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Reducing Pulsar Optical Observations at the Asiago Observatory

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Abstract

Optical monitoring of the Crab pulsar (NP 0532) at the Asiago 122cm telescope consists of accumulating runs covering approximately 15000 revolutions of the pulsar itself, collecting a few photons each one. A program able to deal with such data in order to get the proper information from the raw data, together with the nominal error of the measured features, is briefly described in this paper. Some test on selected runs (ranging from the lowest to the higher signal to noise ratio achieved during the observing campaigns) is also given.

1 Introduction

Since 1974 an observational program of the Crab pulsar is being undertaken using the Asiago Fast Photometer [1] at the Asiago 122 cm telescope. Each run produces a light curve formed by a synchronous accumulation of photons covering several thousands of pulsar's revolutions: the first and most important quantity we want to derive from the data is the position (in the time axe) of the principal peak of the light curve.

Timing of the optical pulse's peak is generally obtained by fitting a *master profile shape*, *i.e.* a high signal to noise curve determined by combining many high resolution measurements, to the observed light curve [2]. The method minimizes the residuals by adjusting some scaling parameters, typically corresponding to a background and a peak height scale factor, and the shift between the two curves by means of some iterative technique. The goodness of fit is estimated by calculating χ^2 for the derived parameters.

This method does not take full advantage of the intrinsic properties of the data: the fact that the light curve is periodic is not used at all. Moreover the fitting procedure often fails due to very noisy data, even if the light curve's peak is still clearly recognizable. These considerations lead us to the adoption of the cross correlation method described in the classical paper of Tonry and Davis [7] because it: (*i*) takes advantage of the intrinsic periodicity of the data; (*ii*) give almost always a recognizable peak, even in the presence of very noisy data. We have therefore developed some procedures, written in the IDL language [5], which implement the cross correlation method and which makes use of the intrinsic characteristics of our data. The program was written so that it requires only two input files, the master profile shape (an ASCII file) and the measured light curve (in FITS format as outputted by the data acquisition system), while all other parameters are defaulted to reasonable values.

2 Reduction of the data

The light curves are formed by accumulating in memory a given number of synchronous scans of fixed length, the synchronization time being an approximation of the source's period. Usually the

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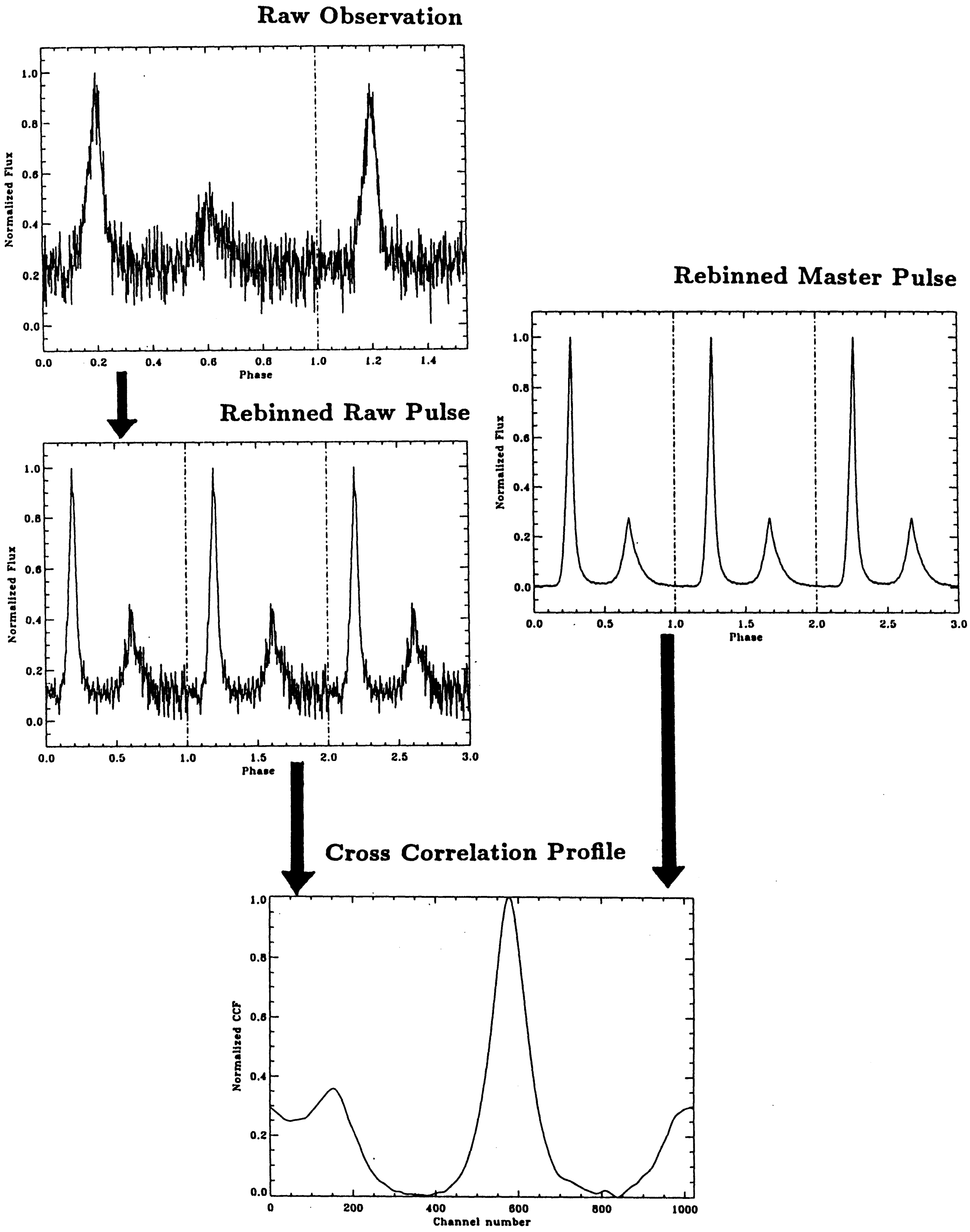

Figure 1: Outline of the overall flow–chart of the operations performed.

number of channels in which accumulation is performed do not cover in time an integral multiple of the source's period, so that the measured curve generally covers more than one period but less than two.

In the adopted procedure this data is rebinned as a function of the phase, whose origin is arbitrarily set at the first measured channel. Each point in the rebinned data set is determined by interpolation with a quadratic polynomial using all points in the original data set whose phase falls within a fixed interval (determined so that it corresponds on average to ~7 points).

Two considerations suggested the adoption of this method:

1. it uses all the points of the original data set and produces a curve which covers in time a complete (approximated) period;
2. it introduces a certain degree of smoothing which compensates for the corruption of the statistic of the original data, which is due to the unequal number of data points used to construct different regions of the resulting light curve.

The *master profile shape*, taken from the data published by Groth [4], is rebinned on the same scale, *i.e.* on a phase scale having an equal number of points. After being rebinned, the data is then cross correlated against the master, and the peak of the cross correlation function (CCF) is fitted with a quadratic polynomial to derive the relative shift between the two curves. Since the formal errors of the fitting are generally very small, we compute the position of the peak many times using an increasing number of points around the CCF maximum, all these results are then averaged and the error of the fit is estimated as the variance of this mean. The minimum and maximum length of the interval within which this procedure is applied are parameters which are generally defaulted but that can be modified by the user.

The CCF is computed using the Fast Fourier Transform algorithm. All the correction procedures, *i.e.* low frequency components subtraction and cosine ending, which are generally required when operating in the Fourier domain, are not applied to our data. These corrections must in general be applied to non periodic data, since the use of the discrete Fourier Transform requires the input data to be periodic and the discontinuities at the ends of the data introduces *ripples* in the Fourier Transform that redistribute the energy of the signal among all the Fourier components. The cosine ending thus reduces the discontinuities and consequently the ripples in the Fourier Transform, the low frequency component subtraction attenuates those components which generally contain most of the energy of the signal but at the same time convey little information (see the paper of Brault and White [3]). Since our data is intrinsically periodic these corrections are not required: this naturally contributes to speed up the reduction process and minimizes the number of parameters that must be supplied to the program (most of which are defaulted to reasonable values). The full flow–chart of the process is outlined in Figure 1.

3 Results and conclusions

The method outlined in the preceeding section was applied to 295 runs taken at the Asiago Observatory from September 1974 to March 1990, much of these observations were reduced by L. Ladisa [6] using the master profile shape fitting procedure which did converge only for 183 runs. With our method we were able to measure the position of the principal peak of the light curve for all observing runs and we could also give an estimate of the error for this quantity.

In Figure 2 the difference between the timings obtained by Ladisa and those obtained with our method are plotted for all the observations in common between the two samples. The mean of the difference is -2.497 μsec, which is much smaller than the standard deviation (see below), thus indicating that there are no (or very small) systematic errors. The standard deviation quoted by Ladisa was $\sigma_L = 30.9$ μsec, while the standard deviation of the difference is $\sigma_{BRS} = 33.9$ μsec, this demonstrates that the (formal) errors estimated with our method are much smaller than those given by the fitting procedure.

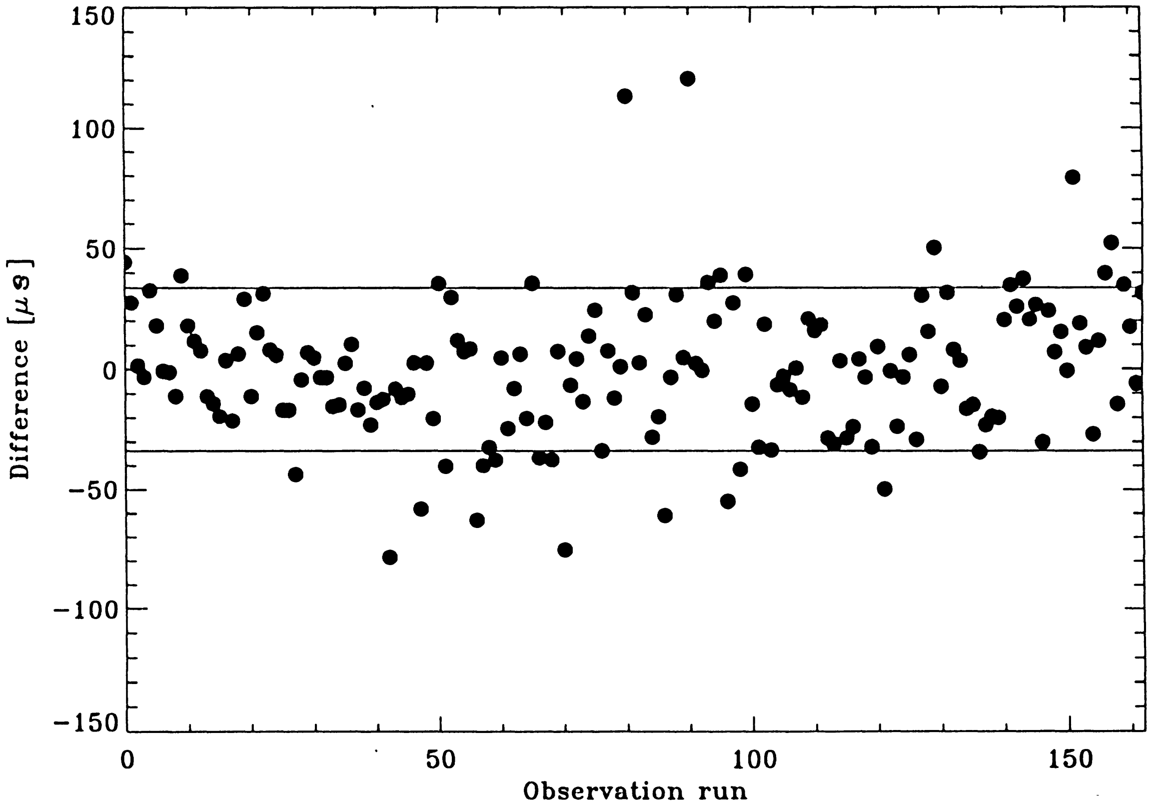

Figure 2: Difference between the peak-location obtained by Ladisa and the values found using the described procedures. The solid lines are placed at $\pm\sigma_L$.

The execution time for the entire procedure applied to one data set is of the order of 40 seconds on a 486-based PC (including various plots which allow to monitor the program and the logging of results into an ASCII file), thus the reduction of all observing runs requires less than 3.5 hours.

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