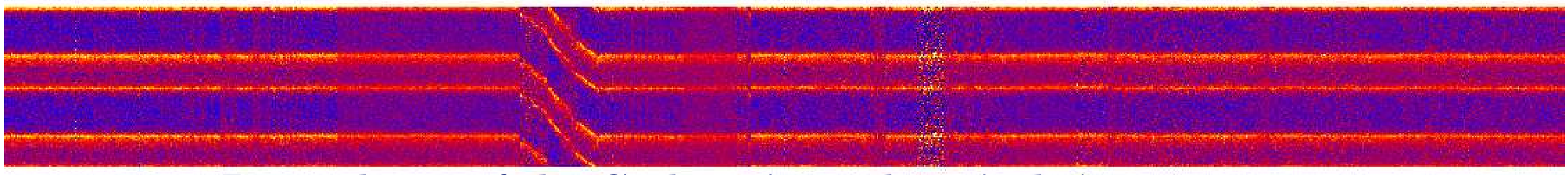

# Dependance of the Crab main peak arrival time on energy

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SUMMARY

We have studied the alignment of the Crab pulsar phase profiles measured in the X-rays and compared results with the profiles in other wavebands. We found that the main pulse in the hard X-ray 20-100 keV energy band is leading the radio one by 8.18+/-0.46 milliperiods in phase, or 275+/-15 us in time. Quoted errors represent only statistical uncertainties. Our systematic error is estimated to be 40 us and is mainly caused by the radio measurement uncertainties. For the soft 2-20 keV X-ray band, we have used data of Crab observations with the PCA monitor on-board the Rossi X-Ray Timing Explorer (RXTE) mission. The time lag value measured in the 3-20 keV band is 0.00933+/-0.00016 (corresponding to 310+/-6 us) parts of the cycle that statistically differs from the time lag measured in the hard X-ray band. Additional analysis shows that the delay between the radio and X-ray signals varies with energy in the 2 - 300 keV energy range. It means that we need take this into account while planning instruments for X-ray navigation.

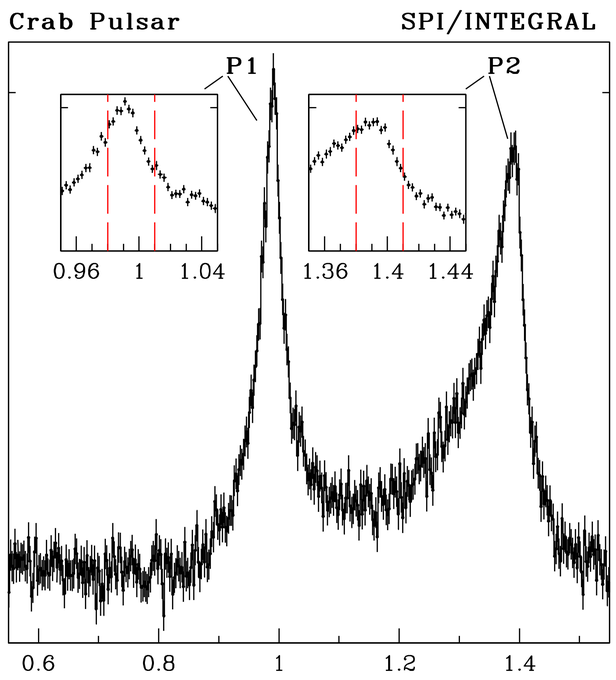


FIG 1. Crab phase histogram in the 20-100 keV energy band in absolute phase with the phase resolution 0.0025. "1" corresponds to the phase of the main radio pulse. Inner panels magnify the main pulse and the interpulse peaks. Dotted vertical lines bound the intervals used for the fit procedure. The exposure is of the order of 100 ks.

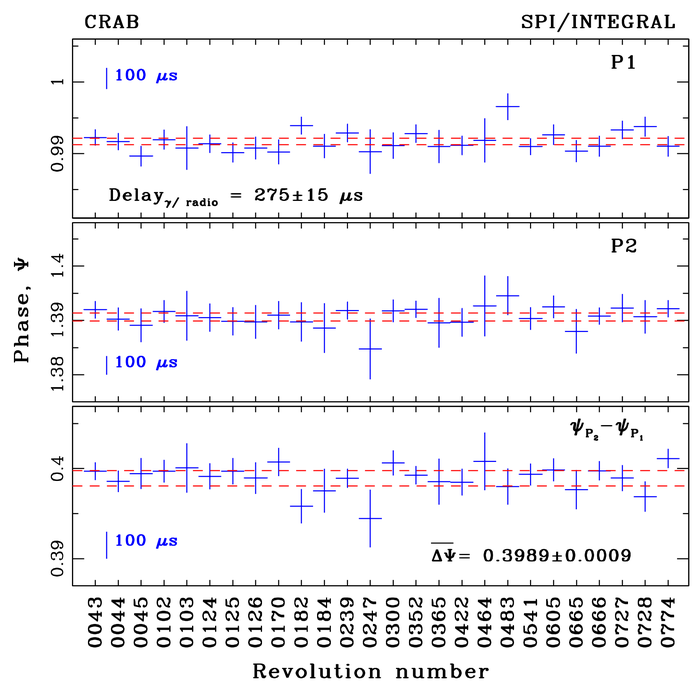


FIG 2. The fit values of the main pulse (P1) and interpulse (P2) positions on the phase plane and of the distance between these pulses versus the revolution number. The horizontal dashed lines show the one sigma (statistical only) confidence intervals for the averaged values. The $20-100$ keV energy band was used.

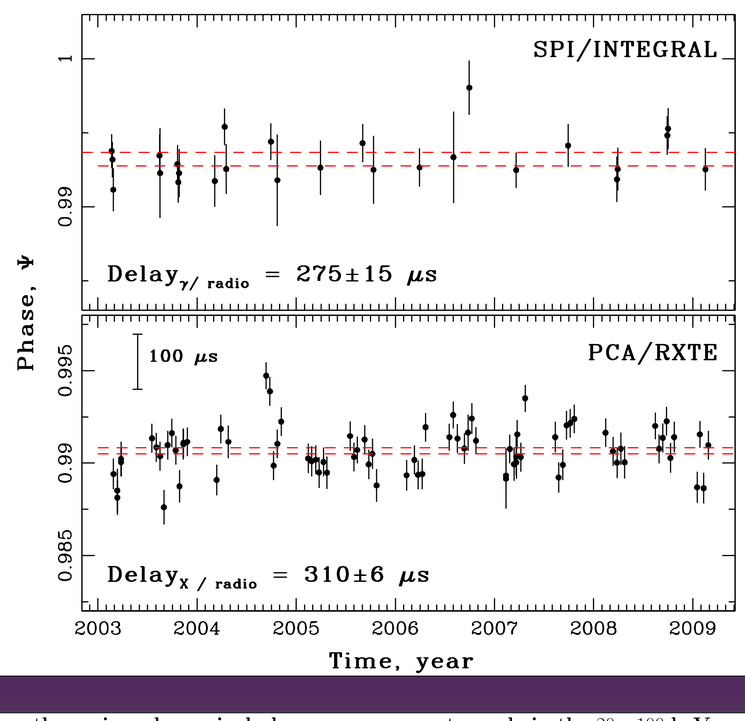


FIG 3. The comparison between the main pulse arrival phase measurements made in the $20-100$ keV energy band with SPI/INTEGRAL, and in the $2-20$ keV energy band with PCA/RXTE. In both cases the same radio ephemerides and fit procedure have been used. The horizontal dashed lines show the one sigma (statistical only) confidence intervals for the averaged values.

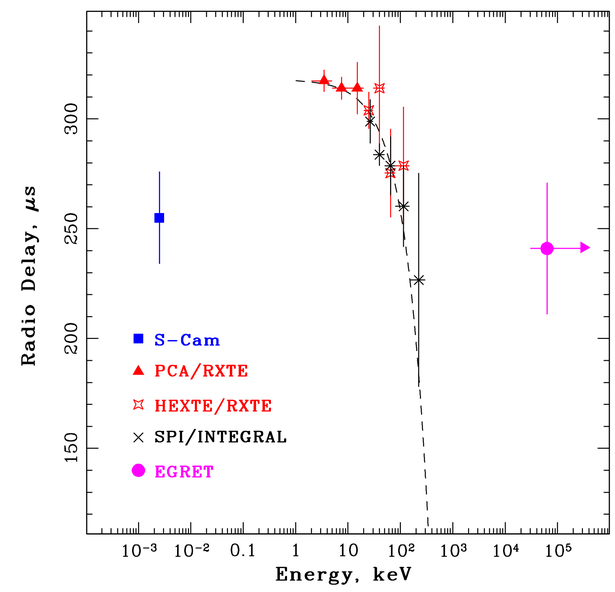


FIG 4. The radio delay with respect to energy. The optical (S-Cam) and $\gamma-$ray (EGRET) points are from Oosterbroek et al.2008 and Kuiper et al.2003, respectively. The data of the RXTE instruments and SPI are presented in this paper.

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RESULTS: 1. The main pulse in the hard $X-$ray $20-100$ keV energy band is leading the radio one by $8.18\pm0.46$ milliperiods in phase, or $275\pm15$ $\mu s$ in time. The time lag in the $3-20$ keV band is $310\pm6$ $\mu s$.

2. The dependence of the main pulse phase position on energy is complex and can not be described in terms of linear law. Moreover, the very accurate optical measurement indicates that the radio delay evolution with energy is not a monotonic function at all.

CONCLUSIONS: The delay between the radio and X-ray signals from Crab varies with energy in the 2 - 300 keV energy range. The same situation could be true for other pulsars and we need take this into account while planning instruments and algorithms for X-ray navigation.