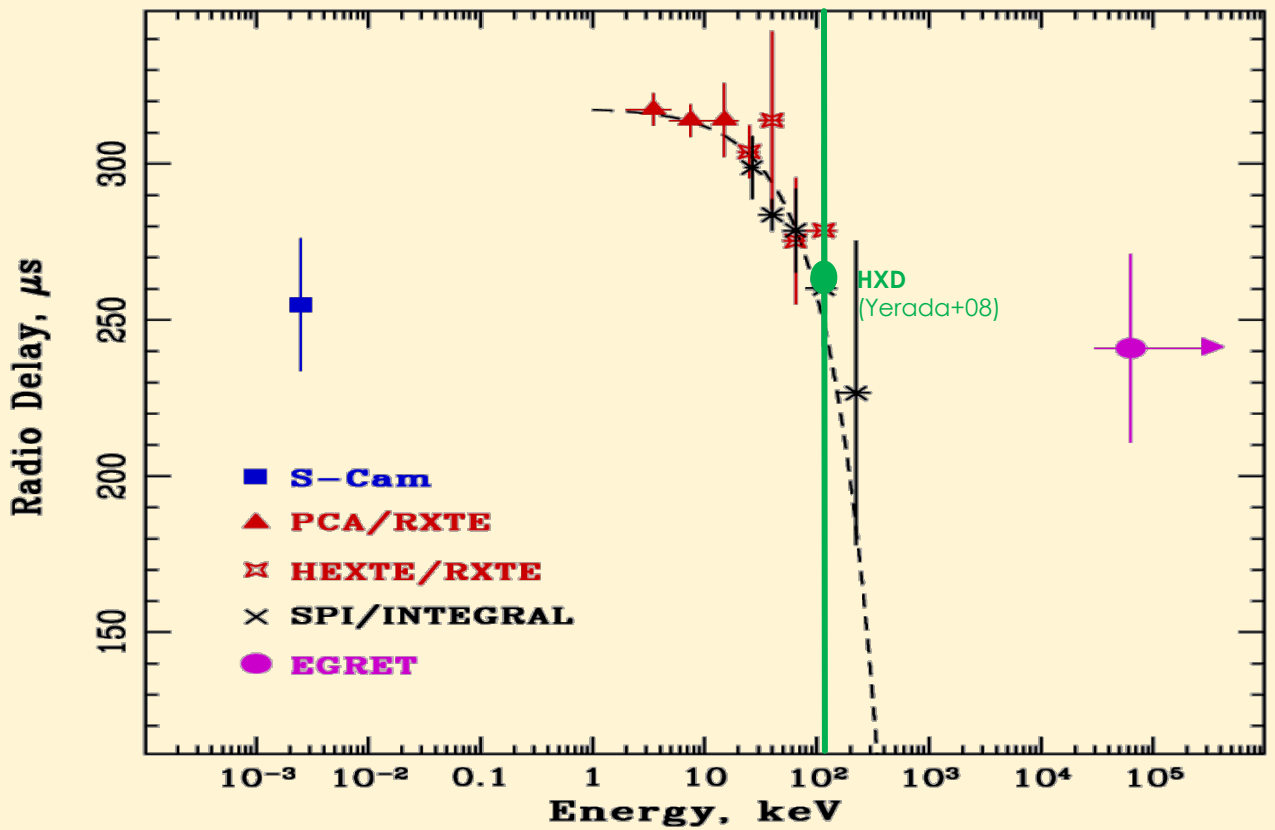
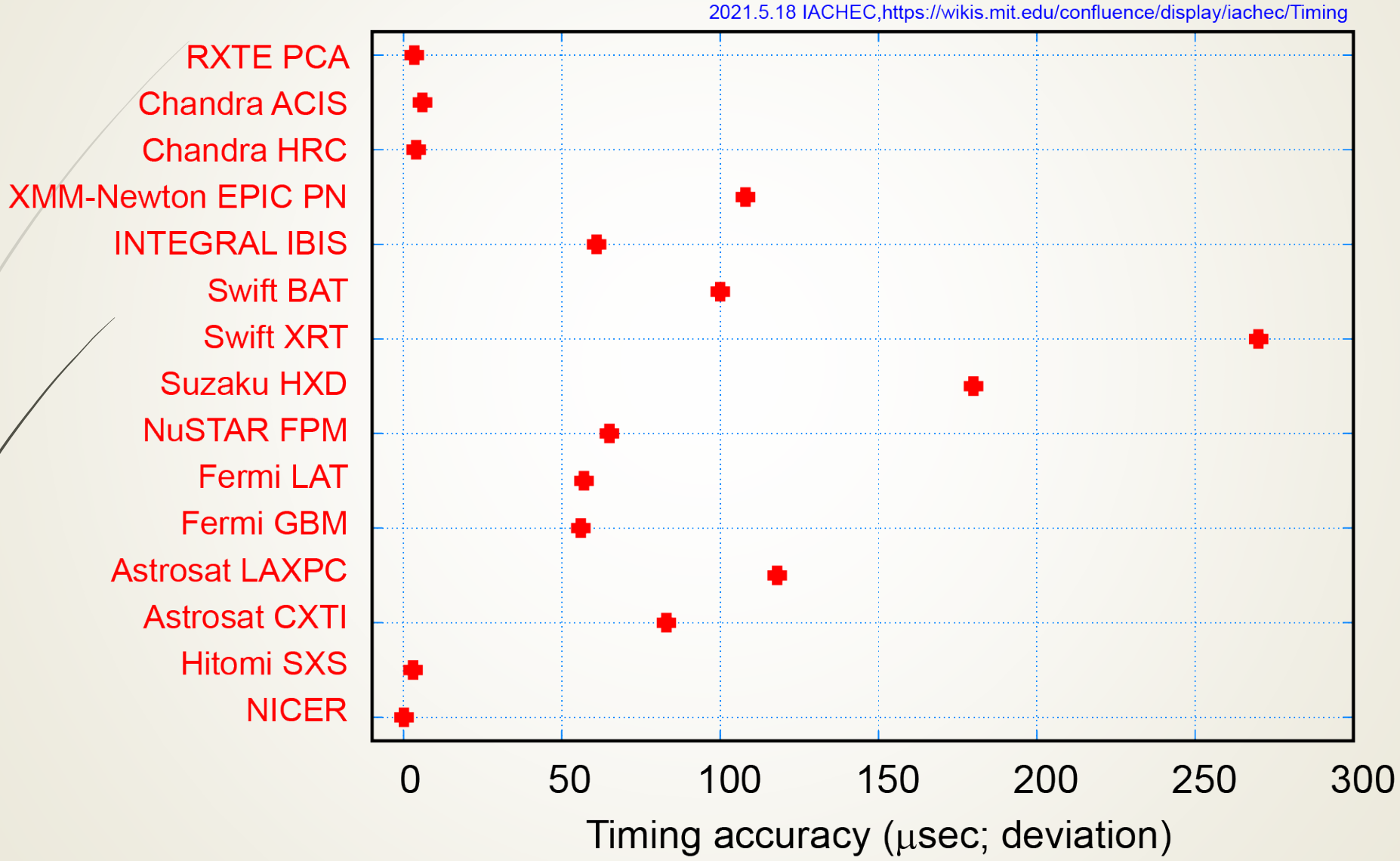


Fig. Timing Calibration status (deviation) ;



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
PSR B1937+21	RXTE/PCA, Chandra/HRC, NuSTAR/FPM, NICER/XTI
PSR B1821-24A	NuSTAR/FPM, NICER/XTI
PSR B1509-58	Suzaku/HXD
GRB	AstroSat/CZTI
A0535+262, Her X-1, etc	Suzaku/XIS

#2. Comparison of Crab ephemeris

Organizer: Matteo Bachetti

Purpose:

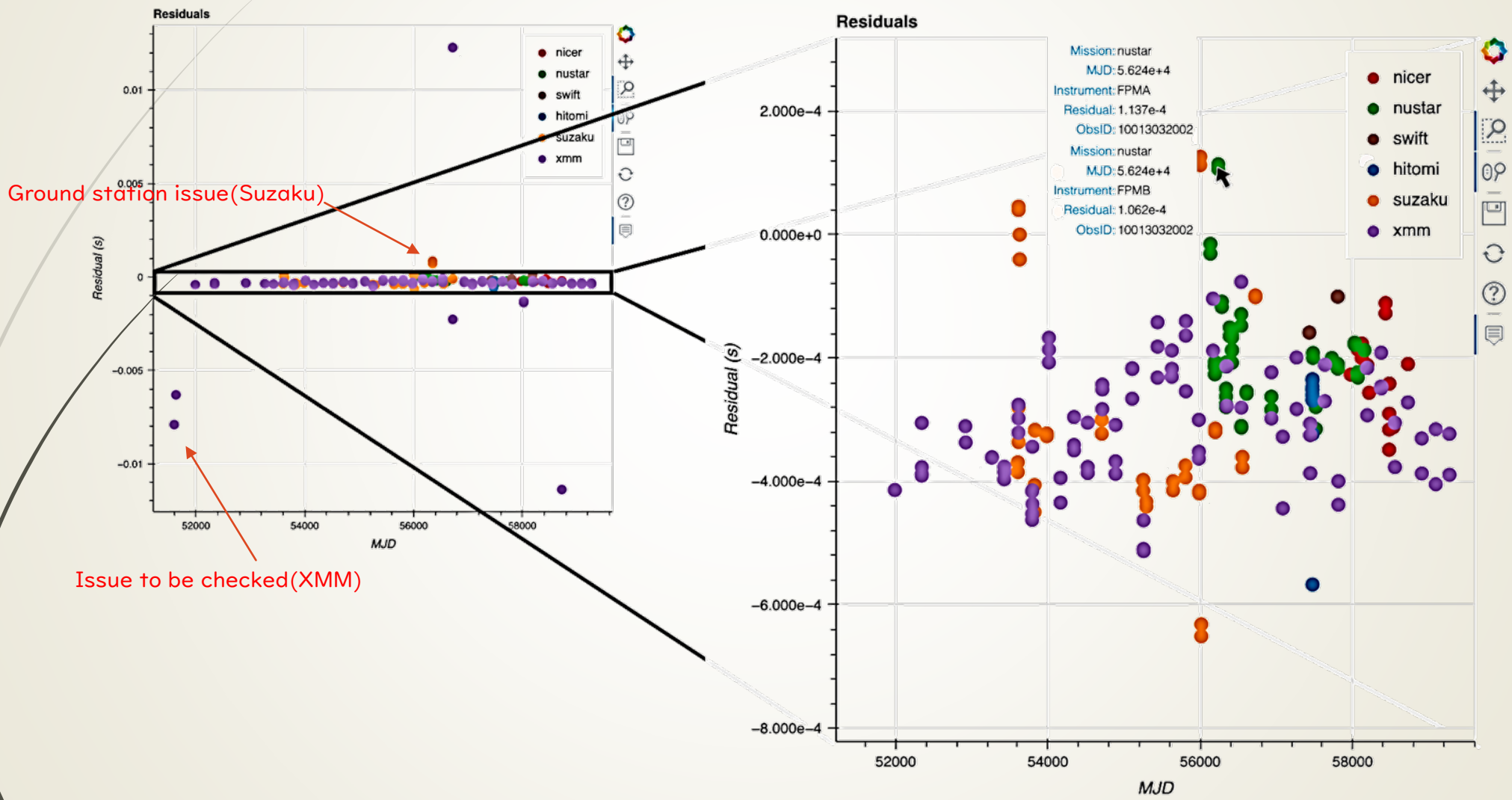
1. Systematic-timing cross-calibration of instruments using archive data.
2. Systematic check of Timing delay of the Crab main pulse between the X-ray and Radio.
   Note: please see also the presentation by L.Kuiper in 13th IACHEC 2018.

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.
   We have a first quick-look result (next page), which will be shared among IACHEC in near future.
3. We see several outliers, which may be due to ground station issues;
   "Known issues" will be also listed ← we are gathering the information now.

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



Please join the WG if you are interested in.

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