



***In-orbit timing calibration of Suzaku satellite,
and
the design of the timing system on Astro-H***

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on behalf of the Suzaku (and Astro-H) team



Timing System onboard Suzaku

No on-board GPS system

Satellite bus

Sub systems (payload)

Onboard Main computer

Master clock



Free RUN

+ temperature drift correction

512 kHz
clock

$10^{-6} \rightarrow 10^{-9}$ stability

TI (20+12 bit)

Orbit error 10km ~ 30 us

Ground



Downlink Station

UTC (yyyymmdd hh:mm:ss.uuuuuu)

resolution ~ 10,100 us

Onboard computer

Intelligent
Node

TI

20+12 bit

Long coverage

Electronics
DAQ

Non-Intelligent
Node

Time counter

5+14 bit

Fine resolution

128 kHz
clock

Compare
Every observation
(typically 2 days)

Sensor

Sensor

HXD	61 μ sec (32 μ s in condition)
XIS	8 sec (normal mode)
	2 or 1 sec (normal mode with 1/4 or 1/8 window option)
	7.8 msec (Psum mode)

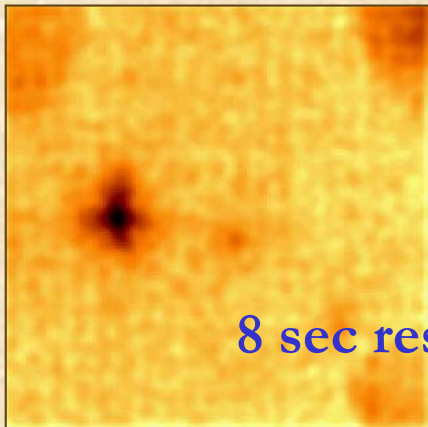
Relative Timing Calibration between instruments, the XIS and HXD

by Matsuta and the XIS team

The HXD has higher timing resolution.

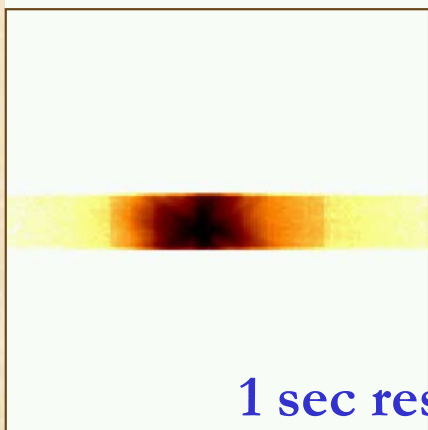
→ Check **cross correlation function** between
light curves of the XIS (1/8 option) and HXD PIN

Clocking Mode: Normal
Full Window

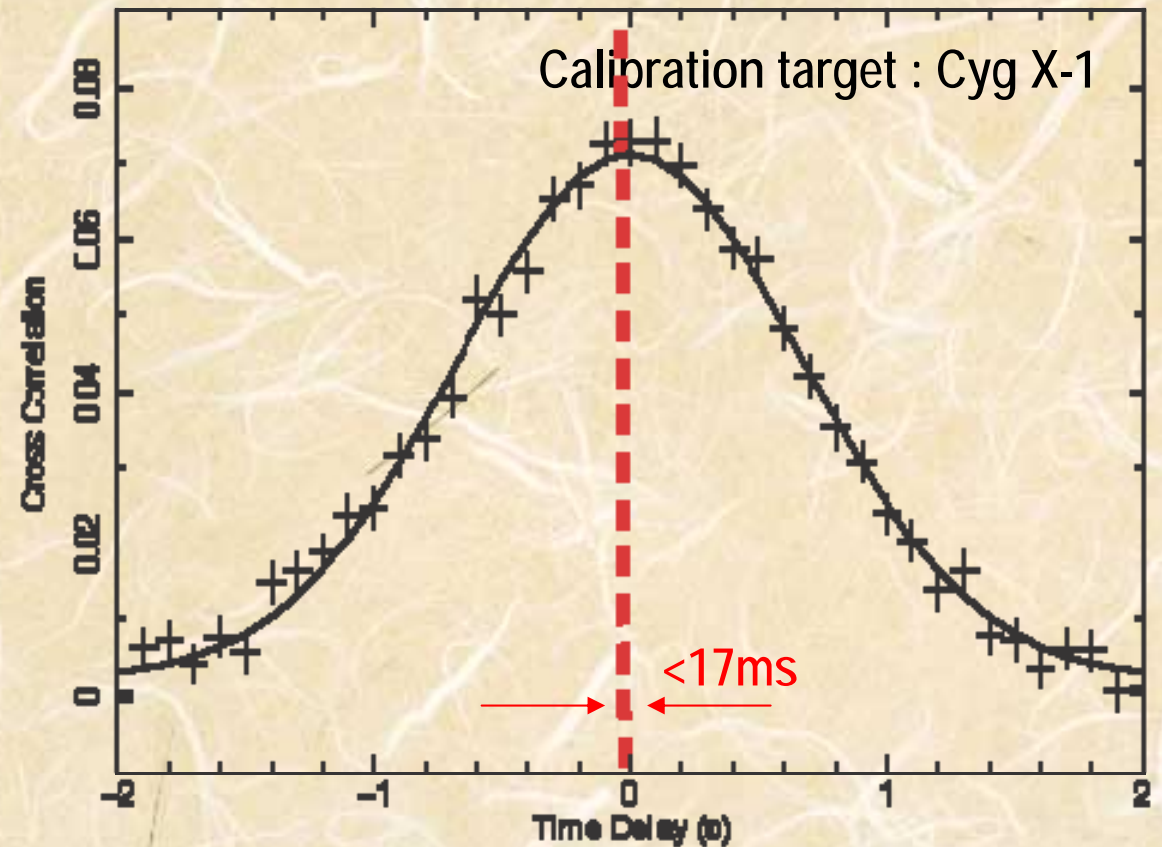


8 sec resolution

1/8 Window Option



1 sec resolution

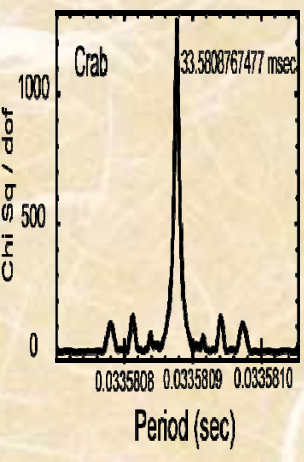
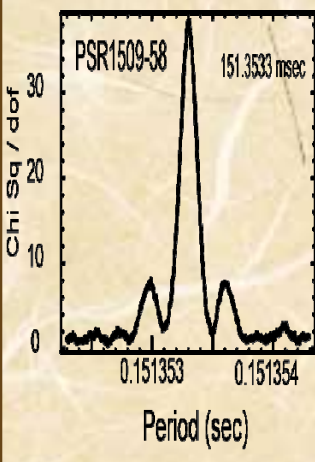
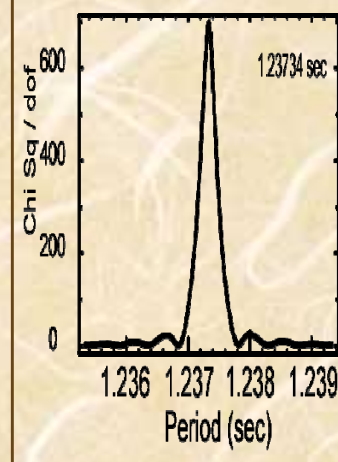
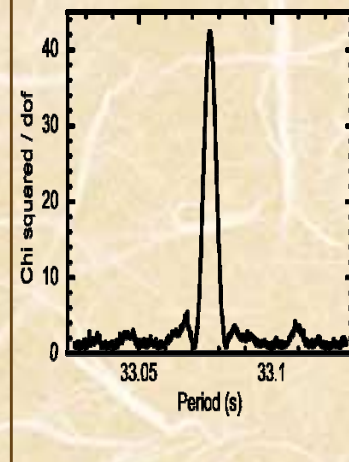
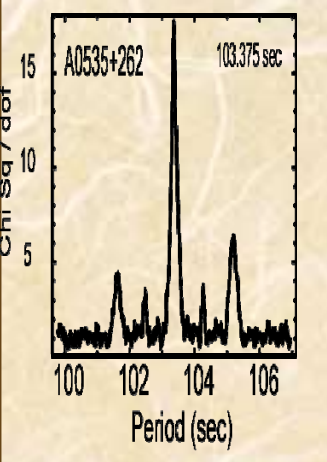
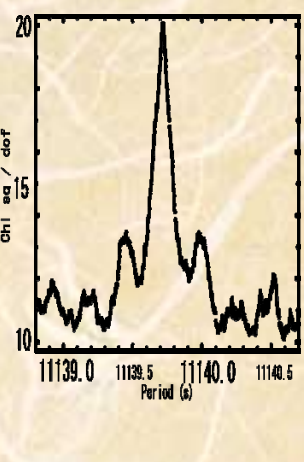
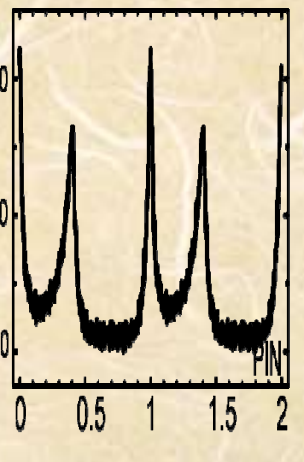
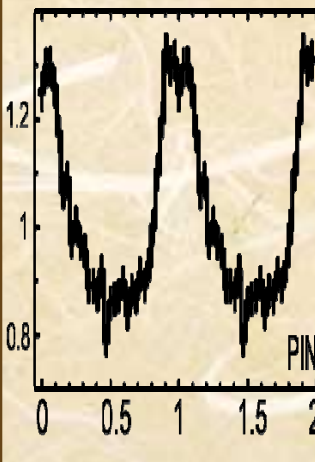
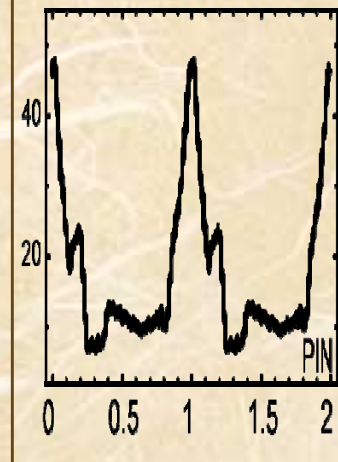
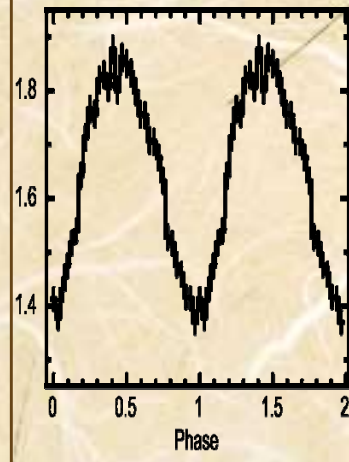
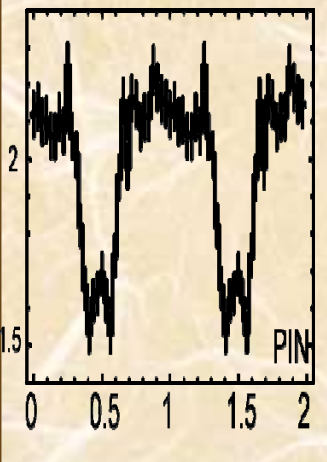
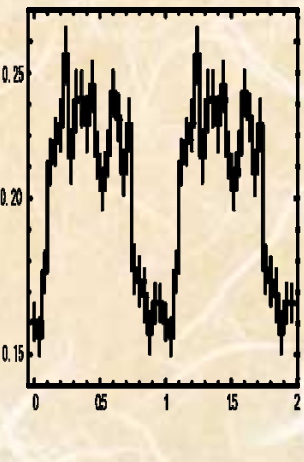


The XIS time is consistent with the HXD time.

→ Concentrate on the HXD timing.



Relative Timing Calibration with periodic signals

Crab	PSR B1509-58	Her X-1	AE Aqr	A0535-262	AM Her
33ms	151 ms	1.24 s	33 sec	103.4 s	11139s
					
					
Terada et.al 2008a	Terada et.al 2008a	Enoto et.al 2008	Terada et.al 2008b	Terada et.al 2006	In studying now

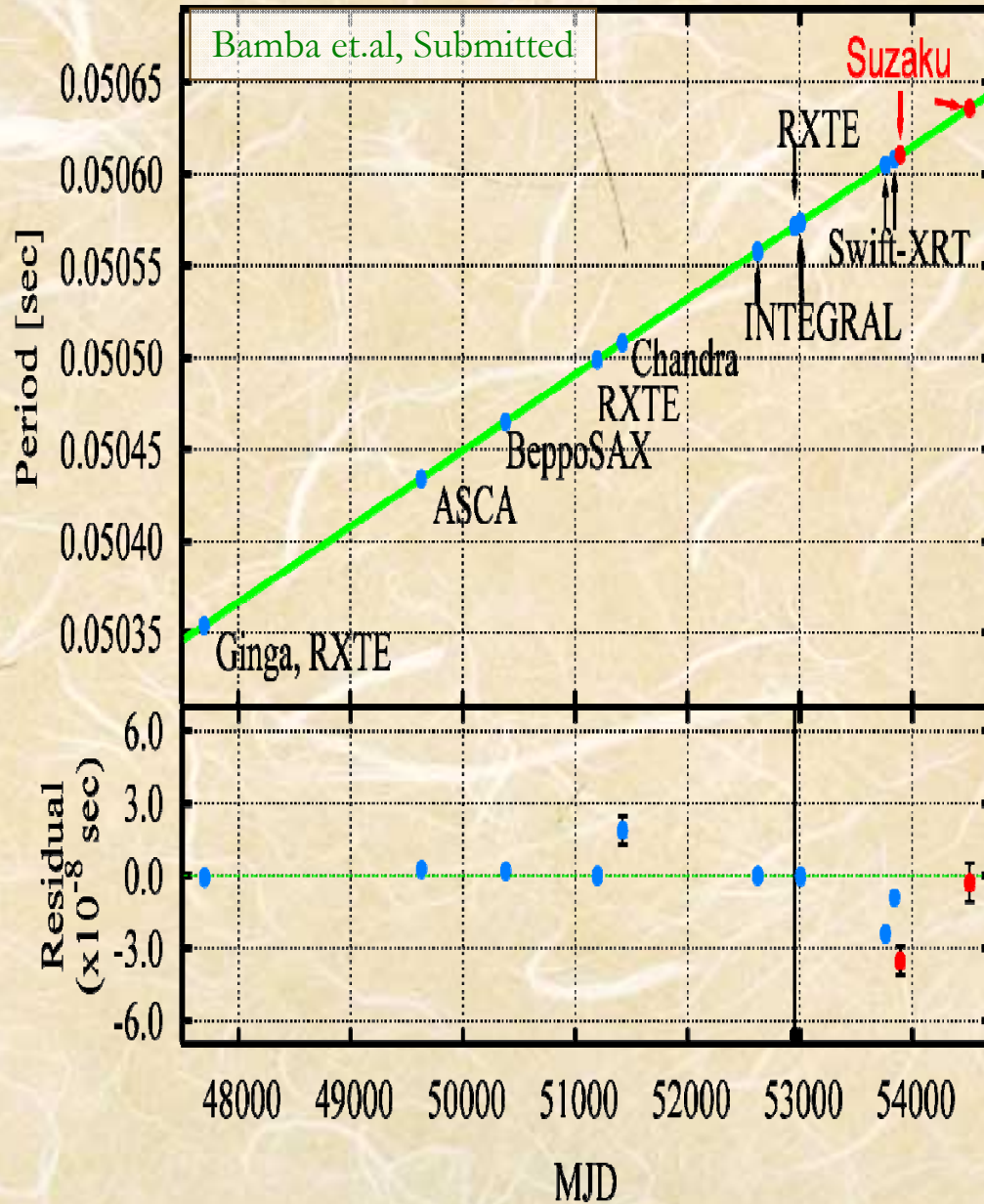
OK in 33ms - 11 ksec range



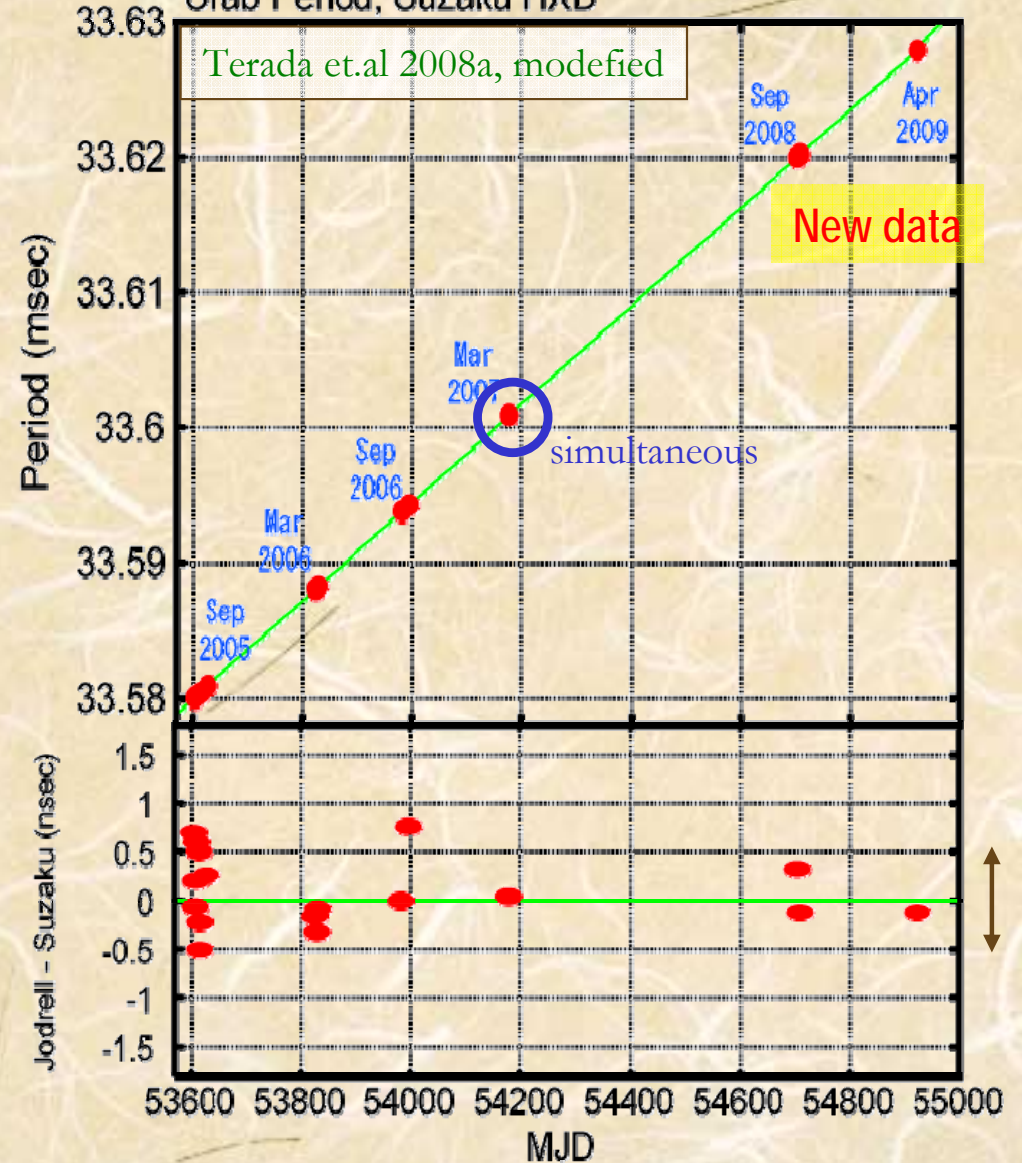
Periodic signals:

Comparison with other observations

PSR B0540-69.3



Crab Period, Suzaku HXD

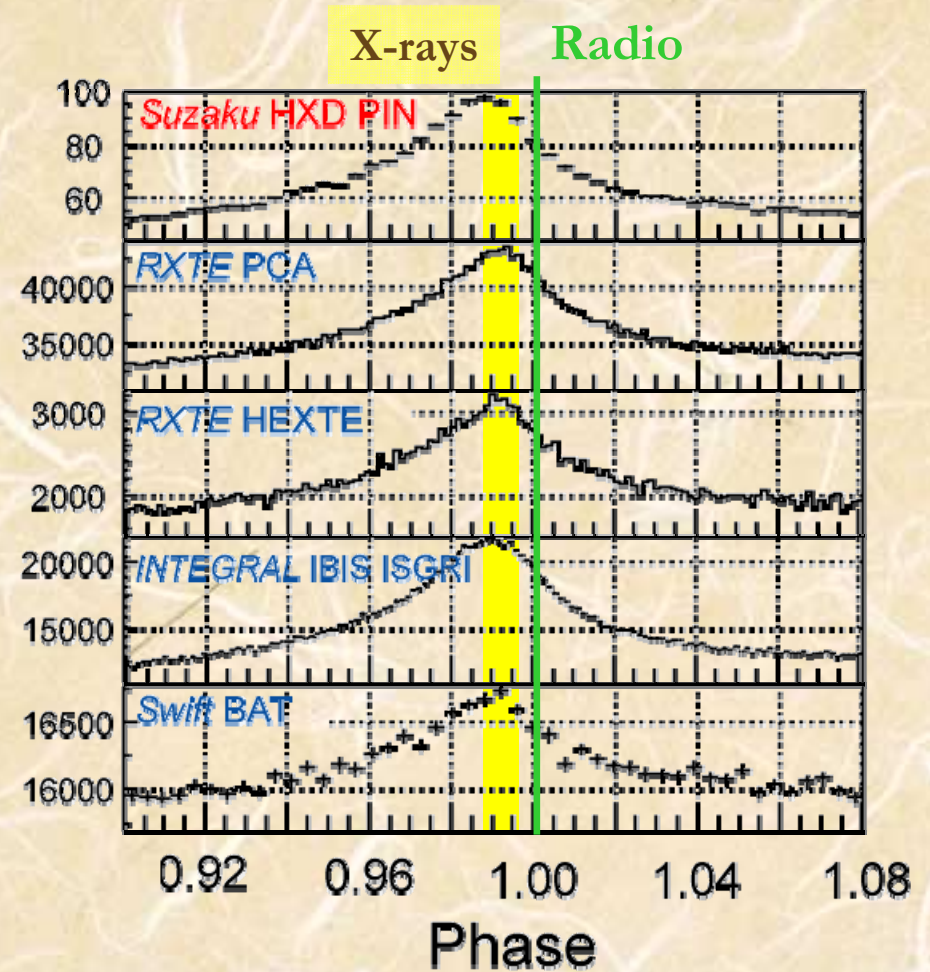
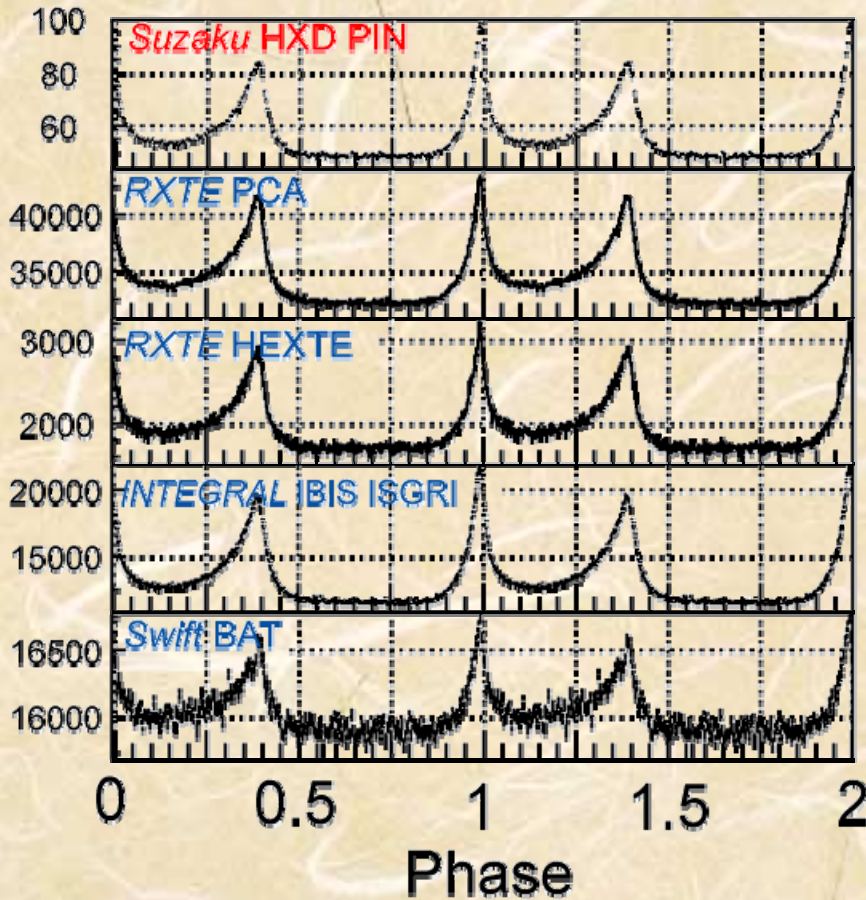
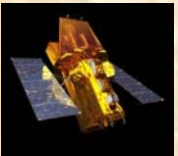


Confirmed , 1 nsec stability par day (1.9×10^{-9})

Cross Timing Calibration with Crab

March 17-20, 2007, simultaneous observation of Crab (Y.Terada et.al 2008a)

One of the successful results of IACHEC activities!

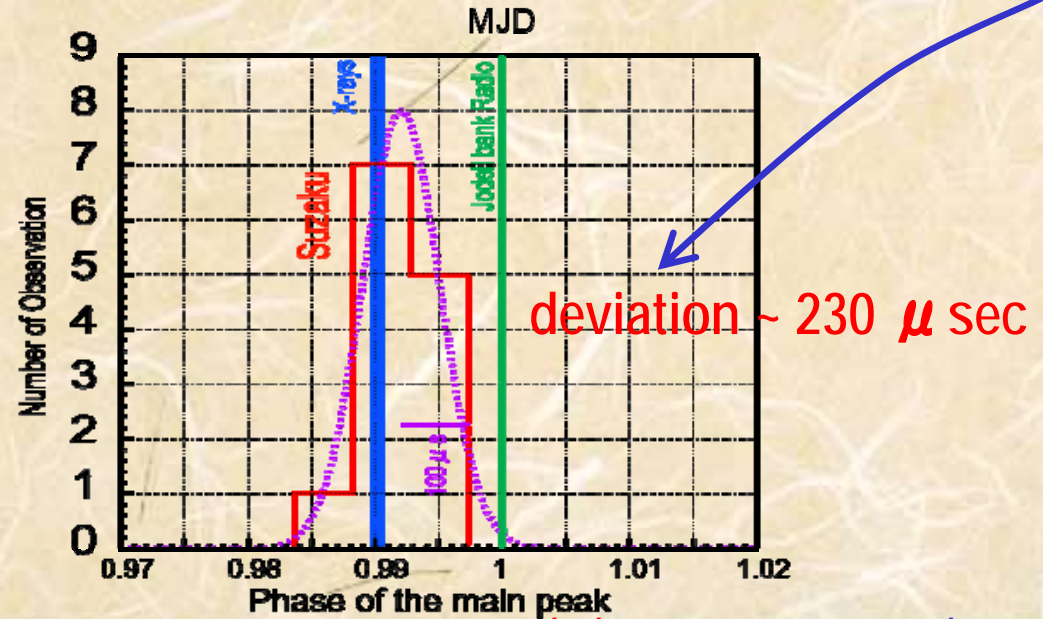
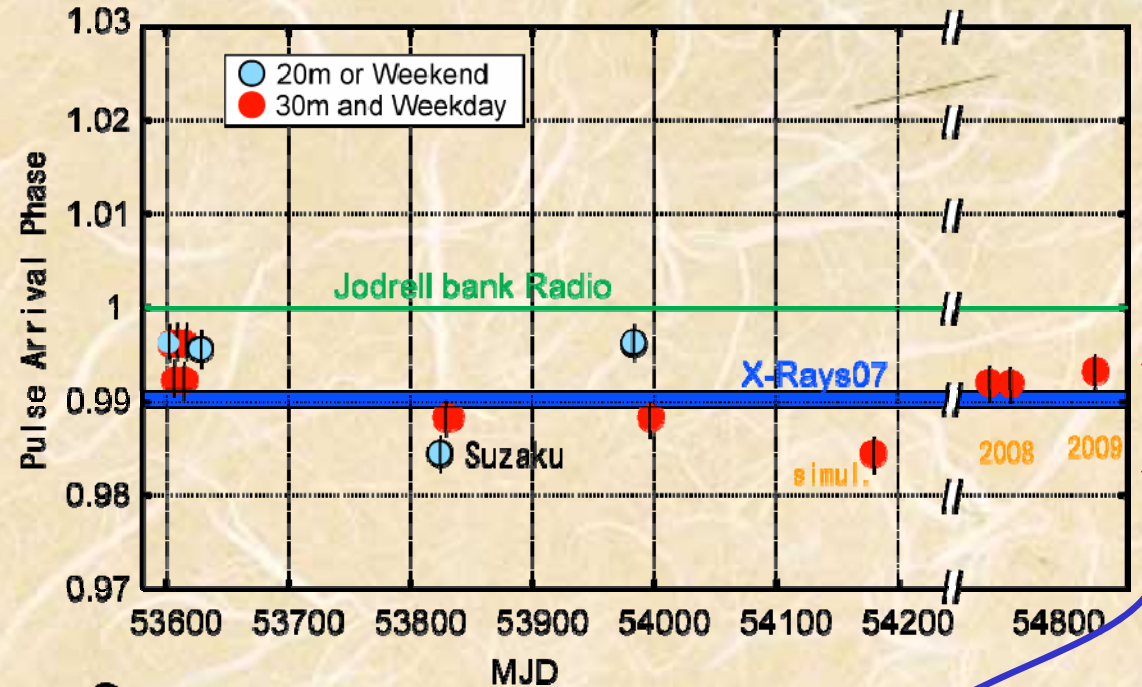
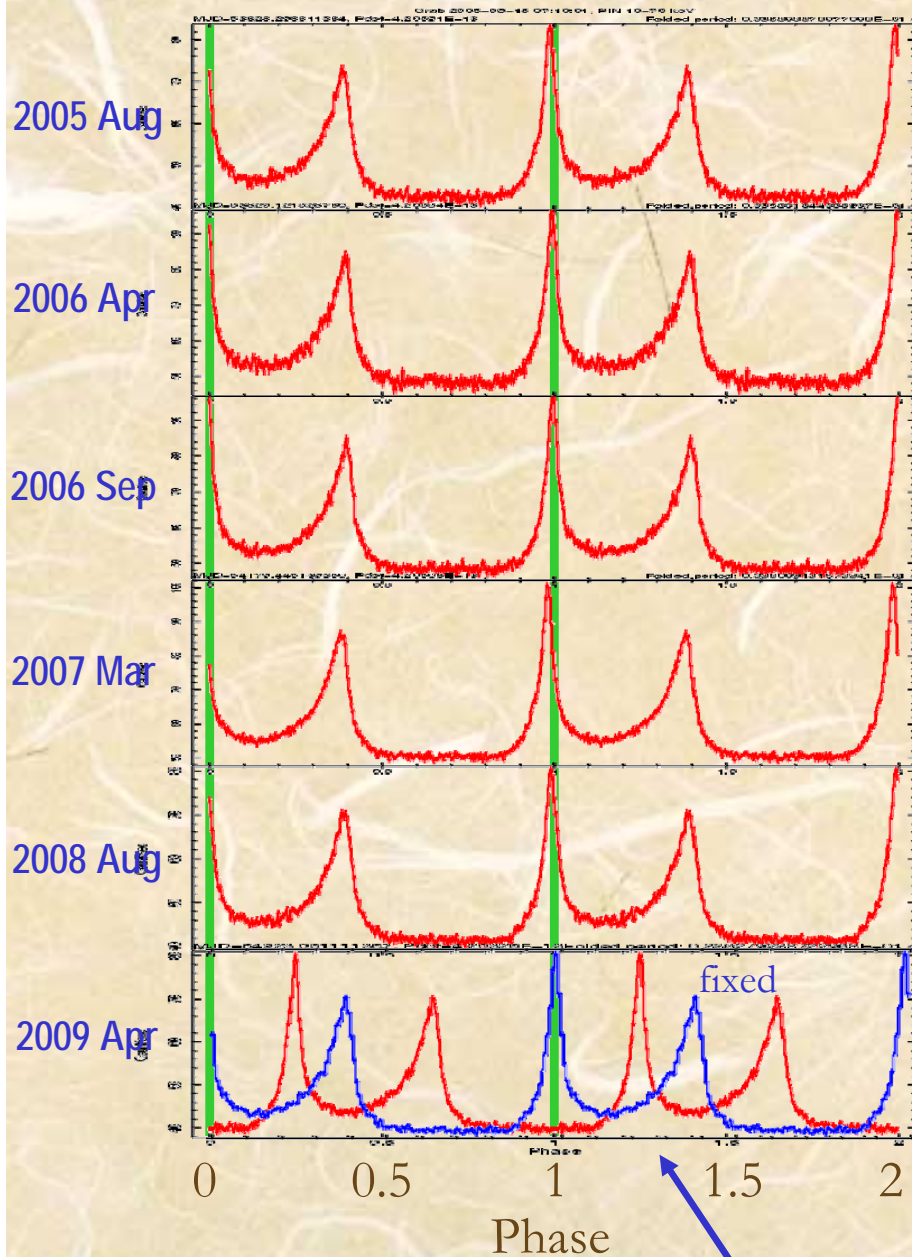


- Arrival time in X-ray exceeds 330 μ sec from that in Radio band. (same result as Rots etal 04)
- Arrival times with X-ray satellites are consistent within $\sim 100 \mu$ sec



Absolute Timing Calibration with Crab

Compared with Pulse arrival times of Jodrell Bank Radio Observatory



Known BUG in processing after 2009/1/1 (1.000000 sec) / FIXED



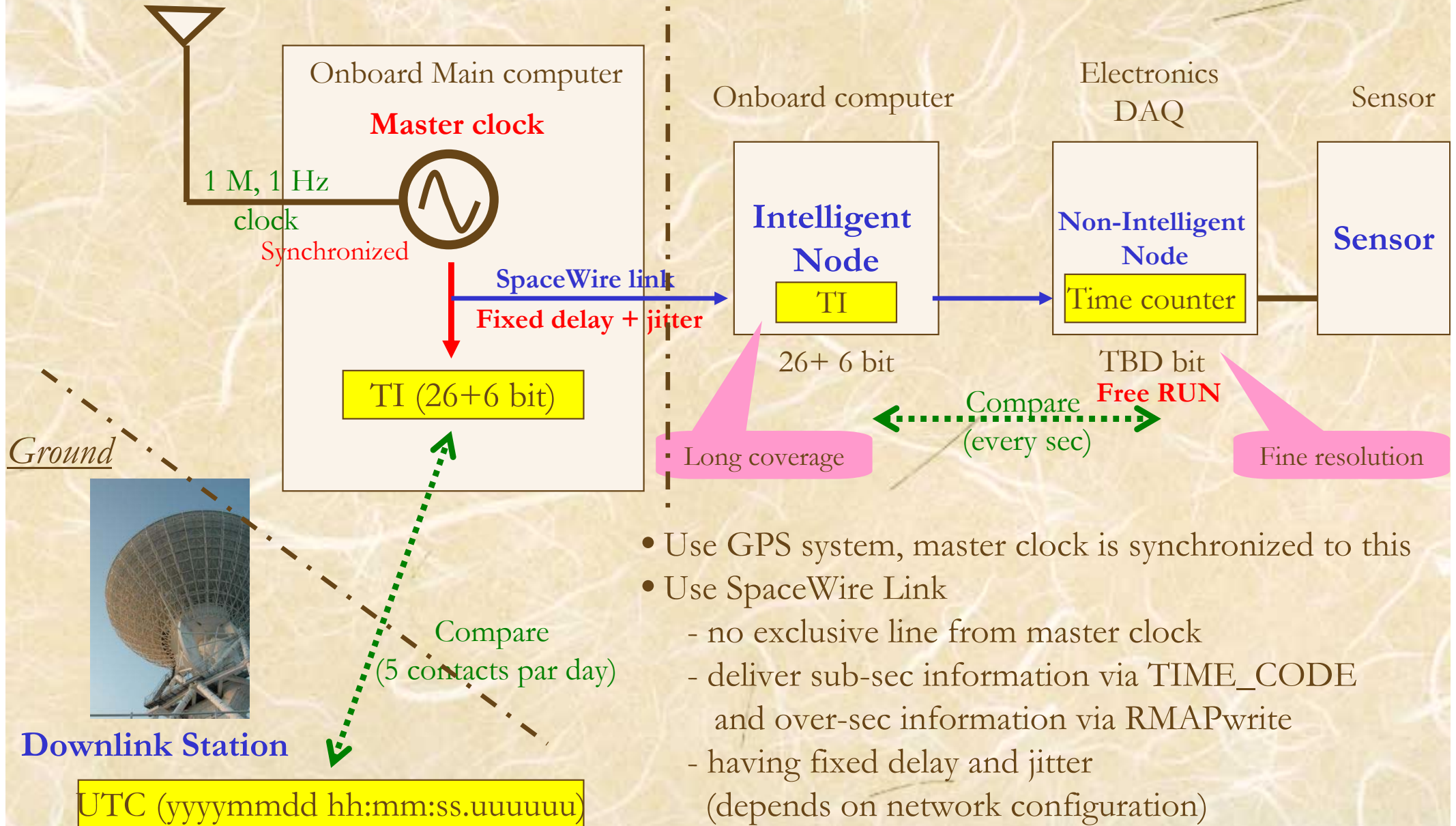
Timing System in the future mission, Astro-H

Now in design phase

On-board GPS system

Satellite bus

Sub systems (payload)



- Use GPS system, master clock is synchronized to this
- Use SpaceWire Link
 - no exclusive line from master clock
 - deliver sub-sec information via TIME_CODE and over-sec information via RMAPwrite
 - having fixed delay and jitter (depends on network configuration)



Summary

- Suzaku carries the HXD with 61 usec timing resolution and the XIS with normally 8 sec timing resolution.
- The times between the XIS and the HXD are consistent with each other within 20msec.
- The stability was confirmed as 1.9×10^{-9} from the comparison between arrival time of the main pulse of Crab in Radio and Suzaku.
- Simultaneous observation of Crab with Suzaku, INTEGRAL, Swift, and RXTE was performed in 2007 as a timing calibration. The absolute timing of these satellites are confirmed in 100 usec order.
- The timing accuracy of Suzaku was tested by many Crab observations, and confirmed as < 230 usec.
- We are now developing the timing system on Astro-H, which uses Spacewire network.

Timing working group was inactive in the last IACHEC workshop.

→ Restart the activity in this 4th workshop?