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

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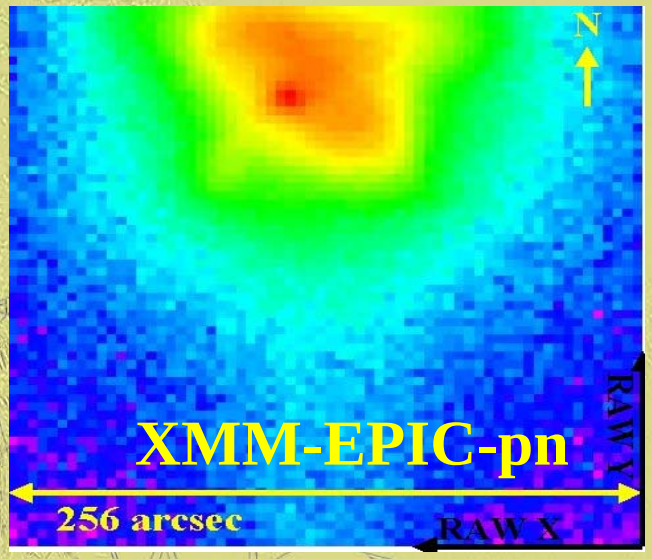
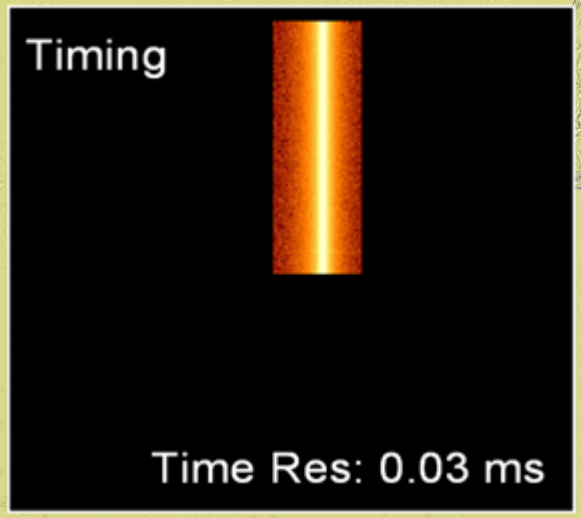
overview

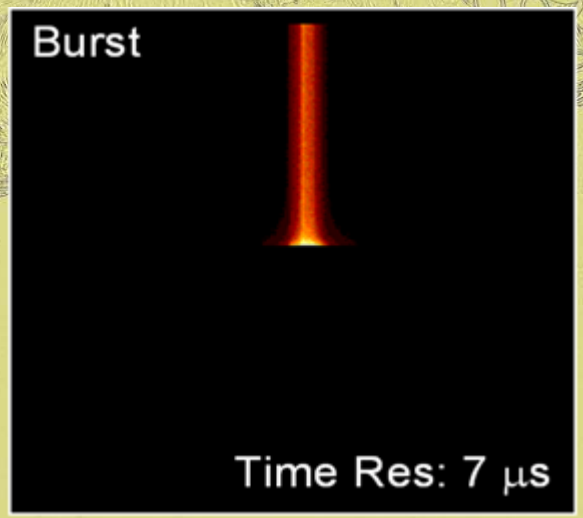
- introduction
  - XMM-Newton
  - pulsars
- relative timing analysis
  - period searching
    - χ^2, Z^2 *and H tests*
    - *accurate search: X-ray ephemeris*
  - error analysis
  - Monte-Carlo simulations
- conclusions

timing analysis using XMM-Newton

- 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 μs)
- 2 Crab observations per year
- various other pulsars

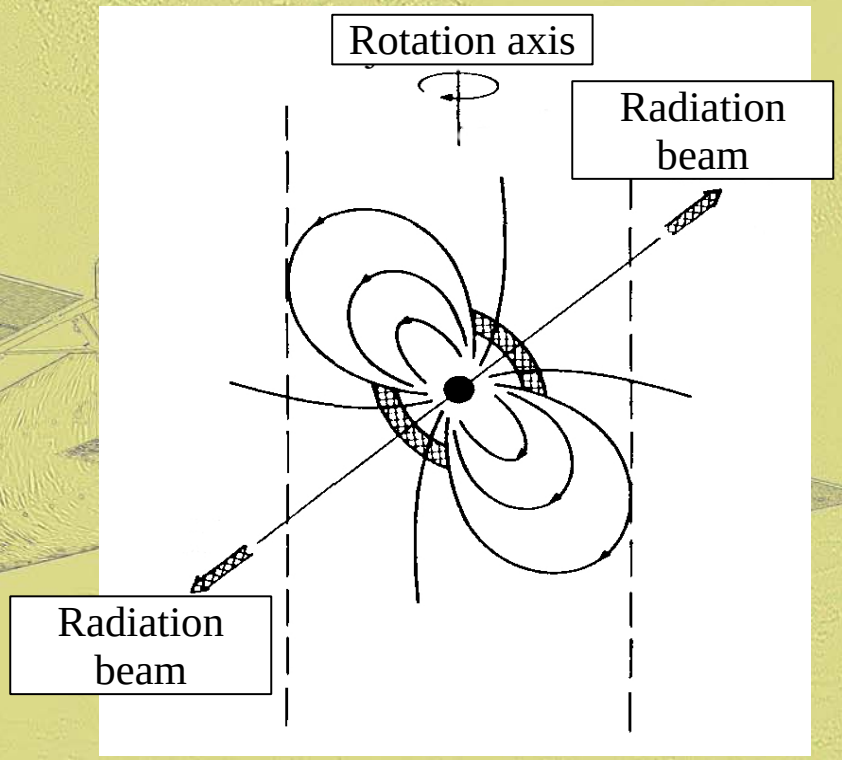




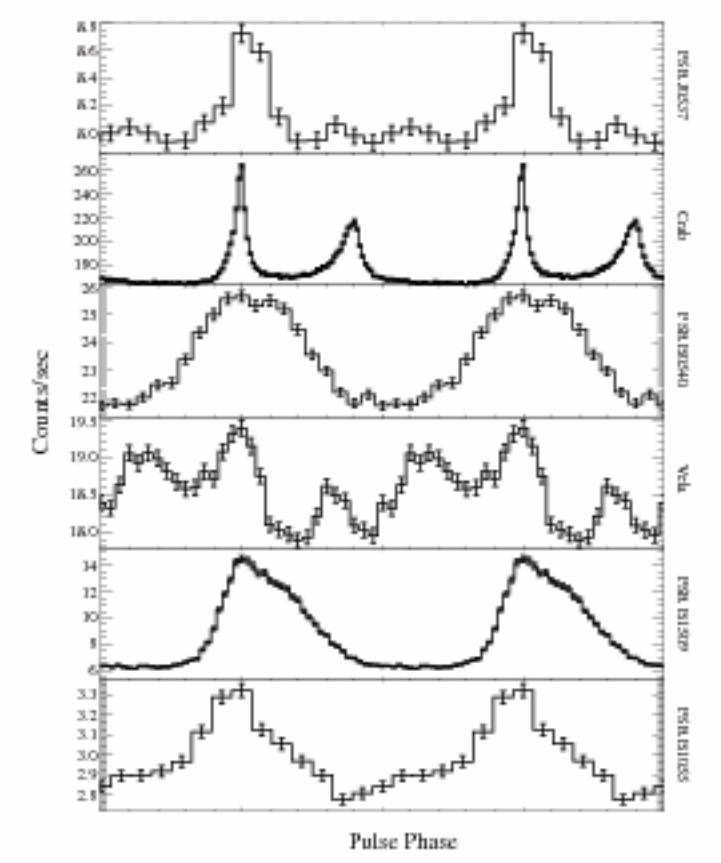


pulsars: general information

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

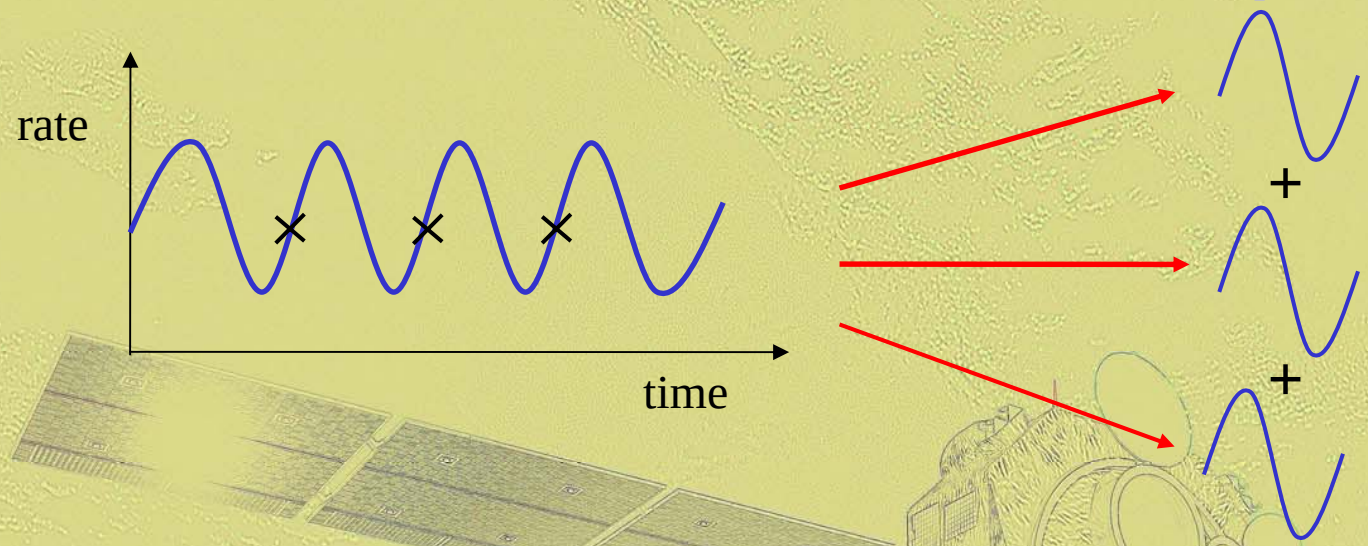


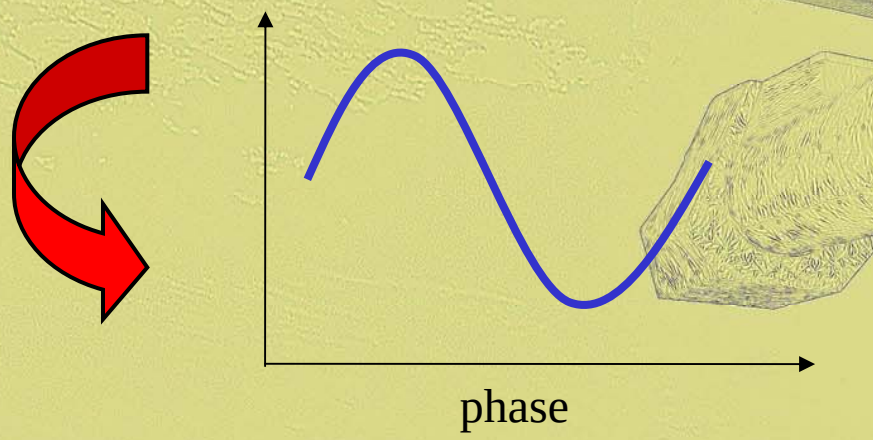
pulsars analysed

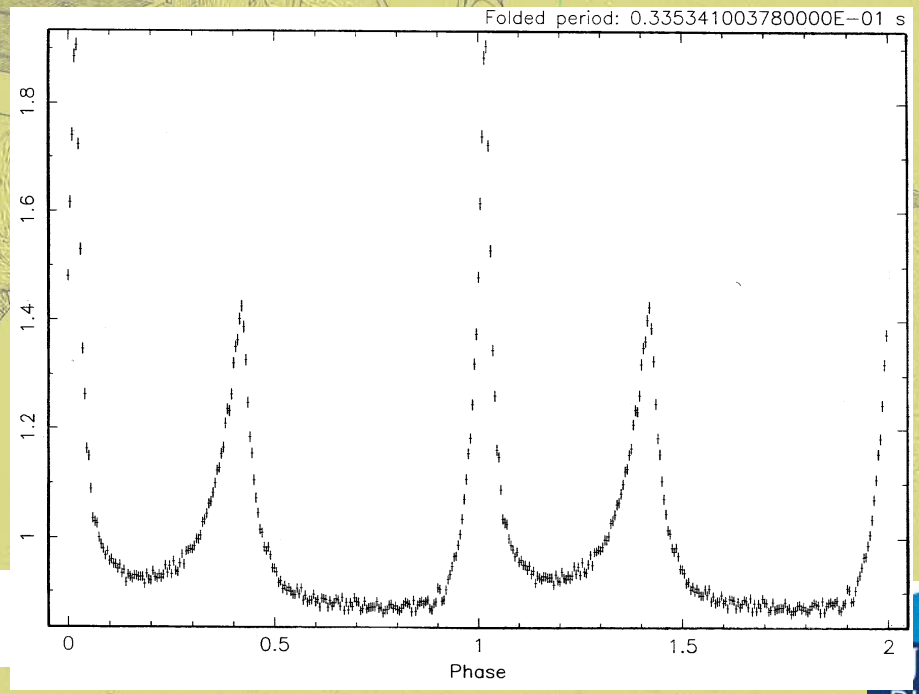


- PSR J0537-69: p ~ 16 ms
- Crab: p ~ 33 ms
- PSR B0540-69: p ~ 51 ms
- Vela: p ~ 89 ms
- PSR B1509-58: p ~ 151 ms
- PSR B1055-52: p ~ 197 ms

pulse profiles



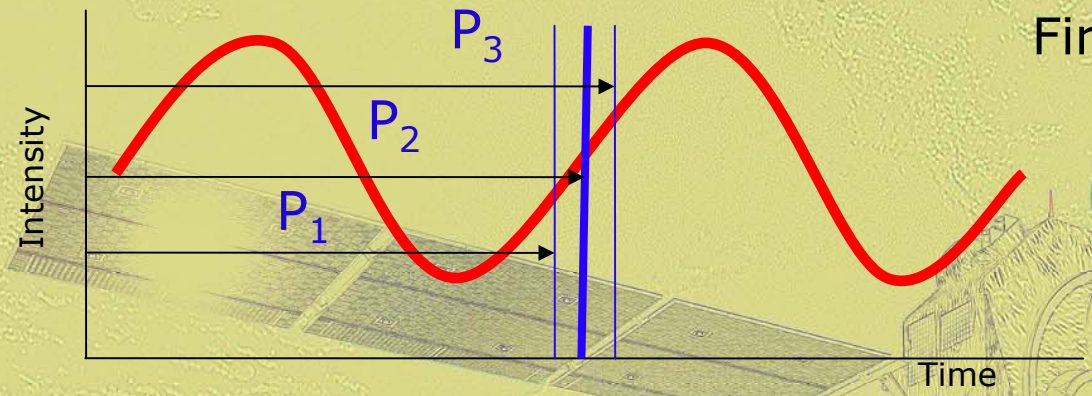




0.5 - 10 keV

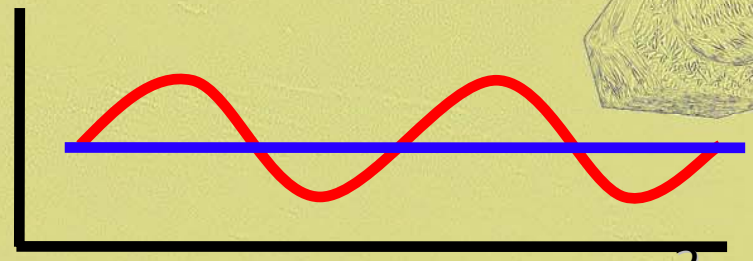
epoch folding

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

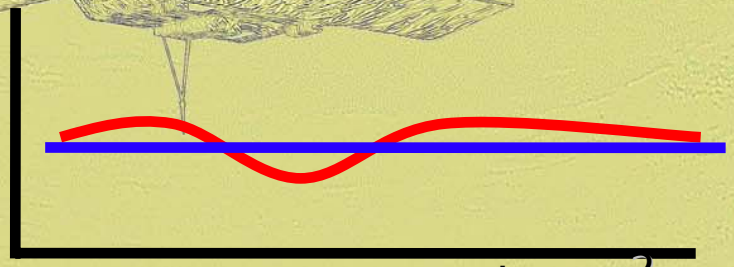


First trial: radio period

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



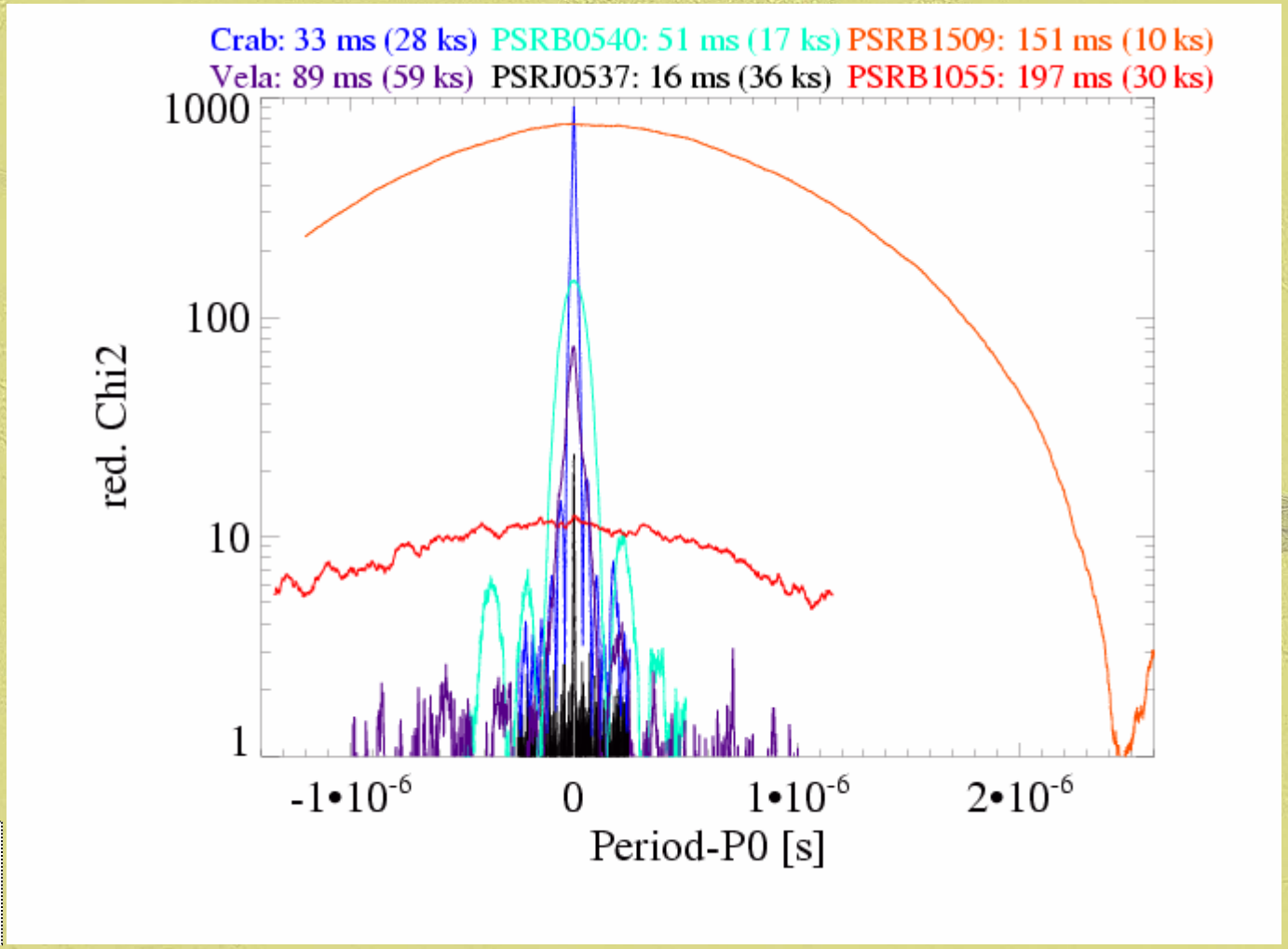
Good period → High χ^2



Bad period → Low χ^2

the χ^2 distribution

- the weighted mean of the periods with χ^2 gives the best X-ray period



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

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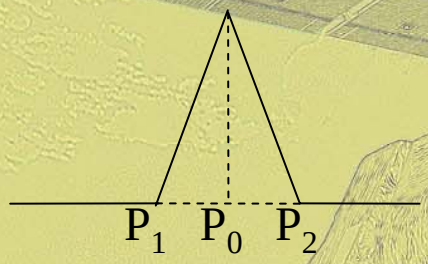
error analysis: *approximation*

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



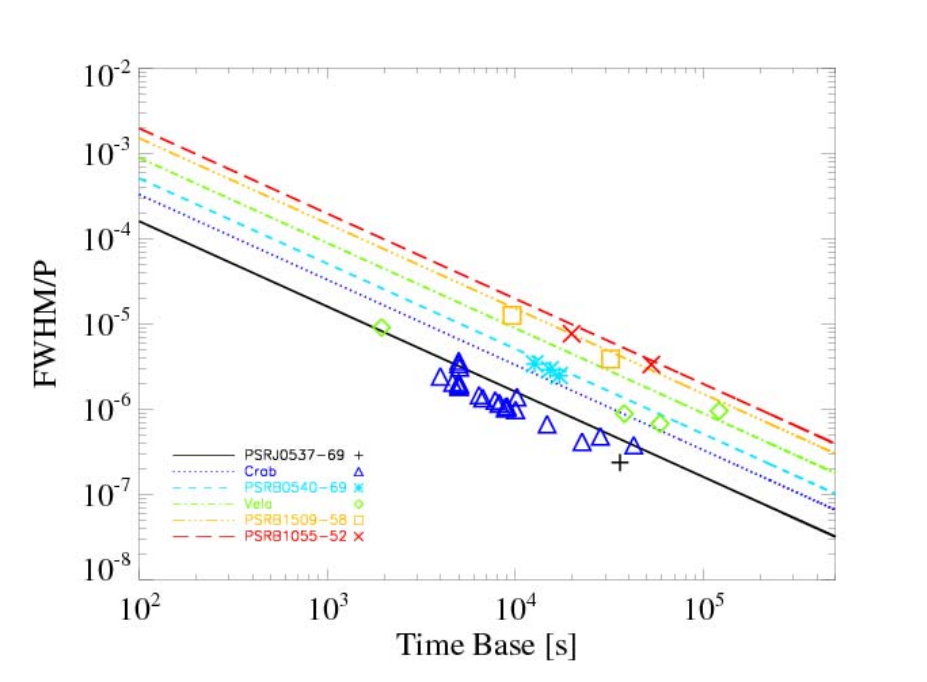
$$\left.\begin{aligned} P_1 &= \frac{TOB}{NPER+1} \\ P_2 &= \frac{TOB}{NPER-1} \end{aligned}\right\} \text{ where } NPER = \frac{TOB}{P}$$

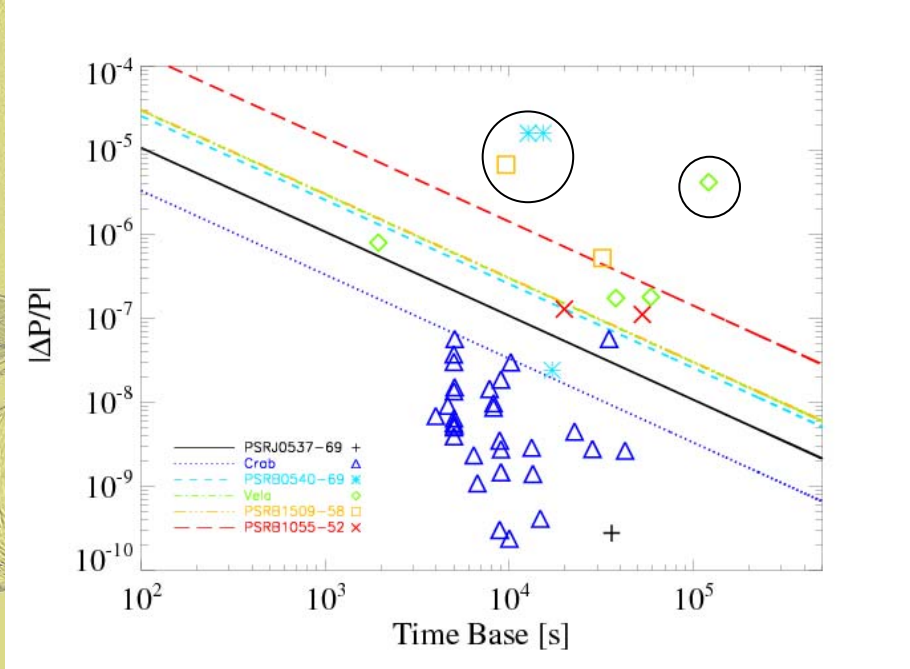
$$FWHM \approx \frac{P_2 - P_1}{2} \Rightarrow \boxed{FWHM \approx \frac{P^2}{TOB}}$$

- approximation: $\Delta P = \dfrac{FWHM}{DOF}$
- compare the real and approximated errors of the periods

error analysis: *comparison*

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

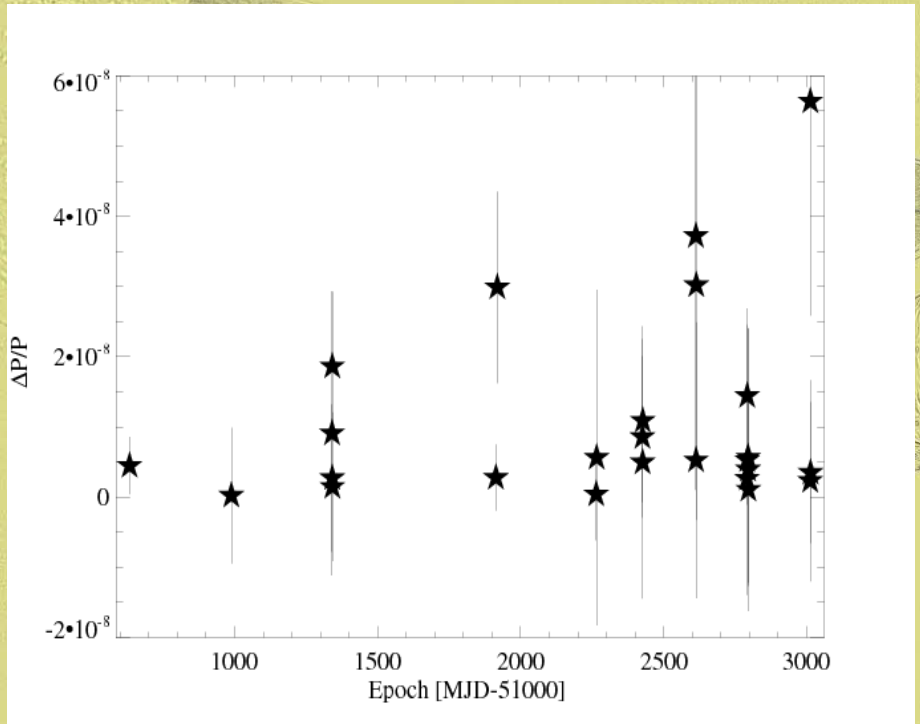


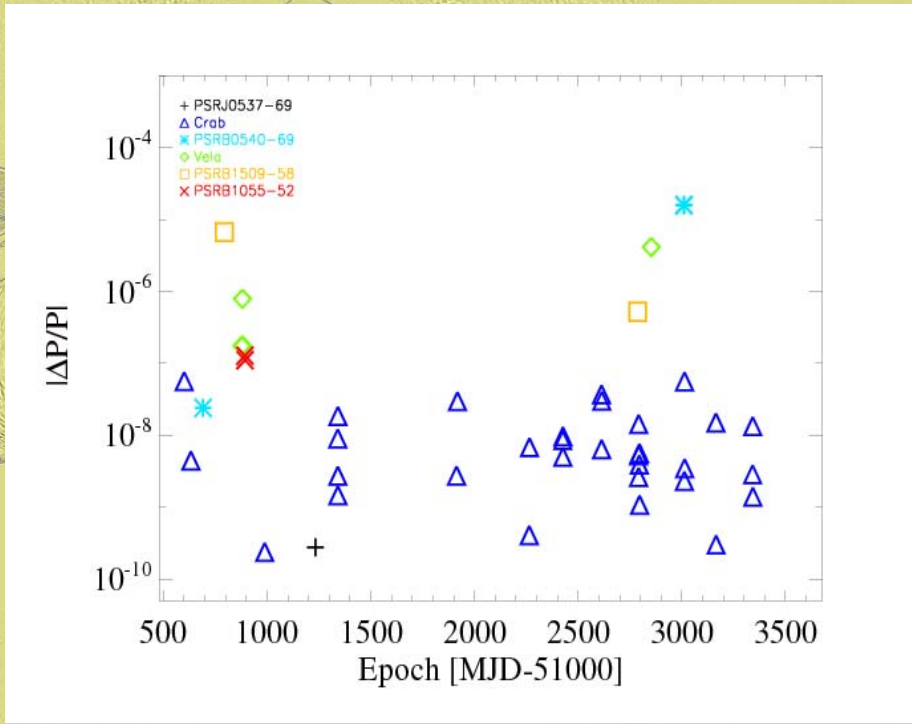


- removing wrong observations:
  - observations inside circles have less reliable ephemeris and will not be considered

relative timing analysis: *results*

- left: results for all Crab observations => $\sigma = 5x10^{-9}$
- right: results for all the pulsars => $\sigma = 7x10^{-9}$





Monte-Carlo simulations (I)

- 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).

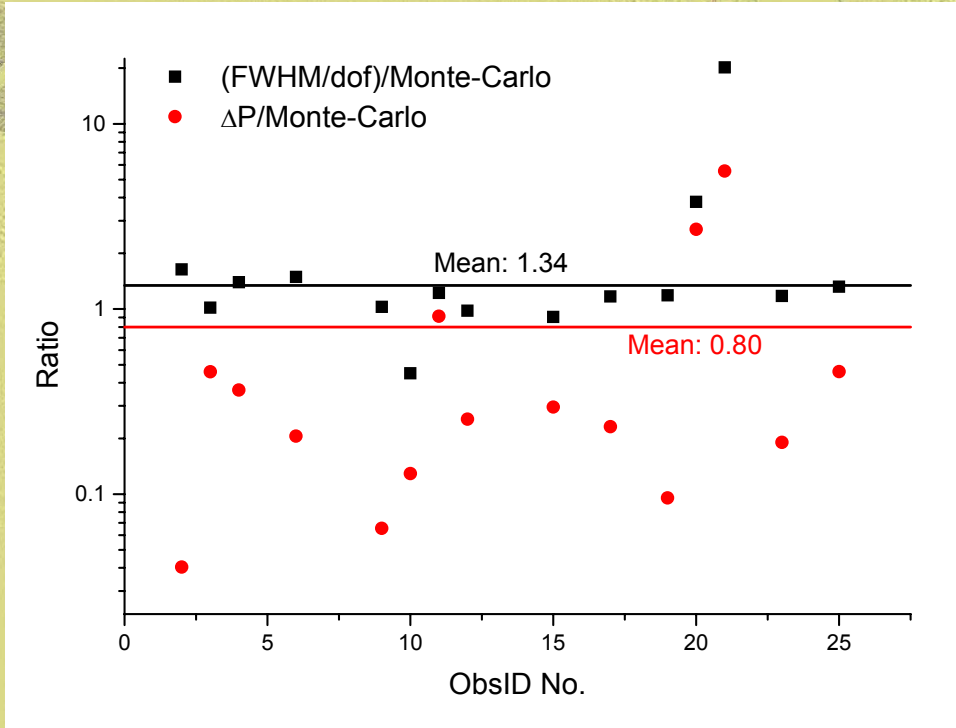
4.) perform epoch folding for that simulated lightcurve.

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.

Monte-Carlo simulations (II)

- black: ratio between ΔP calculated using the approximation formula divided by the M-C results
- red: ratio between the observed ΔP divided by the M-C results



conclusions

- 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 ΔP obtained observationally.

- the difference between the X-ray and the radio period can be consider negligible.