Calibration uncertainties in modeling: timing calibration

"short comment"

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Timing Calibration of Instruments

Timing Measurements

a. Verification of the Timing System Design … Performance Check
b. Confirmation of the Timing Uncertainties … Calibration

We may mix those two aspects, especially in the discussion of Timing calibration.

Ground timing calibration

Identify items of uncertainties in the timing system.
Confirm them by items & check total within the mission requirement
(ex., Hitomi Timing, Terada+ JATIS 2018)

In-Orbit timing calibration

End-to-end Verification of timing performance (inc. orbital determination)

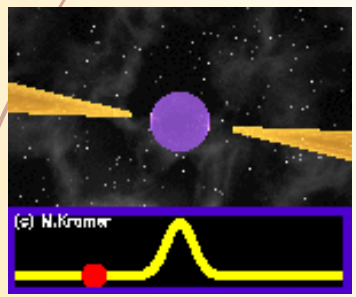
In-orbit Timing calibration

- In-orbit timing calibration is performed by checking absolute timing of
  a. Pulse Phase of Neutron star Pulsars
  b. Rise Time of X-ray flares of astrophysical objects
  etc

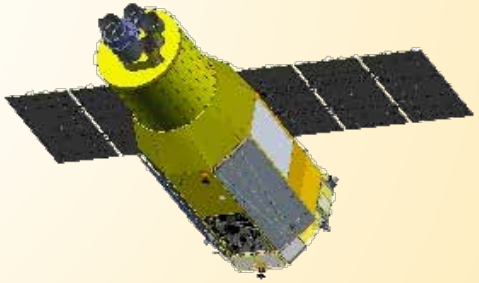
à (Semi-) Simultaneous observations with X-ray or Radio observatories.

- Points in timing calibration with NS Pulsars

Source



Detector



#1. Intrinsic delay etc
#2. Pulse Profile

#3. Time resolution, Event selection and dead time etc

#4. Photon statistics

See one by one.

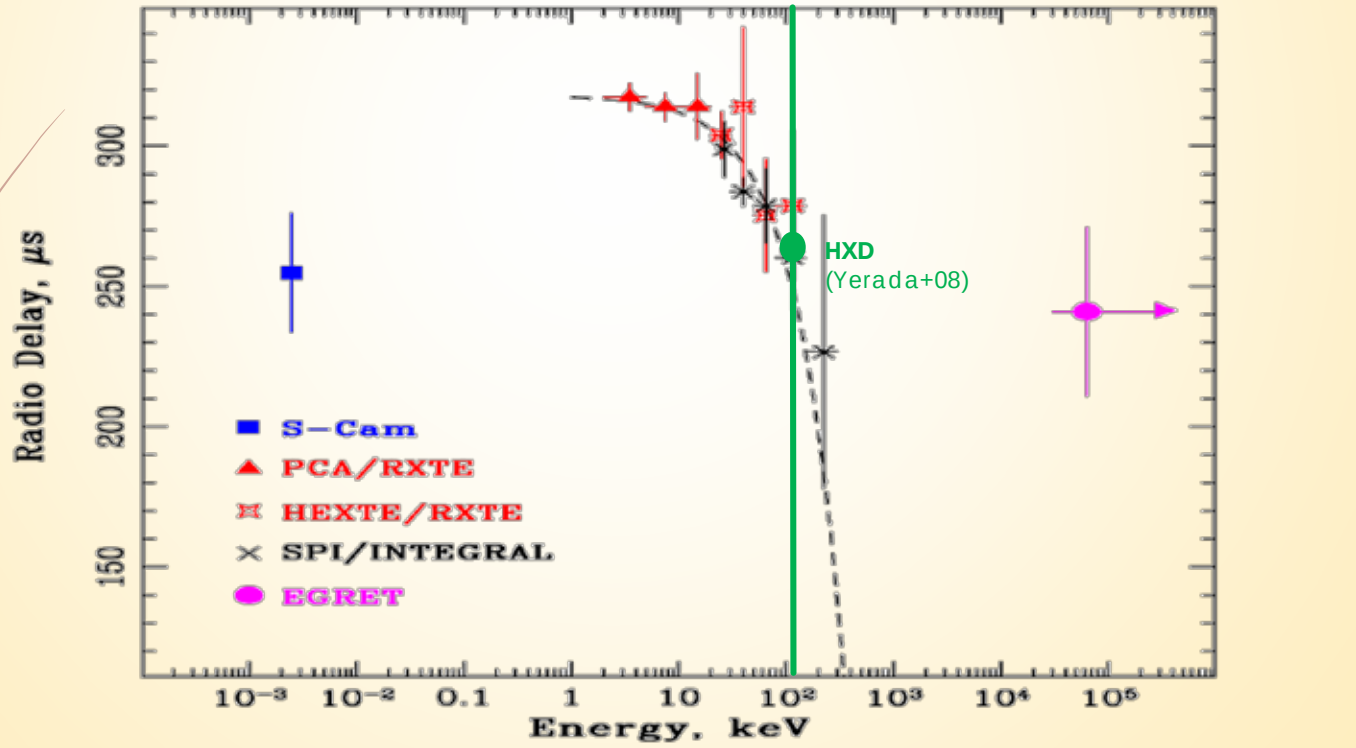
#1. Intrinsic Timing Delay

X-ray radio simultaneous observation:

- **Arrival time of main pulse is different in Radio and X-ray**
- **The timing deference depends on the X-ray energies.**

Crab

Molkov, Jourdain, Roques 2010



Pulsar Science ? or Calibration ?

#2 Pulse Profile

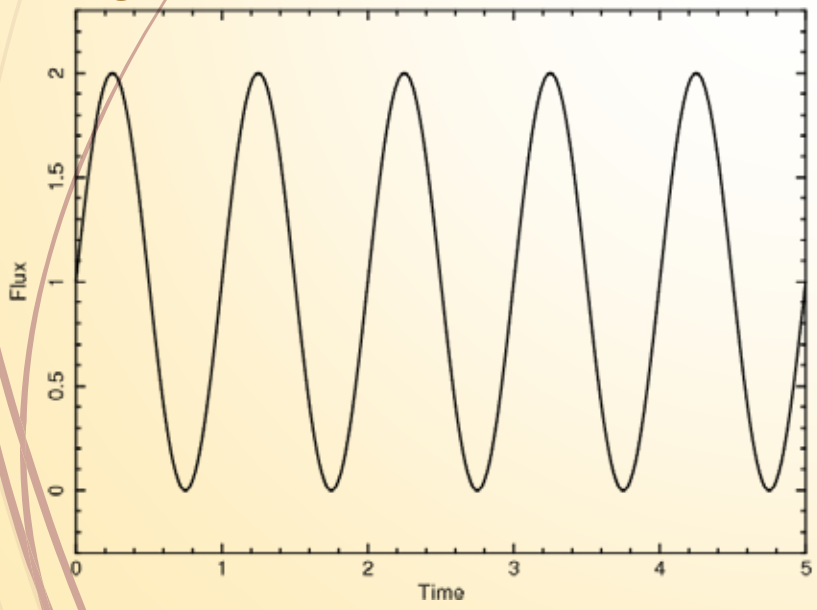
- **Determination of Pulse Period : Periodogram**
  Error depends on the pulse profile (Larsson S., 1996 A&AS)

$$\sigma_P^2 = \frac{6\sigma_{\rm tot}^2}{\pi^2 N T^2} \frac{P^4}{\sum_{k=1}^{m} k^2 A_k^2}, \qquad (5)$$

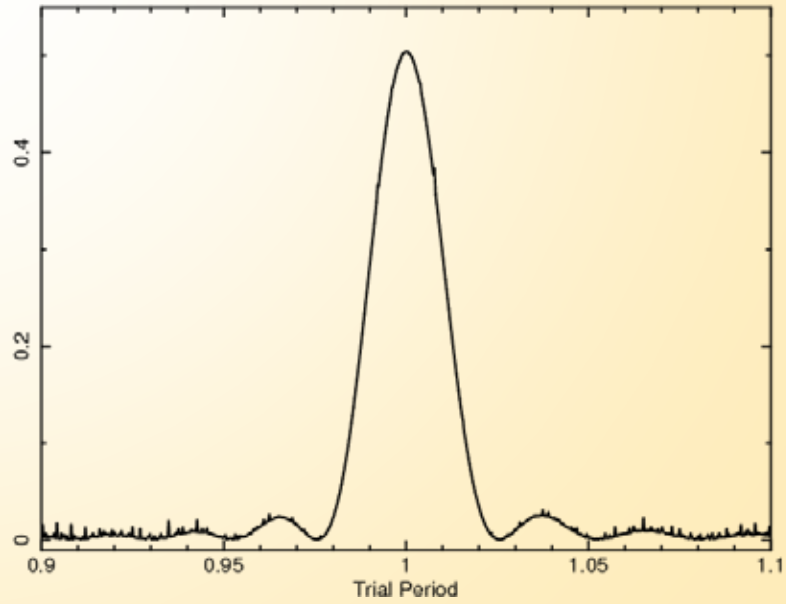
à **Better determination in Longer exposure or Sharp Pulse,**

- **Simple demonstration**

Light Curve



Periodogram



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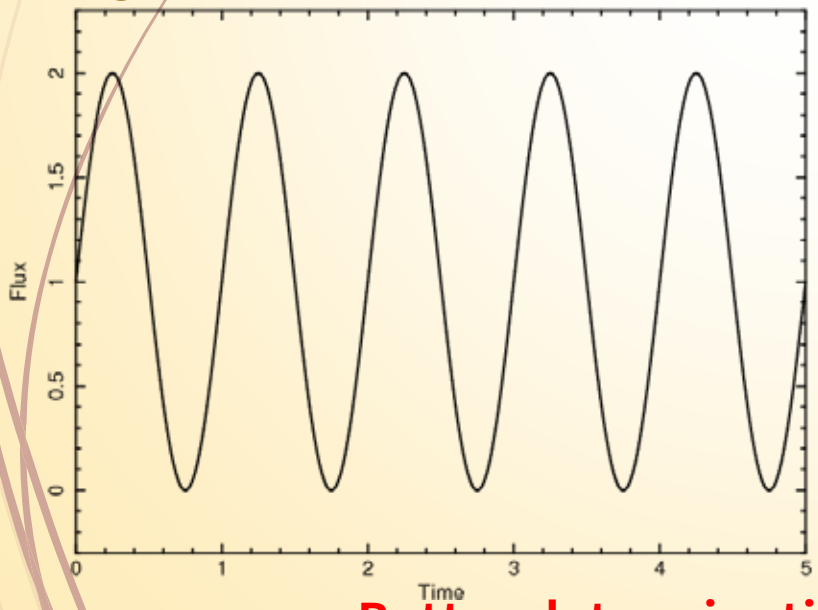

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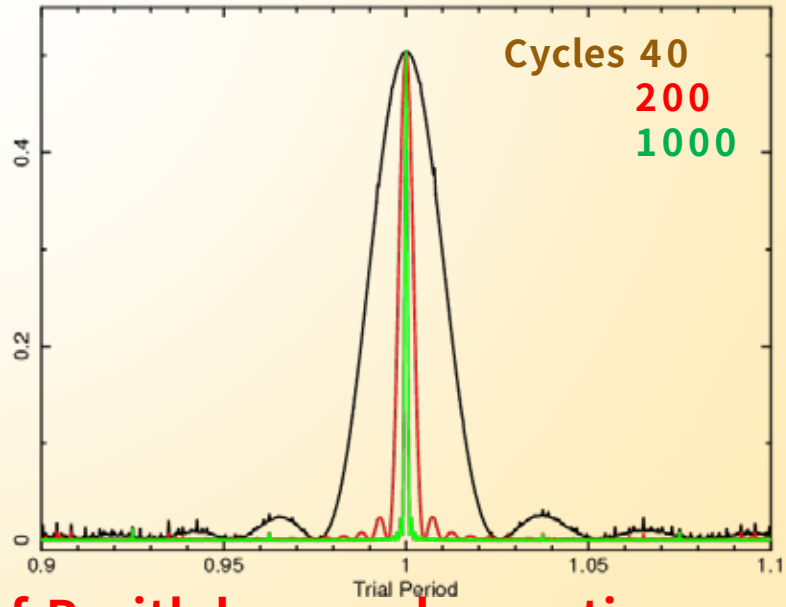

Better determination of P with longer observation

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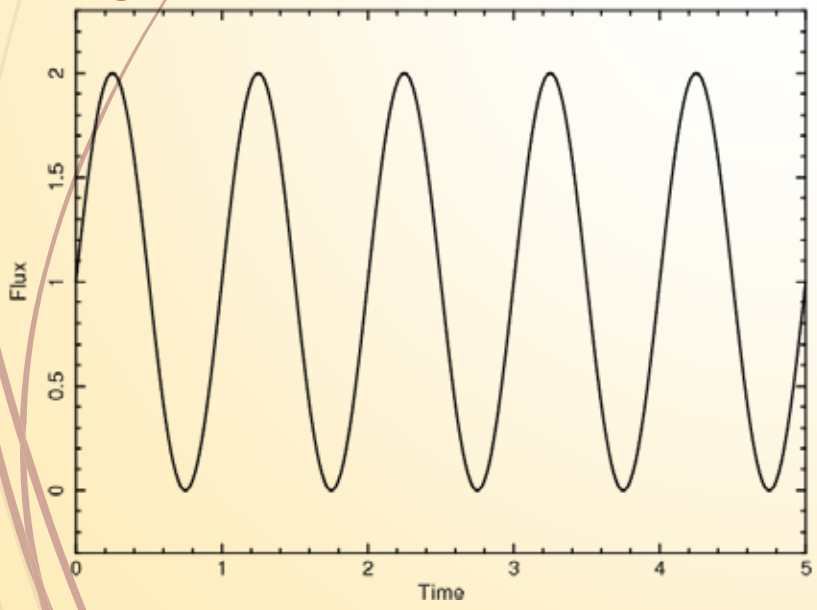
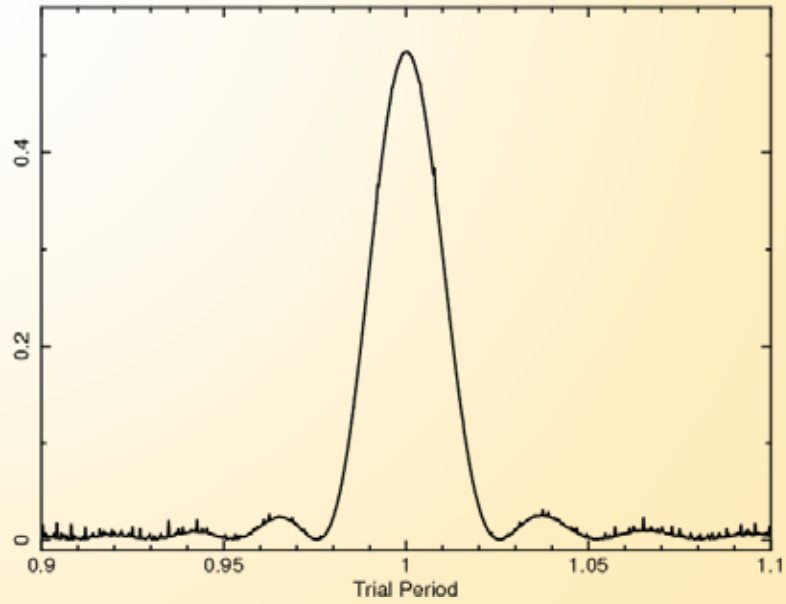


Periodogram



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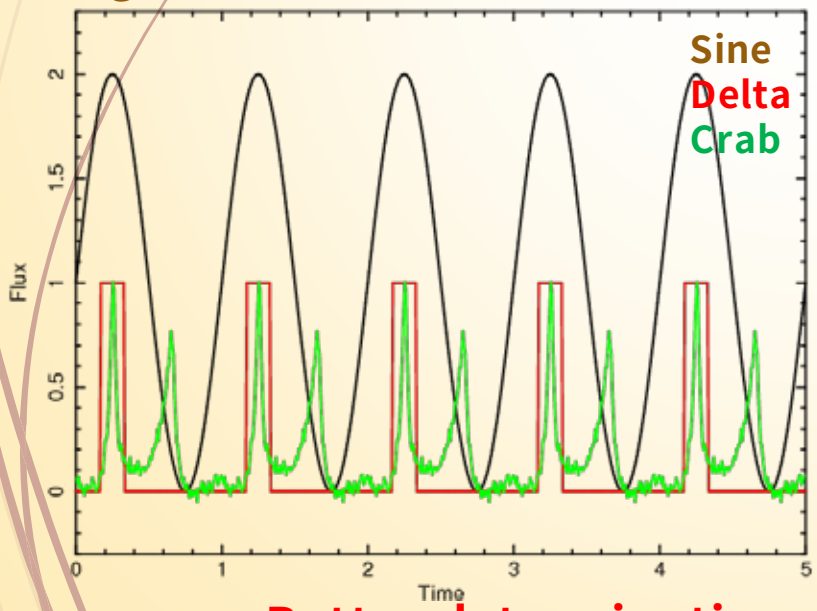
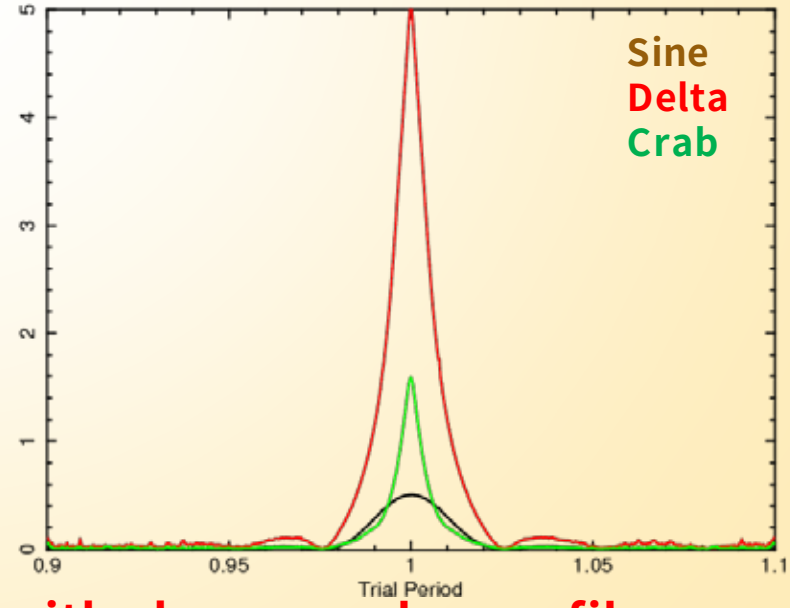


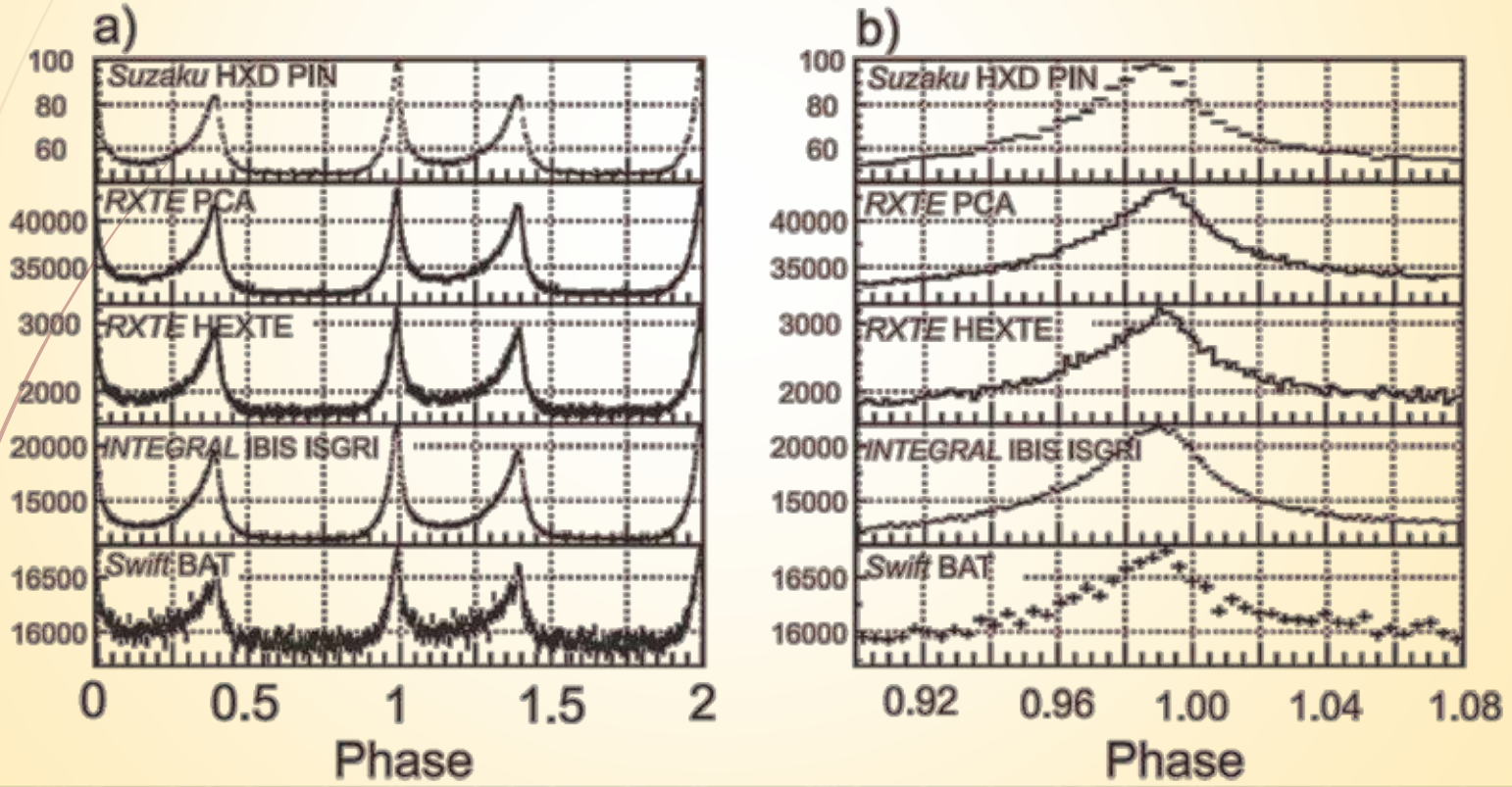
Periodogram



Better determination of P with sharper pulse profile

#2 Pulse Profile

- Timing error in Period determination depends on pulse profile
- Note: the profiles of known pulsars are smeared by the timing resolution of uncertainties of instruments.



Y.Terada+ 2008 (thanks to IACHEC coordinated obs)

#3 Timing response, Statistics

Hardware profiles

- ü **time resolution** ⋯ **resolution in timing determination**
- ü **dead time** ⋯ **affects *D*time distribution**
- ü **event selection** ⋯ **same above**

Example of Hitomi estimation of timing performance

The fraction of ΔP per P is roughly determined by the number of pulses N during the exposure T

$$\frac{\Delta P}{P} \propto \frac{1}{N} = \frac{P}{T},$$

⇨ $\xi_\infty \equiv \frac{\Delta P T}{P^2}$ ~ constant.

In Hitomi case, $\xi_\infty = 0.828$

Table 1 Summary of LOCAL_TIME counters

Instrument	Bit length	Time resolution
SXS	28-bits	5 μs
SXI	32-bits	61.0 μs
HXI	32-bits	25.6 μs
SGD	32-bits	25.6 μs
SGD-SHIELD	32-bits	16 ms

⇨ $\Delta P = 20.7\ \mu\mathrm{s} \times \left(\frac{P}{1\ \mathrm{s}}\right)^2 \left(\frac{T}{40\ \mathrm{ks}}\right)^{-1} \xi(P, F),$ **Simulation**

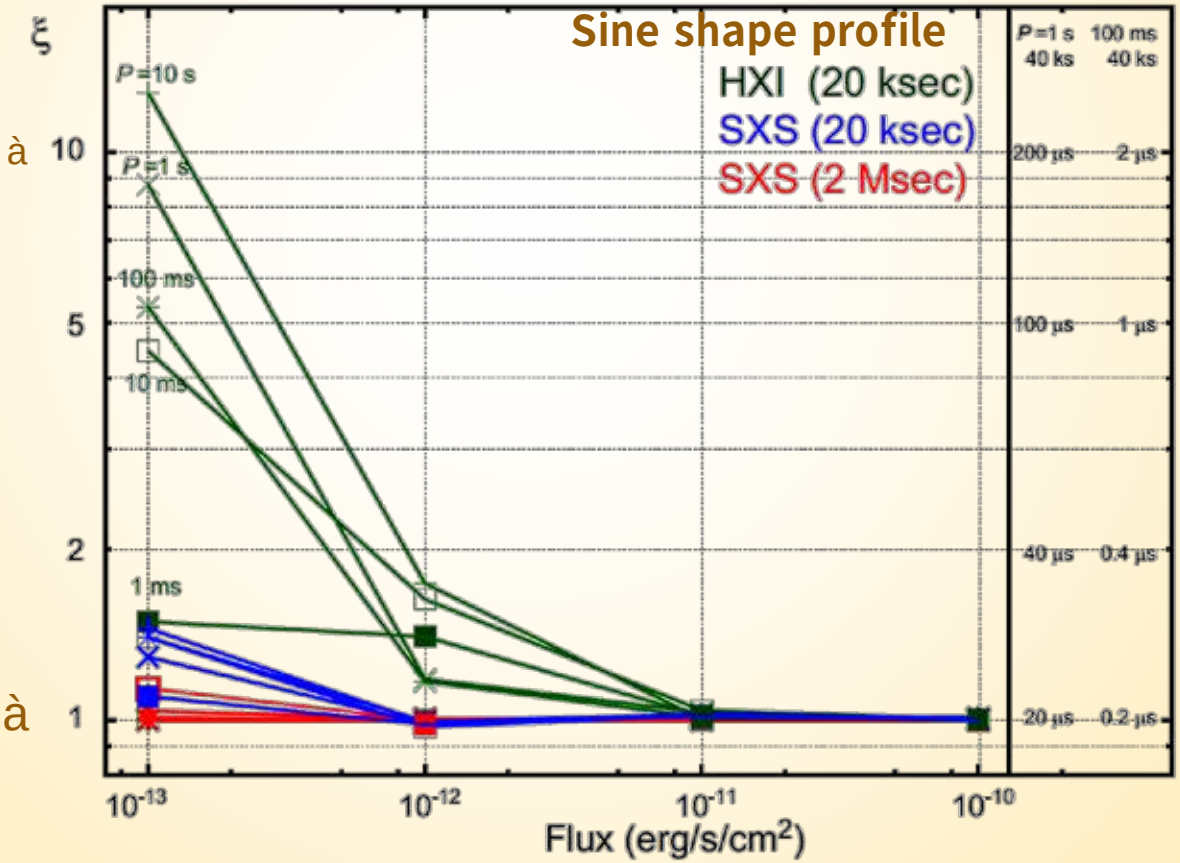
#3 Timing response, Statistics

Example of Hitomi estimation of timing performance (cont.)

$$\Delta P = 20.7\ \mu\mathrm{s} \times \left(\frac{P}{1\ \mathrm{s}}\right)^{2} \left(\frac{T}{40\ \mathrm{ks}}\right)^{-1} \xi(P, F),$$

10 times worse à

Ideal case à



Worse determination of P in dimmer pulsars