

# X-ray timing analysis of six pulsars using ESA's XMM-Newton observatory

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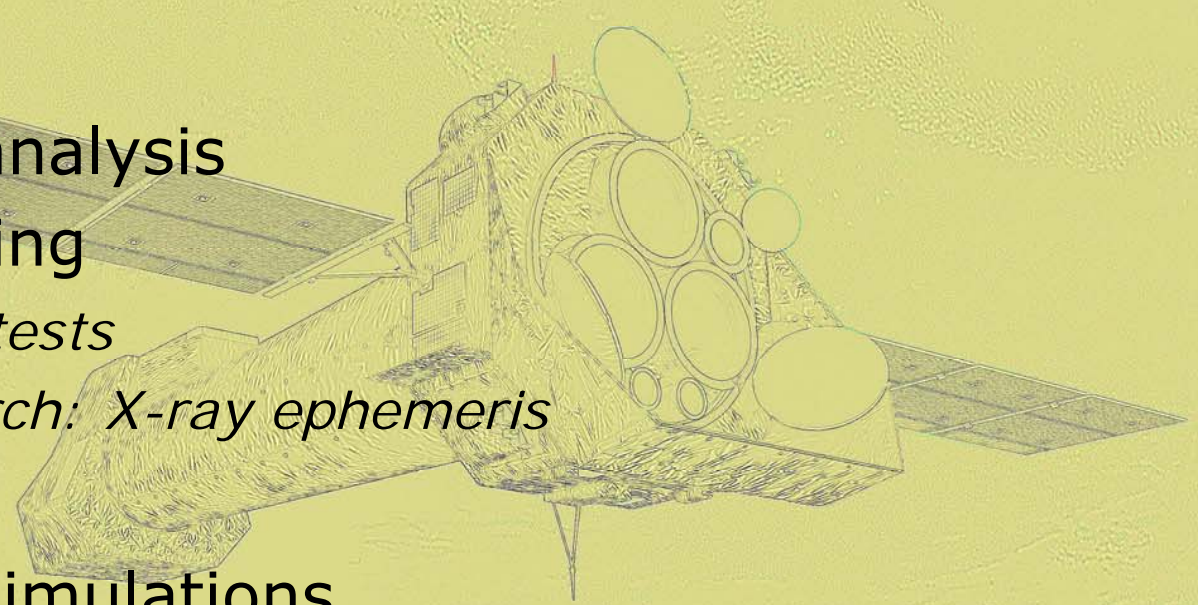
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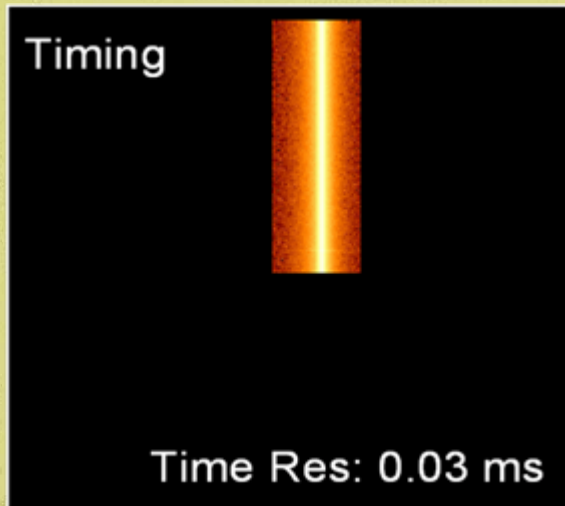
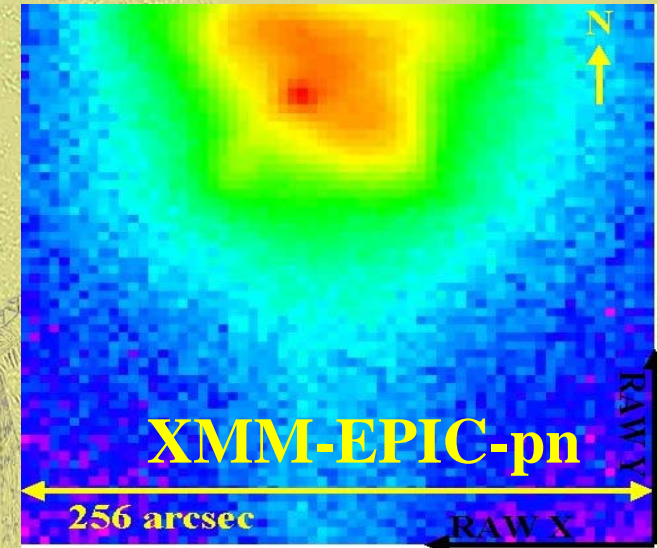
<sup>3</sup> IAAT, University of Tübingen, Germany

**5<sup>th</sup> JETSET School High Performance Computing in Astrophysics  
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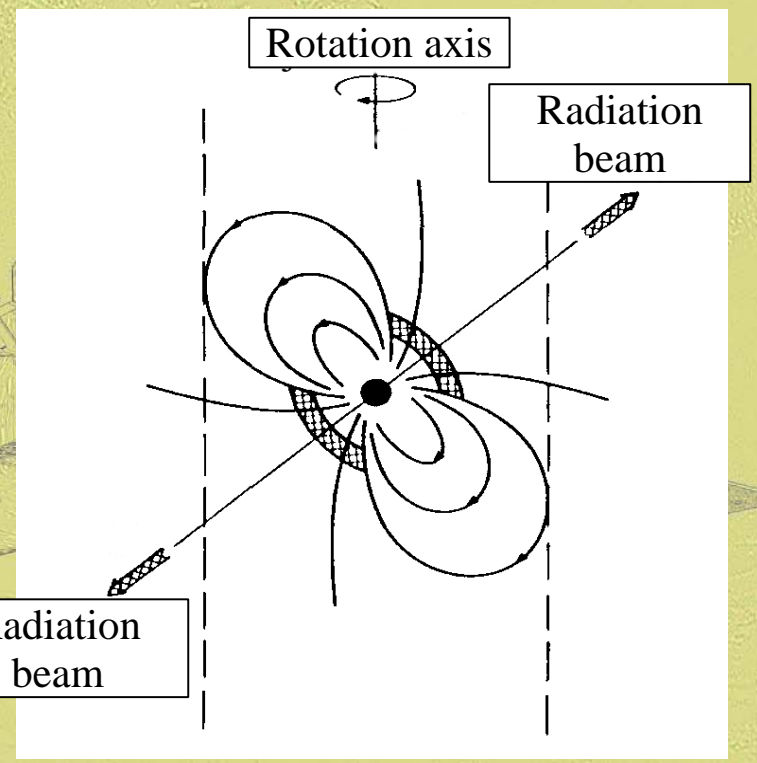
- introduction
  - XMM-Newton
  - pulsars
- relative timing analysis
  - period searching
    - $\chi^2$ ,  $Z^2$  and  $H$  tests
    - *accurate search: X-ray ephemeris*
  - error analysis
  - Monte-Carlo simulations
- conclusions

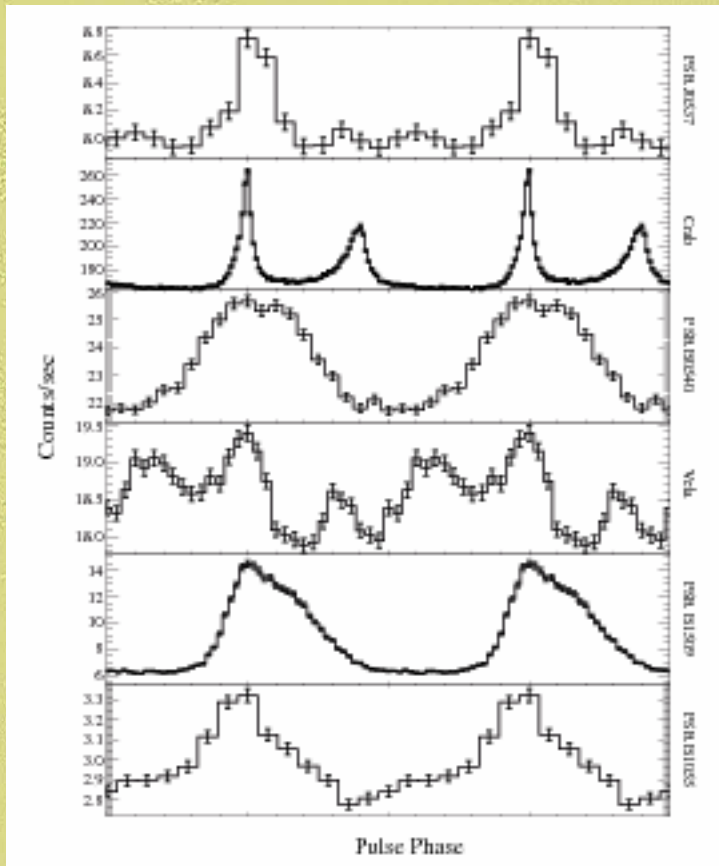


- EPIC-pn camera provides two fast read out modes
- different time resolutions depending on the mode used: Small Window (6 ms), Timing (0.03 ms) and Burst (7  $\mu$ s)
- 2 Crab observations per year
- various other pulsars



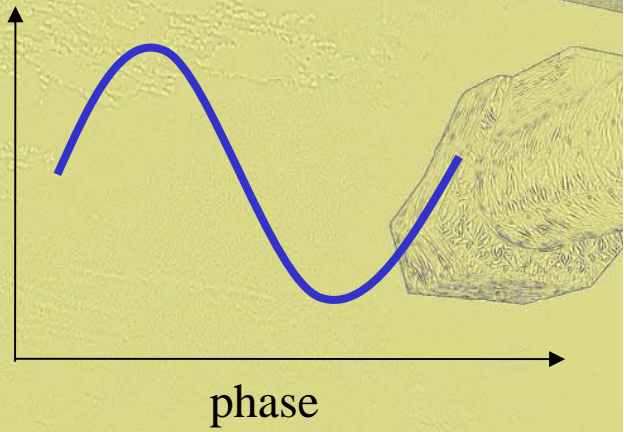
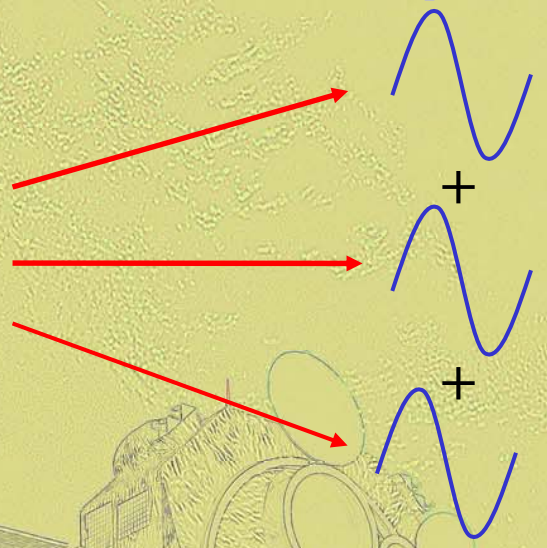
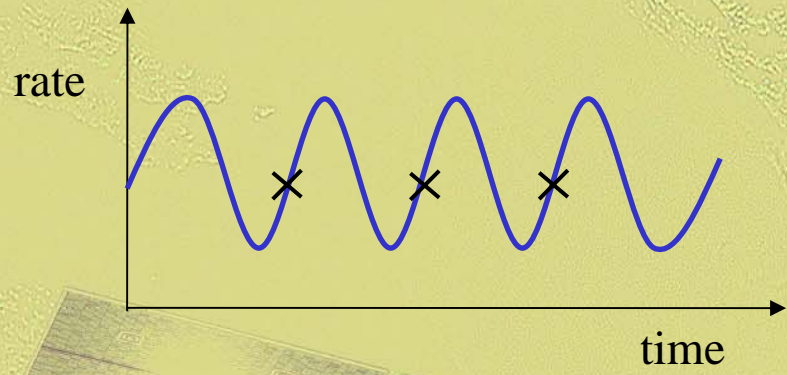
- neutron stars with high spinning velocities and strong magnetic fields
- radius  $\sim 10$  km
- density  $\sim 4 \times 10^{14} \text{ gcm}^{-3}$
- temperature  $\sim 10^6$  K
- magnetic field  $\sim 10^9\text{-}12$  G
- the periods of the pulsars analysed are between 15 ms and 200 ms



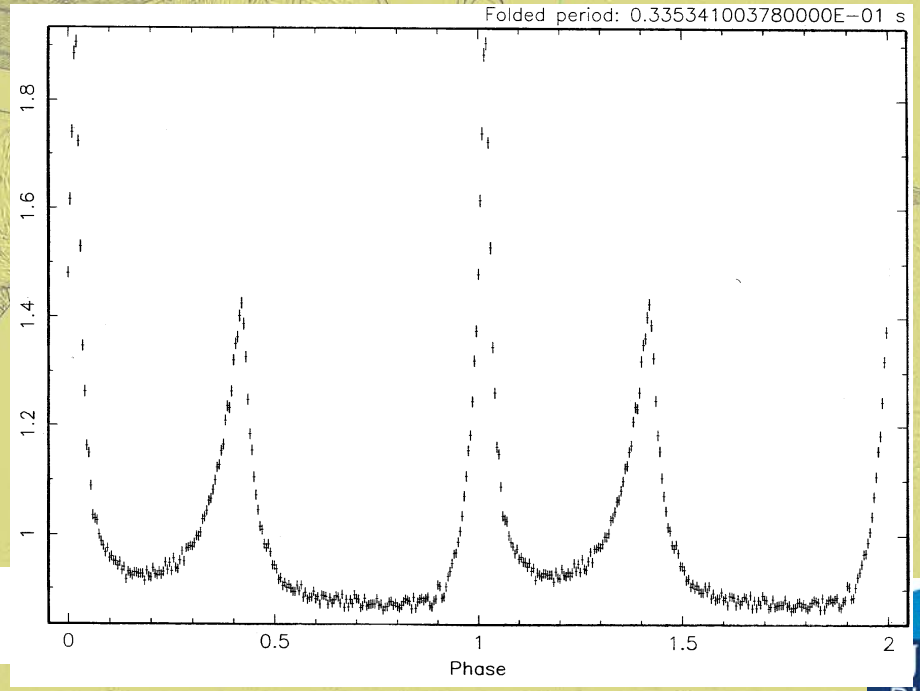


- PSR J0537-69:  $p \sim 16$  ms
- Crab:  $p \sim 33$  ms
- PSR B0540-69:  $p \sim 51$  ms
- Vela:  $p \sim 89$  ms
- PSR B1509-58:  $p \sim 151$  ms
- PSR B1055-52:  $p \sim 197$  ms

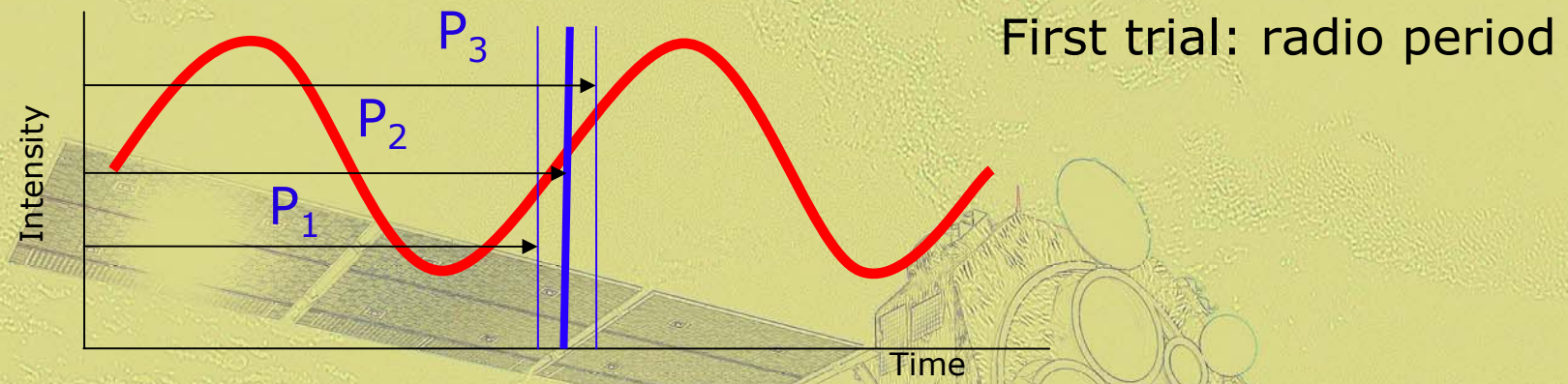
# pulse profiles



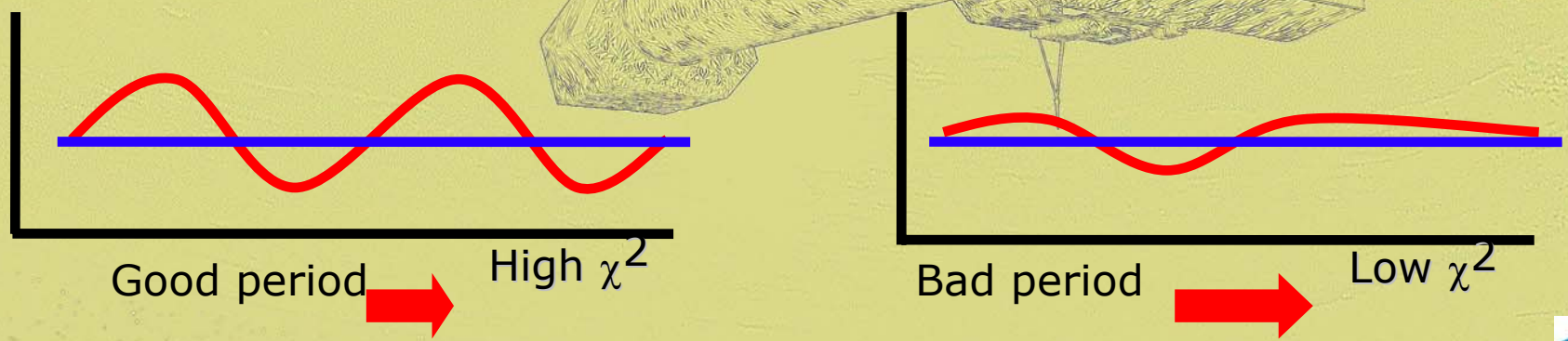
0.5 - 10 keV



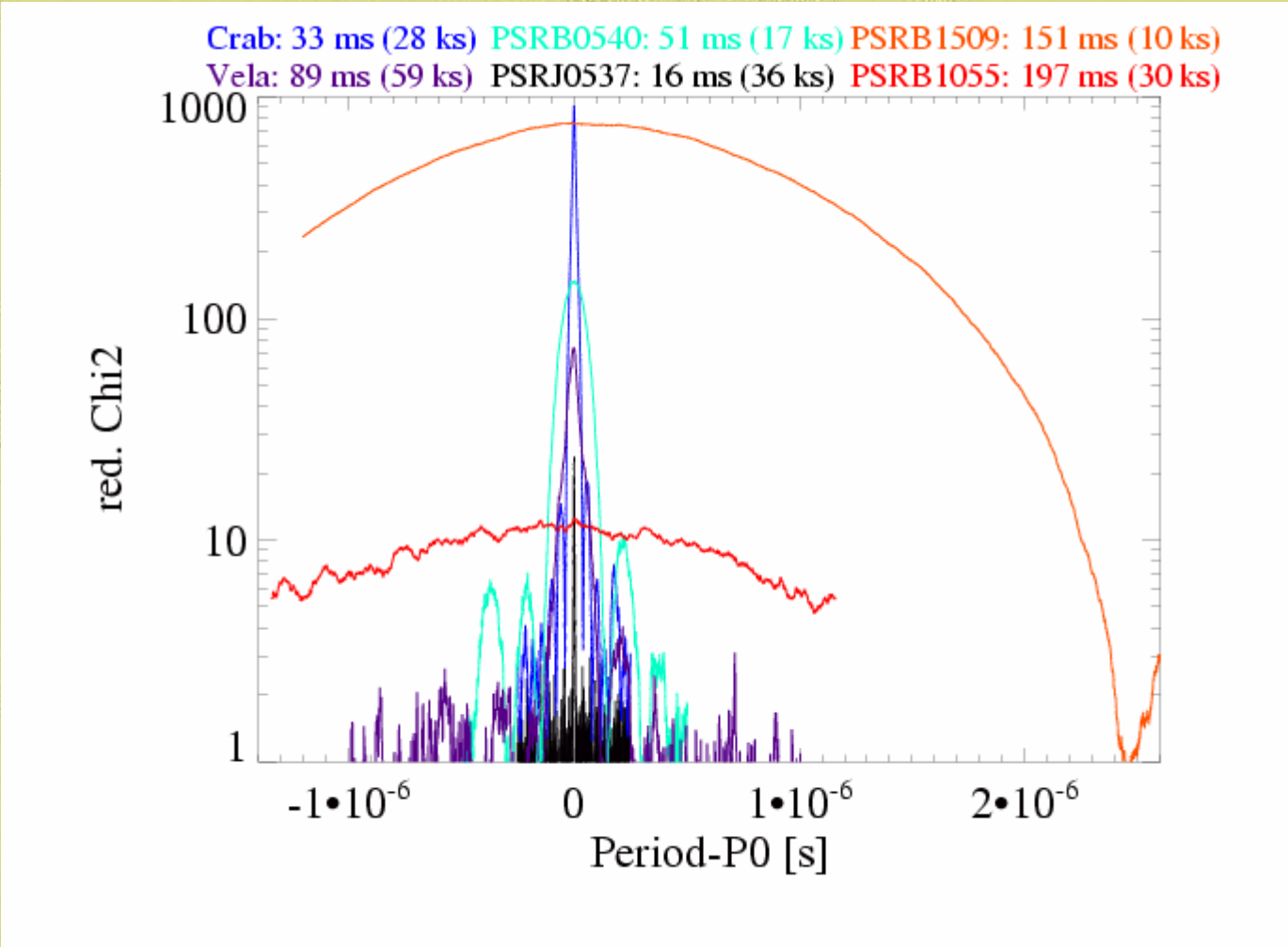
- fold the data over a range of test periods,  $P_i$ :



- for each test period determine  $\chi^2$  of the fit of the **folded light curve** vs. a **uniform distribution**:

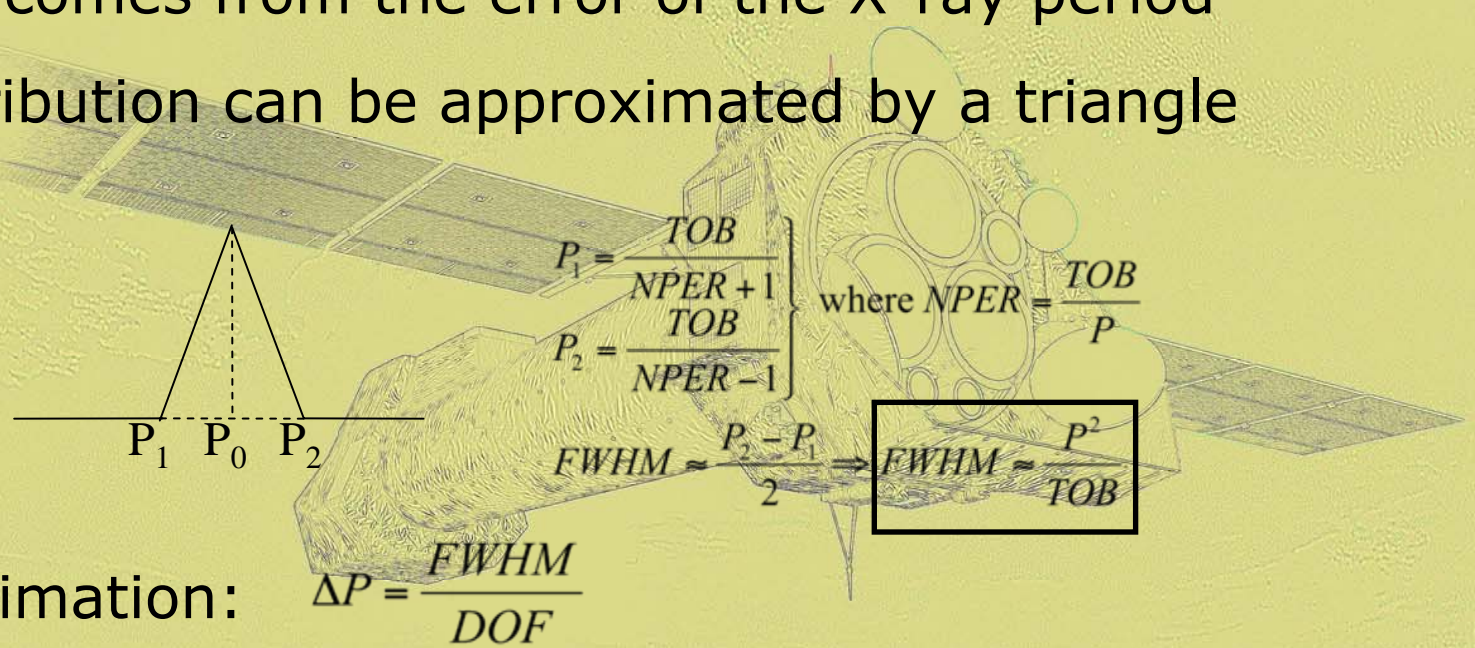


- the weighted mean of the periods with  $\chi^2$  gives the best X-ray period



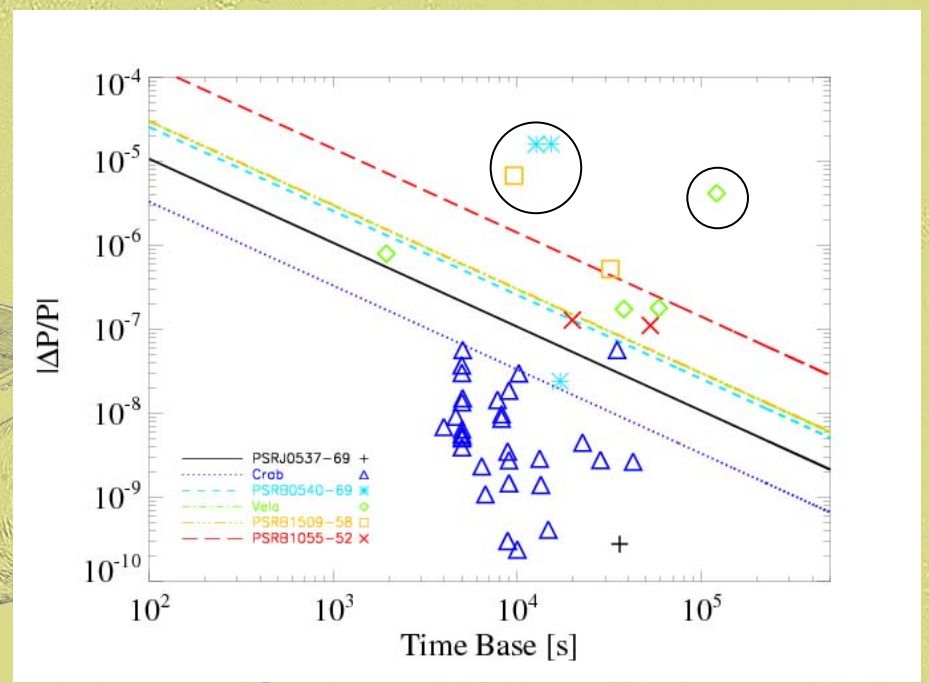
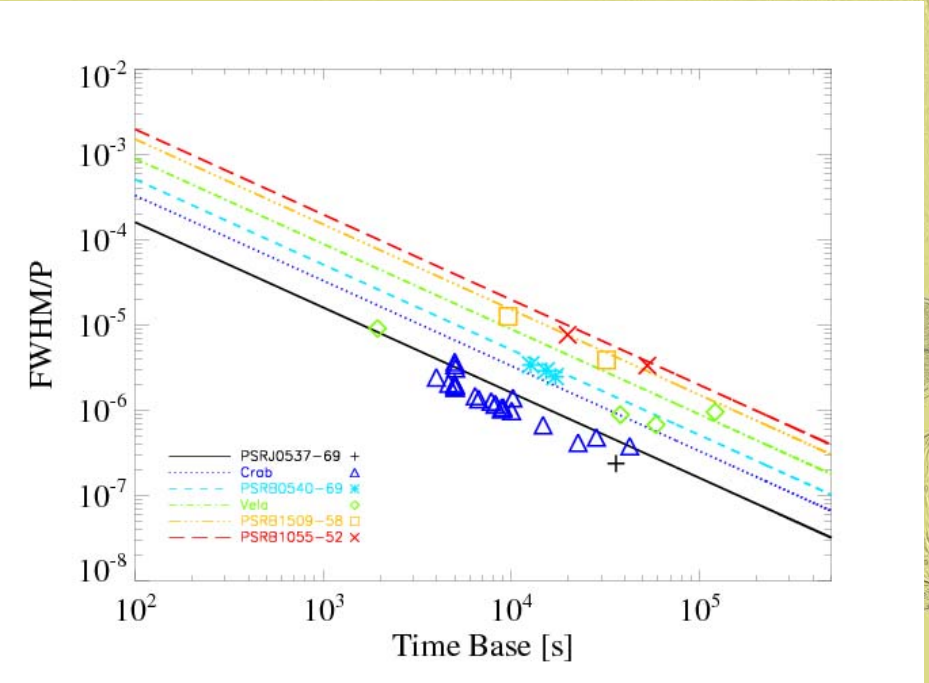
$$FWHM = \frac{P^2}{T}$$

- $\Delta P = P_X - P_R \rightarrow$  error of our observation
- assume that the radio period has no error
- the  $\Delta P$  comes from the error of the X-ray period
- $\chi^2$  distribution can be approximated by a triangle



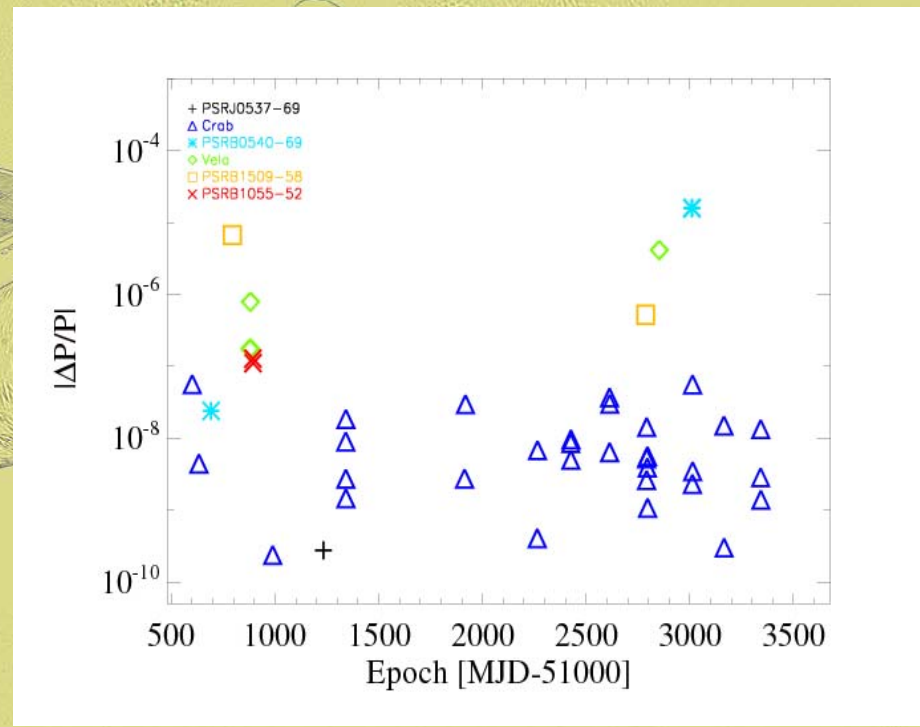
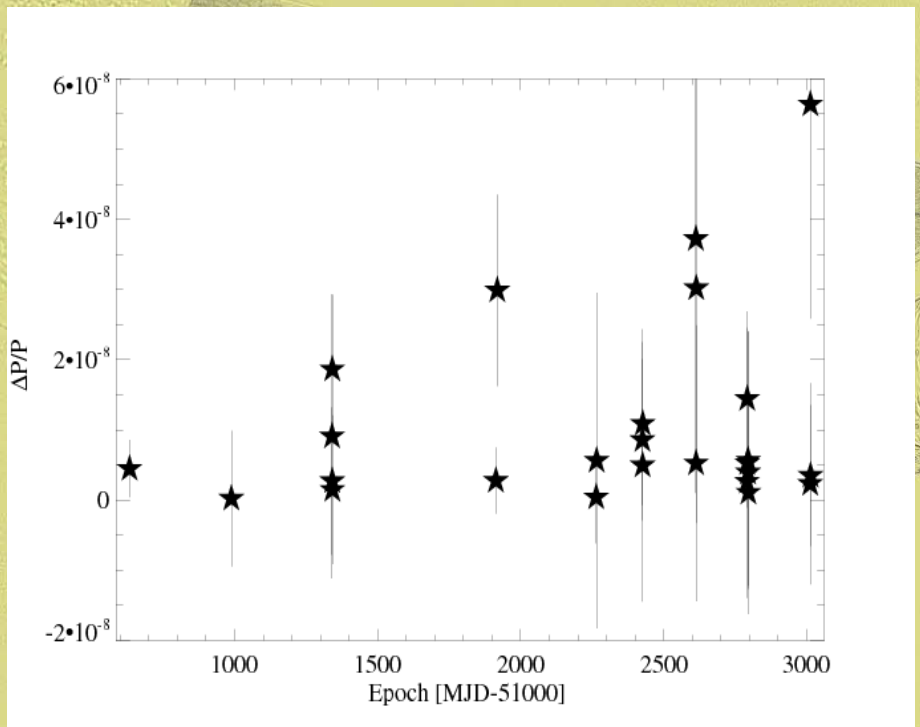
- approximation:
- compare the real and approximated errors of the periods

- comparison between theoretical values (lines) and observational values (symbols)



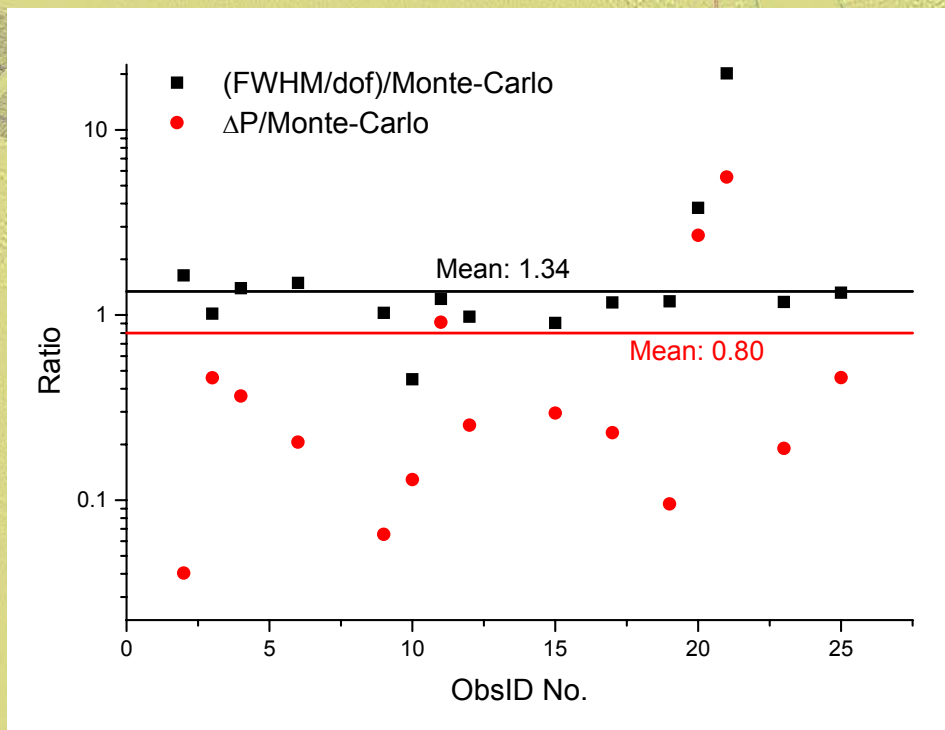
- removing wrong observations:
  - observations inside circles have less reliable ephemeris and will not be considered

- left: results for all Crab observations =>  $\sigma = 5 \times 10^{-9}$
- right: results for all the pulsars =>  $\sigma = 7 \times 10^{-9}$



- M-C simulation was done to some Crab observations using the IDL routine *epferror* from the aitlib of the IAAT
- estimate the error of a previous received period using the epoch folding approach
  - 1.) calculate a mean profile with given period.
  - 2.) compute the intensity for all times applying the period multiplied profile.
  - 3.) simulate an error for all times (standard: using Poisson statistics, or use the error for normal statistics).
  - 4.) perform epoch folding for that simulated lightcurve.
  - 5.) go to step 2.) Ntrial times, sum up the maximum of epoch folding found.
  - 6.) compute the standard deviation of the Ntrial maxima obtained and take these as the error.

- black: ratio between  $\Delta P$  calculated using the approximation formula divided by the M-C results
- red: ratio between the observed  $\Delta P$  divided by the M-C results



- the relative time accuracy of the EPIC-pn camera considering 31 observations can be estimated as:

$$\Delta P/P < 1 \times 10^{-8}$$

- in most of the cases the relative time accuracy obtained observationally is at least as good as the predicted by the approximation.
- the Monte-Carlo simulation errors of the period are smaller than the  $\Delta P$  obtained observationally.
- the difference between the X-ray and the radio period can be consider negligible.